THE POLITICS OF TECHNOLOGICAL CHOICES:

BUSINESS-STATE RELATIONS AND

NUCLEAR ENERGY POLICY-MAKING IN WEST GERMANY

by

JAMES ALLEN COONEY

B.A., Harvard University (1969)
M.Ed., Harvard University (1972)
Ph.D., Massachusetts Institute
of Technology (1982)

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Signature of Author _____
Department of Political Science, January 12, 1982

Certified by _____
Suzanne Berger, Thesis Supervisor

Accepted by _____
Chairperson, Departmental Committee on Graduate Studies

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ABSTRACT

THE POLITICS OF TECHNOLOGICAL CHOICES: BUSINESS-STATE RELATIONS AND NUCLEAR ENERGY POLICY-MAKING IN WEST GERMANY

JAMES ALLEN COONEY

(Submitted to the Department of Political Science on 12 January 1982 in partial fulfillment of the requirements for the degree of Doctor of Philosophy.)

This thesis analyzes how technological choices are made in advanced industrial societies. Using German nuclear energy development as a case study, it examines technological choices both on the general level of overall policy and on the more detailed level of one project, the pebble bed high temperature reactor (HTR). The discussion centers on the varying interactions of the business and state sectors during the research and development, demonstration, and commercialization stages of development.

Part I sets forth the theoretical framework and explains the rationale for the choice of the specific case studied. Two approaches for explaining technological choices are presented: the market approach and the political-organizational approach. The market approach allows us to ask to what extent private industry can guide policy in the Federal Republic where conditions and attitudes are highly favorable to the market determination of technological choices. The political-organizational approach lets us test whether the state can control these choices when its interest in doing so is high, as it seemingly has been with the German designed and developed high temperature reactor.

Part II examines overall post-war German nuclear energy policy, looking especially at the light water and fast breeder reactors. In contrast to the French and British reactor programs which concentrated efforts early on a specific design, the Germans intentionally sought to foster multiple options. The changing objectives, the institutions established to determine policy, and the division of responsibility among sectors at different times are described and their impact on actual policy decisions considered.

Part III provides a parallel analysis to Part II, but the focus on the HTR permits us to qualify the findings for the overall policy described in Part II. Part III emphasizes the differing objectives and institutional interactions not only between the business and state sectors but also within them over the three phases of development of the HTR: the 15 MW experimental reactor, the 300 MW demonstration thorium high temperature reactor (THTR), and post-1975 efforts to decide upon a successor to the THTR project.

The conclusions of the thesis are summarized in Part IV. (1) Both market and political-organizational factors are important for explaining how technological choices are made. Although market forces may appear determinant (such as with the commercial breakthrough of light water reactors in the Federal Republic), underlying political-organizational factors play a crucial role in defining the context in which market factors operate. (2) The various actors within the business and state sectors should be differentiated. For the high temperature reactor, for example, we cannot refer simply to "business" or "state" objectives. Rather we must consider which reactor manufacturer, which utilities and which branch of government stood behind the reactor's development. International factors can also limit the scope of action for the policy actors; for high temperature reactors, however, the international factors were not too significant so that development was essentially domestically determined. (3) Policy leadership for a high technology varies with the project's stage of development: the government has maximum impact in the research and development stage; the reactor manufacturers are most important in the demonstration stage; the utilities are especially influential as commercialization nears. Transitions from one stage to the next are of special importance in determining the course of technological choices. (4) The German approach to technological development is decentralized and made on a case-by-case basis. The government has been more successful at promoting the development of a number of options than in compelling other policy actors subsequently to narrow options. This is the problem which the government now faces for high temperature reactors. German policy actors have learned that a balance has to be struck between supporting the most sophisticated and the most feasible technological applications of a project.

Thesis Supervisor: Suzanne Berger
Title: Professor of Political Science

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List of Abbreviations

AEC--Atomic Energy Commission (U.S.)

AEG--Allgemeine Elektrizitäts Gesellschaft

atw--Atomwirtschaft Atomtechnik (the leading journal about the nuclear industry, published by the Atomic Forum, an industrial lobby)

AVR--Arbeitsgemeinschaft Versuchsreaktor (the 15 MW experimental high temperature reactor)

AGR--advanced gas reactor

BBC--Brown Boveri and Cie

BBK--Brown Boveri and Krupp (i.e., the partnership between BBC and Krupp for building HTRs)

BMFT--Bundesministerium für Forschung und Technologie (the Federal Ministry for Research and Technology)

CDU--the Christian Democratic Party in the Federal Republic

FAZ--the Frankfurter Allgemeine Zeitung

FBR--fast breeder reactor

FDP--the Free Democratic Party in the Federal Republic

GAC--General Atomic Corporation, subsequently the Gulf General Atomic Corporation after Gulf bought a major share

GHH--Gütehoffnungshütte Sterkrade

GKSS--Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt m.b.H.

HHT--helium high temperature reactor

HKG--Hochtemperatur-Kernkraftwerk GmbH (utility group formed in late 1960s to erect a pebble bed HTR)

HRB--Hochtemperaturreaktorbau (i.e., the successor to BBK after Krupp dropped out of the partnership--subsidiary of BBC)

HRG--Hochtemperaturreaktor Gesellschaft

HTR--high temperature reactor

IEA--International Energy Agency

IAEA--International Atomic Energy Agency

JCAE--Joint Committee on Atomic Energy (U.S.)

KFA--Kernforschungsanlage (i.e., the Nuclear Research Center in Jülich)

KFZ--Kernforschungszentrum (i.e., the Nuclear Research Center in Karlsruhe)

KSH--Kernenergiegesellschaft Schleswig Holstein mbH, Kiel

KWU--Kraftwerk Union, the largest reactor manufacturer in the Federal Republic

LWR--light water reactor

MAN--Maschinenfabrik Augsburg-Nürnberg

MWMV--Ministerium für Wirtschaft, Mittelstand und Verkehr im NRW (Ministry of Economics, Small Business and Transport)

MW--megawatt

NRW--North Rhine-Westphalia, West Germany's largest Land

Nukem--Nuklear-Chemie und Metallurgie GmbH, Hanau (fuel element supplier)

NWK--Nordwestdeutsche Kraftwerke, Hamburg

PNP--Projekt Prototypanlage Nukleare Prozesswärme(process heat project)

Preussenelektra--Preussische Elektrizitäts-AG, Hannover

PTH--Projektträger Hochtemperaturreaktor (the agency of the BMFT which coordinates work on HTRs at the KFA Jülich)

RWE--Rheinische-Westphälische Elektrizitätswerk, the largest German utility

SPD--the Social Democratic Party in the Federal Republic

THTR--thorium high temperature reactor

VEW--Vereinigte Elektrizitätswerk Westphalen, the second largest German utility, Dortmund

PART I

CHAPTER ONE

A FRAMEWORK FOR ANALYZING TECHNOLOGICAL CHOICES

Jerome Wiesner, former science advisor to President Kennedy and M.I.T. president, has called technology "the most dominant force in modern life" and "the engine that propels modern society."[1] Donald Cook, then president and chief executive officer of the American Electric Power Company, has described technology as a "primal event" in the history of the world and suggested that it must be understood as a "mainspring of history" if man is to comprehend it.[2] The economist Robert Heilbroner states that the "extraordinary predominance of technology" is the "decisive characteristic of modern times "[3] and argues further that although technological development may not have caused every single event of this century, it is the ultimate cause of what this century has become as a whole.[4] Whether or not such claims are exaggerated, it is clear that technology is a central and defining characteristic of modern society.

World War II marked the beginning of large-scale government promotion of certain technologies. With the intensive national attempts to master technologies such as radar and atomic energy, new doors were opened for understanding how

significant technological choices can be for societies. Since then, both governments and private industrial firms have become increasingly aware of the importance of technological choices and recognized the direct bearing which the development of new technologies has on political and economic power.

A prime example of this development is the nuclear energy sector with the political and economic questions which pertain to it. The nuclear industry certainly represents one of the most sophisticated industries a nation can have, and at the same time it stimulates other high technology products.[5] On the economic side, high stakes are involved for business and government because of both the huge expenditures and the long time frame needed for technological development. On the political side, national prestige and security issues are relevant. In addition, energy interdependence and the establishment of superiority in export markets are factors which relate to both economic and political considerations.

The development of nuclear energy in the Federal Republic of Germany is particularly striking. Although the Allies did not permit the Germans to resume nuclear research after the war until 1955, the German nuclear industry quickly overcame the head-start other countries had. By the late 1960s, the industry had established itself as

competitive with other reactor producers, and German products had gained world-wide respect. In fact, the former director of the U.S. Oak Ridge National Laboratory, Alvin Weinberg, suggested in the mid-1970s that West German technology might even be superior to that in America.[6]

Nuclear energy has always enjoyed the status of being the most favored high technology in the Federal Republic. West German governmental research policy started in the 1950s with the support of nuclear policy, and industry and government expenditures have continued to be more directed to nuclear energy than to other advanced technologies such as space, computers or the aircraft industry.[7] Both the Federal Republic and other European countries realize that nuclear technology may play as important an economic role in the future as the aerospace industry and computers have played in the past, and they want to guard against U.S. domination of this field as well. National interests are, therefore, high.

From the start of their nuclear program, the Germans have followed a cautious approach, keeping several options open. Domestic and international factors have influenced the German policy choices. They were willing to import reactor technology, especially from the United States. As a result, the Germans had a wide range of reactor alternatives as opposed to the French or British who, for military and prestige reasons, each concentrated efforts on one

design. At the same time, the Germans were very protective of their domestic industry because they wanted it to develop and become internationally competitive. The Germans joined few international partnerships. Our aim is to see how and why the choices in the German nuclear program were made and what impact they had on further technological development. Special attention will be given to the pebble bed high temperature reactor (HTR) which was the one solely German designed and developed reactor.

PURPOSE OF THE THESIS

The purpose of this thesis is to use the example of German nuclear energy development to gain some insight into how technological choices are made in advanced industrial societies. We will consider both the determinants of technological choices and the feedback from the political system on the course of technological development. By the term technological choices, we refer to the series of decisions taken in the course of technological development. To understand how such choices are made, we must understand who the actors are, and what their roles and objectives are over time. Specifically, we will examine how the business and state sectors are related. To do this, these sectors will be broken down to identify the relevant actors within each -- the reactor manufacturing firms, the electrical utilities which purchase and operate the reactors, and the government actors on both the federal and Land (i.e., state in the American sense) level.

The argument presented is that economic, political and organizational factors all affect the course of technological development, but the degree of importance and nature of effect varies according to the stage of development. The development is traditionally broken down to three stages and we will also use these three stages for our analysis: first, there is a research and development stage, then a demonstration stage, and finally a commercialization stage. For the German nuclear energy case, and in line with the findings of Peter DeLeon in his study of the development of nuclear reactors in six nations,[8] this thesis suggests that government has been most important in the initial R&D stage of development, manufacturers in the demonstration stage, and utilities in the commercialization stage. We will further suggest that our findings about the relationship between the stages of development and the input of the different actors have relevance beyond just the German nuclear example; they also are relevant to other technological choices because of what they indicate about transitions between stages of development.

Although there is a body of literature which views technological choices mainly as a function of economic factors, we argue here that political-organizational factors have a broader relevance. As we will see, even in those instances in which economic factors appear to be most influential, for example with light water reactors in the

Federal Republic, the political context often defines the economic context and has a major impact on the technological choices made.

Our analysis of political factors also leads us to argue that political decisions made in the early stages of development retain a lasting impact, thereby disputing the claim made by market advocates that technological choices in the commercialization stage should rest fully on the private sector. Both the government and private sector in West Germany pay lip service to the assertion that the government should stop influencing technological development after the R&D stage of development. We will show, though, that by the time complex technologies reach the commercialization stage, so many political decisions have already been made with government participation that it is impossible to separate out the political concerns. The choices of technological objectives, the setting up of policy-making structures and institutions, and decisions on financing all involve political inputs, and the effect of these inputs does not disappear simply because a technology moves to commercialization.

While emphasizing political factors, we will see that technological choices result from a complex interaction of the business-state sectors, and this interaction changed over the course of development of the nuclear program in

West Germany. We have identified three such developmental phases*: (1) an open-ended period from 1955-1963 in which serious debates about nuclear energy took place; (2) a period of consensus from 1963-1973 within the nuclear community that nuclear energy should be developed because of the benefits it brought the German economy; and (3) a post-1973 period of opposition to nuclear energy from outside the nuclear community which prompted the community itself to close ranks in favor of nuclear development.

The thesis is structured around the interactions of the policy actors and objectives involved in making technological choices for nuclear reactors in these three phases. We will see how relations varied over time not only among the manufacturing, utility and government sectors, but also within them.

ORGANIZATION

To examine the linkage between the German policy-making process and technological decisions, we will study how choices of specific nuclear designs were made in the Federal Republic. This chapter sets out the context for the analysis. The first section deals with the relationship of technology and public policy. The increasingly critical perspective on

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*The phases refer to specific periods of German energy development; the stages refer to a general pattern of technological development.

technology in the 1970s, a definition of technological choices, and the relation of technological choices to institutions and market decisions are first considered. The second section presents a discussion of how economic and political-organizational factors determine technological choices; it highlights the over-riding significance of the political context. The third section of the chapter applies the framework to the German case and justifies why we are studying German nuclear energy and, in particular, the pebble bed high temperature reactor.

The body of the thesis examines the case of German nuclear energy development in detail. Part II, consisting of Chapters Two and Three, provides an overview of German nuclear policy to show how the relationships of actors and objectives have changed over time. Chapter Two introduces the three phases of development in the German program and relates them to the three reactor types (the light water, high temperature and fast breeder reactors) being actively developed at present. The chapter focuses on changing objectives within the German program and explains the key roles played by the utilities in determining German nuclear energy strategy. Chapter Three focuses on the institutions established for nuclear policy-making and their continuing significance. It outlines the political reasons which enabled the utilities to exert such influence: the government and manufacturing industry left a policy vacuum which

the utilities readily filled, to the surprise of the other policy actors who preferred a different strategy.

Part III, consisting of Chapters Four to Seven, moves from this general discussion of overall German nuclear development to a more specific study of the pebble bed high temperature reactor (HTR). In parallel with Part II, it looks first at the changing objectives over the course of HTR development and then at the interactions among and within the sectors. Chapter Four relates the development of the HTR to the three phases described for overall nuclear policy. Chapters Five, Six and Seven then focus in depth on each of the three stages of the HTR program: the small 15 MW experimental reactor, the 300 MW demonstration reactor, and the post-1975 efforts to reach agreement on a successor to the prototype reactor constructed in the demonstration stage.

Chapter Eight, the conclusion, relates the findings of the HTR case study to the conceptual argument outlined in Chapter One. It points out the advantages and disadvantages of focusing narrowly on German nuclear policy and the HTR, and it discusses the broader applicability of our findings.

TECHNOLOGY AND TECHNOLOGICAL CHOICES

As background to our discussion of technological choices, we will first examine how technology itself is viewed and

how these views have changed. Because technology has a profound effect on the social and physical environment -- whether we speak of nuclear reactors, sophisitcated weapons systems, space exploration or standards for water quality -- the interactions of technological factors and political, economic and social developments should be considered carefully. The catalyst for the contemporary emphasis on technology as one of the important responsibilities of governments stems from World War II. The American victory in the war caused a new awareness in Europe of the significance of technological advances. Many shared the belief, as asserted here by the economist Harry Johnson, that the United States won the war "by virtue of its vastly superior natural resources and technology rather than by virtue of any apparent superior moral fiber, political determination and diplomatic skill, to which the European powers customarily credited their victories."[9] The Western Europeans saw clearly the need for increased productivity, based on deliberate efforts to cultivate technology, if they were to regain their international political importance. They too placed their hopes for the future on technological development.

The Relationship of Science and Technology

For the first 20 years after World War II, science and technology were associated with economic and social progress. The prevailing concern was to find strategies and institutions

which would effectively support scientific research and technological development. Considered historically, the alliance between science and technology is new. In earlier centuries, technology was quite independent of science. Science was a thought process, an accumulation of basic knowledge about the natural universe. Technology was the practical application of such knowledge to aid in the production of goods and services.[10] The inventions which provided the basis for the industrial revolution -- the steam engine, the loom, the lathe -- were not a product of science but of technology. They were invented by practical men.

Today, though, the methods of science and technology are essentially interdependent. Studies about the industrial research process have described "the marriage of science and technology," particularly after 1945.[11] Although some researchers still stress the "autonomy of technology" from science, the more classic description of the relationship is that of "mirror-image twins."[12] In the twentieth century, or at least certainly since World War II, science has become the major source of new technologies, to the extent that they are usually considered as applied science. From a social perspective, some welcome the relation because they feel that science has been harnessed to the purposes of obtaining desirable practical consequences.[13] Others are concerned about it because they feel that scientific progress does not adequately consider

social needs. E. J. Mishan, for example, argues that science and technology only address specific and immediate ends and fail to perceive social repercussions: according to his argument, society loses control over the larger destiny to which it is impelled by the forces of science and technology.[14]

Changed Perspectives on Technology

The social crises which emerged in the late 1960s caused a waning of the optimistic faith in science and technology that had flourished in the earlier period of unprecedented economic growth.[15] Both growing disillusionment with the excessive beliefs that science and technology possessed the key to painless economic and social improvement, and growing concern with the effects of technological change, increasing affluence, and associated social strains on "the quality of life" caused a marked decrease in faith in science policy and technological development.[16]

The decreasing faith in technological development is not surprising and is in line with the major shifts in thinking in the last 20 years about the benefits of economic development and social change in general. In the 1960s there was a dominant optimism regarding political modernization and economic development, but the stormy course of the 1970s with its economic recessions and energy crises brought an abrupt awareness that the stability

perceived earlier was a myth. Shirley Williams, one of the founders of the British Social Democratic Party, even calls it a "delusion," and says we should not expect stability today, but rather instability.[17] In the 1960s there was a smug satisfaction about the predictability of politics in advanced industrial nations. It was seen as a function of social and economic transformations. Andrew Shonfield's book, Modern Capitalism,[18] reflected this optimism and marked the high water point among economists who felt that they understood the economic dynamics of political systems: the system could be controlled through management and "fine tuning." Technological advances were just another contribution to this rosy picture; they were another part of the "fine tuning."

The perspective of the 1970s was quite different. It brought a preoccupation with political instability, the intractibility of policy, the possibility of policy failure, and the political alienation of mass publics.[19] The political process came under question and politics took place increasingly outside traditional political institutions -- witness the regional ethnic movements, ecologists' and feminists' movements, and anti-nuclear protestors. The role of politics and the state was obscured in the first two post-war decades by rapid economic growth and far-reaching social transformation, but it was rediscovered in the 1970s. Recognition emerged that neither economic

and social developments nor technological developments can be insulated from political factors.

The widespread protests which took place against nuclear energy during this period in West Germany and elsewhere shared common motivations with other protests of the 1970s. The protests were not against the state and society for failing to provide for economic growth and material prosperity, but against their very success in doing so.[20] The protesting groups were disillusioned in part because they disagreed with the growth-oriented philosophy which seemed to motivate state actions and in part because the traditional institutions of government, such as political parties, were seen as unresponsive to changing conditions.

Irvin Bupp and Jean-Claude Derian echo this argument in their book, Light Water: How the Nuclear Dream Dissolved.[21] They argue that the way the innovation process for light water reactors was managed by business and government in the U.S. and Western Europe contributed to the identification of nuclear power technology with something that many citizens in these countries dislike and distrust about their societies; this dislike and distrust is the principal cause for the dissolution of the nuclear dream.[22] Here too, the successes achieved by business and government are the root of the complaint. Bupp and Derian maintain that such political factors can have unintended consequences on

technological development. Thus, in the 1970s the political aspects of technological development have become more evident and these aspects merit close scrutiny because of their intended or unintended consequences on technological choices.

Technological Choices

As a more critical perspective on technological progress arose and as the political side of technological development became apparent, the issue of how technological choices are in fact made took on greater significance. In-depth studies of decision-making and influence on specific technological projects became an especially useful technique for trying to sort out the actual influences on technological development.

The development of a technology occurs in a series of steps -- or technological choices -- which are influenced by political, economic and social conditions as well as by the individual actors involved with policy-making. As used here, the term technological choices refers to the series of decisions made in the course of development of a technology; it does not refer to one specific decision or choice, but rather to the series of decisions culminating ideally in a final commercializable product.

Our focus on technological choices will make it clear that there is nothing inevitable about the course of technological development. It is, instead, the result of a complex interaction of innumerable decisions reflecting technological, political and economic inputs. Following a similar approach in his study of national reactor development programs, Peter DeLeon, the editor of Policy Sciences, suggests juxtaposing the "objectives" and "attributes" of technological development.[24] For him, the objectives are couched largely in terms of organizational goals (e.g., an active science community, an integrated decision-making system, a concomitant military program, the effect of being a late-comer or early-starter for a technology, national R&D heritage, multiple options, and resources invested).[25]

The benefit of this framework is that it focuses attention on the ties between a set of institutional objectives, which represents various economic and political goals, and a set of attributes which influences the formulation of objectives. The framework "provides a concept and tool for coherently explaining a technology development in terms of the political, institutional and economic forces that shape a given public policy."[26] DeLeon's objectives of technological development center on the policy level, and the attributes center on the structural level -- i.e., they are characteristics which influence how the organizational

structures are established. Our concentration on technological choices also stresses the linkage between policy objectives and structural arrangements.

Technological Choices and Stages of Development. Both the importance of the actors for technological choices and the nature of the objectives of a specific project change over time, and this influences the direction of a program. The normal route of technological development is (1) a research and development stage, (2) a demonstration stage, and (3) commercialization. These stages are important since the factors influencing technological choices vary across the stages. In terms of policy actors in German nuclear energy, governments or government research establishments tend to dominate the R&D stage, the reactor manufacturing industry is usually most critical in the demonstration phase, and the utilities, as reactor operators, assume their most critical role as commercialization nears. Objectives also shift from stage to stage. Nuclear programs are usually launched with explicit government statements about the importance of national prestige and basic science, but the efficient production of a technology eventually becomes the major objective.[27] Governments are more interested in national prestige, utilities in efficient technology.

The transitions from one stage to the next are a key element in the success or failure of reactor development programs. The transitions functioned smoothly in some countries, including the Federal Republic, but serious problems arose in the early British and French programs where control of the program remained in the hands of the government after an institutional transition should have occurred.[28] This emphasis on transitions highlights the requirement for policy actors to work together; successful technological development depends on the cooperative and continual involvement of the reactor developers (usually the government through research programs), the vendors and the operators from the early stages of development through commercialization. Our focus on technological choices provides a means to monitor how these interactions have progressed in one technological area.

Technological Choices and Institutions. Our examination of the impact of structure on technological choices particularly emphasizes the role of institutions and their influence on policy-making. Both the institutional format as a whole and the individual institutions will be considered.

In his study of the political aspects of attempts to control the use of plutonium, Gene Rochlin argues that different technological options will be recognized if more attention is paid to political and institutional considerations

than to technological and industrial ones.[29] Rochlin says that decisions for technologies such as nuclear power often serve as a means to play out political disputes. No intelligent policy choice can be made that is inconsistent with economic or technical realities, but neither can an intelligent policy be put into practice if it is inconsistent with the social and political constraints within which it must operate.[30] The issue for Rochlin is not whether one set of criteria replaces the other, but which set dominates in defining a range of choices.

Rochlin suggests that the true significance of political and institutional constraints is too often overlooked. Henry Lambright makes the same point, arguing that there is a great deal more "politics" in the mangement of defense, space and atomic energy than is commonly realized. According to Lambright, "High technology is more than advanced or science-based technology. In the military, space and atomic contexts, it is government-based technology. The agencies that sponsor the launching of technology influence the deployment of their creations."[31]

The type of organizational structure established for the development and implementation of a technology has a direct bearing on the success of the project. Roger Williams, former Science Advisor with the Science Council of Canada, maintains that the structure of the British nuclear industry basically guaranteed the failure of British nuclear policy.

The British institutional format -- consisting of a public R&D monopoly supplying a virtual operator monopoly with five consortia squeezed uncomfortably between the two -- precluded any open discussion of important issues such as differences about reactor designs, non-nuclear alternatives, or demand modification for reactors rather than supply expansion.[32] Williams says that good decisions and good execution are the sine qua non of a carefully designed policy and management structure, but if one simply throws institutions up and together -- as the British did -- success is highly unlikely.[33]

In the case of German nuclear energy, we will look closely at the institutional arrangements that were first established because they have remained influential throughout the stages of development. Moreover, institutional factors go beyond the relationship of government actors to manufacturing firms or utilities; they also include relations within each of these sectors. Here too, institutions can constrain or facilitate technological development.

Technological Choices and the Market. Success for advanced technologies is usually measured by the number of commercial orders placed -- i.e. the market determines whether a technology is successful. The appropriateness of the market for such determinations continues to be a matter of debate which relates to the interaction of political and economic objectives.

One argument is that the market mechanism, which traditionally has been the means for people to register their preferences, does not work for advanced technological innovations. Edward Chase, for instance, believes that the market mechanism is not a reliable guide for making technological choices because it does not become engaged quickly enough, and it "simply is not up to reflecting the long-range values that have to be weighed if a rational use is to be made of the new technology."[34] Supporting the notion that markets have a declining functional relevance, John Kenneth Galbraith asserts that advanced technology is the "enemy of the market" because the specialization of men and process and the commitments of time and capital required by advanced technology make the market work badly.[35] Galbraith maintains, further, that the market system cannot provide the control of the environment which is needed for the development of advanced technologies.[36]

The opposing argument is that only the market judges technological options objectively, and that decisions on commercialization for advanced technologies should be left to supplier and user firms. In that way, a more realistic economic assessment and better accounting of the trade-offs between time and cost are likely to be made. The claim is that proper economic assessment leads to rational technological outcomes, but governmental assessments are not very reliable. Government involvement tends to distort the market according to this argument, and therefore it should be kept to a minimum.

The crux of the debate between those criticizing and defending the market is whether political or economic objectives are seen as more important. In fact, though, political and economic objectives should be seen in terms of how they balance with each other. This balance should be considered both in terms of its development through the three stages described earlier and in terms of the changes of leadership between the stages. The motivations for a project at the R&D stage do not necessarily reflect the objectives of the project as it approaches commercilization. At the commercialization stage, the utilities as the orderers and operators of reactors are likely to play a more significant role and more attention will be given to economic calculations, but this role is shaped by political decisions based on the political objectives of earlier stages. Moreover, the structure of the decision-making process, which itself is a function of political factors, also shapes the abilities of specific actors such as the utilities to influence policy. The advocates of the notion that economic factors are the key variable in technological development fail to note the inevitable impact of political factors; the critics of the notion fail to acknowledge the modifying influence of economic factors.

In contrast to the view that the market alone determines technological outcomes, the view can also be taken that political factors can be used to create conditions

favorable to technological development. These then act as incentives for the private sector, and thereby facilitate commercialization. J. Herbert Hollomon makes this point in describing how the classic studies of railroad technology "demonstrate that significant railroad invention followed the decision to grant land to railroads and expand the railroad system in the U.S."[37] Government actions contributed directly to the diffusion of railroad technology by influencing the conditions for diffusion. In the case of nuclear reactors, the complexities involved with development make the intricate interactions among actors and objectives even more important. The next section sets out a specific framework for viewing the interactions between political and economic objectives.

THE RELATIONSHIP OF ECONOMIC FACTORS AND POLITICAL-ORGANIZATIONAL FACTORS IN DETERMINING TECHNOLOGICAL CHOICES

Two Approaches to Policy-Making

The main theme of the preceding section on technological choices is that the successful development of a given project depends on the pattern of interactions between economic and political objectives. Policy actors can be divided into those who stress the economic objectives and those who stress the political objectives of technological development. We propose to call these two approaches to technology policy-making (1) the market approach and (2) the political-organizational approach. Each approach sees

a different pattern of how economic, political and social factors relate, and each has a different view of the business-state relationship. The market approach emphasizes economic factors and cost calculations of the private sector as the main determinants of technological choices; the political-organizational approach looks at the national priorities and institutional arrangements to determine what channels economic factors.

Although we contend that the political-organizational factors define the context in which the economic factors operate and thus are more significant, this is just part of our larger argument that policy outcomes depend on how the two sets of objectives interact. The balancing is part of a learning process for the actors in advanced technology projects: the business and state actors learn to cooperate and form alliances with each other. A greater sharing of resources is required due to the technological complexities, the long time frame, and the large expenditures involved. The balancing of political and economic objectives reflects an awareness among the policy actors for a specific project that policy-making leadership must shift as the project moves through the stages of development.

Our aim is not to see which approach provides a better explanation of policy-making because each has relevance. Instead, our aim is to see the relative importance of each

approach and the relationship between the two approaches at each of the three stages of development. In the past, the responsibilities of individual actors in technological development were seen as isolated, and the stages of development were viewed as distinct. Utilities waited for the offers of power plant manufacturers before making decisions on orders; supplier firms concentrated only on the components they produced, and not on larger-scale plans. Government subsidies ceased when the prospect of commercialization became evident. Now, though, new patterns are emerging because efforts, skills and resources have to be pooled for advanced technological projects.

The next two sub-sections look respectively at the market approach and political-organizational approach to technological policy-making. The two approaches will form the basis for our analysis of German nuclear energy policy.

The Market Approach

People whose thinking reflects the market approach to technological policy-making believe that economic signals provide good incentives for making choices as long as these signals are not distorted. Governments may distort the economic signals if they let intervening variables like prestige or international competition interfere. Governments are too apt to concentrate support on advanced technological projects, such as fast breeder reactors or

supersonic planes, which they are then unwilling to give up even when the projects are not profitable to pursue. The innovative spirit is dampened. Private industry, on the other hand, makes decisions about whether to go ahead with new ideas based on potential profits. This provides a clear-cut measure for evaluating technological development and hence decisions determined by market forces are easily changed if necessary. Bad ideas are dropped more readily than the government is willing to do. The market approach focuses mainly on the commercialization stage of technological development, and its supporters argue that the private sector makes the best decisions about commercialization when other factors interfere as little as possible with calculations of profit.

The role of politics in the market approach is a negative one -- or a corrective one. Supporters of the approach feel that decisions made in terms of political factors are made on too limited a basis, because such decisions are not usually a reflection of open competition among technological alternatives. Decisions made according to the marketability of a technology, in contrast, are more incremental and flexible than those based on political factors. The role of the government, according to the market approach, is to do its utmost to create a free market environment by trying to remove the regulatory and legal barriers to technological development. Government can help to put the economic system back in working order, and this would help

overcome the nuclear stalemate of the 1970s because people would understand better the economic necessity of nuclear energy.

In this approach, government involvement in the R&D stage of development is acceptable and even essential, for example to stimulate interest in a project or reduce the risks for industry. With controversial technologies such as fast breeder reactors, the government could also guarantee industry at least a partial refund of R&D expenditures in case a political decision against the project is made. Once commercialization nears, however, economic considerations determine outcomes. The belief is that the government should not get involved with direct subsidies to commercial technology; private industry is capable of financing technological development, even for expensive, sophisticated technologies. According to Keith Pavitt, even when civilian technologies were successfully developed with government support, it was not government policy which made the difference. Rather, it was the close interweaving of technology policy with production and marketing policy, combined with the essential ingredient of competent management in the firms involved, that was responsible.[38]

Proponents of the market model focus attention on technological innovation, and claim that it occurs most efficiently if market decisions determine its course. Pavitt,

for instance, maintains that the best way for a government to influence industrial innovation is not to have any policy which specifically promotes industrial innovation.[39]

One of the most elaborate arguments against governmental support for advanced technology has been presented by George Eades and Richard Nelson.[40] Eades and Nelson use the cases of fast breeder reactors and the civilian supersonic transport (SST) in the United States to show that "forcing technology" through government support is bad because ideas are rigidly adhered to and never abandoned. The projects are pushed to attention at federal policy-making levels as "opportunities to be seized" rather than as reactions to problems. According to Eades and Nelson:

> The federal government increasingly is adopting the role of deciding in detail the R&D projects that will be undertaken, paying the bill and taking the risks, and being generally responsible for the kinds of products and processes that evolve.[41]

This is a new departure in national policy which the authors feel should be watched with suspicion because it counters past practices which accounted for American technological success. American policy used to be characterized by innovative ideas originating from a diversity of sources. Bad bets were abandoned quickly in a process which might not have been orderly but which worked. Eades and Nelson, however, cite the civilian reactor program, the SST, and military R&D since the 1950s as a sad contrast to the former practice because now everyone sticks to a "game plan."[42]

There is no incentive to abandon a project even when it should be dropped.

Eades and Nelson disagree with those who claim that advanced technologies require government subsidies because of long lead times, high risks, and scale of development costs. They say that governments should not underestimate the ability of capital markets and firms to undertake large projects involving substantial risks and long-term horizons. IBM, after all, risked $5 billion in the early 1960s to develop its System-360 family of computers, and industrial R&D on television and polymers in the 1920s are other examples of firms undertaking long range projects with uncertain returns.[43] The real reason why American industry did not invest in the SST or the breeder reactor was that the expected rate of return (i.e. the commercial prospects) was very low. Furthermore, the time-cost tradeoff should also be noted. Speeding up development through government support may bring benefits sooner, but it also brings added costs and risks. The question is whether it is worth it to get fast breeders slightly earlier. The measurement has to be in terms of the marginal differences; too often, government intervention is mistakenly rationalized in terms of "all-or-nothing" arguments, but the technology might well have been developed in either case.

The message conveyed by Eades and Nelson regarding technological choices is that the direct government support

displayed in the American SST and fast breeder cases should not be repeated. Some government sponsorship is appropriate to guarantee that social benefits are heeded, but the support should be only for basic research and development and not for commercial projects.[45] Eades and Nelson prefer a decentralized traditional structure characterized by many sources of technical knowledge and flexible decision-making. They admit that relying on diverse sources to steer industrial policy might create certain inefficiencies, but imposing order through government subsidies leads to worse results. Governments are too reluctant to abandon projects because of pressure groups and questions of prestige.

Arguments similar to Eades and Nelson's have been expressed by Duncan Burn for British nuclear energy policy, John Zysman for the French electronics industry, R. Miller and S. Sawers for aircraft development, and Otto Keck for the German fast breeder reactor.[46] Zysman shows how different government policies can affect the organizational response of firms. Protection and subsidies dampened the competitive pressure to adopt more effective organizations in France so that state support ended up sustaining traditional organizations that are incompatible with modern and competitive industry.[47] Sir Alec Cairncross is even more critical of government's role. Following his own career in the British civil service, he claims:

> The last thing that governments are equipped to do is to promote industrial innovation. They

> can never spot the real winners because they are far too clumsy, ignorant and bureaucratic. Instead they are likely to go in for expensive prestige projects that tie up scarce design teams until another government comes in and scraps the whole affair.[48]

Keck traces the development of the German fast breeder reactor to show that the government's decision to construct the sodium-cooled SNR-300 demonstration reactor was reached more by a process of elimination than by a specific decision. The alternatives such as the steam-cooled prototype reactor were gradually dropped until nothing but the sodium-cooled reactor remained. It had become the core of the program and to have opted against it would have meant dismantling the entire government/industry apparatus. Thus, the program's momentum, rather than any specific decision, paved the way for the SNR-300.[49] Keck is critical of this and recommends a decision strategy which would distinguish between exploratory R&D financed by the state and commercial R&D financed by business enterprises from their own funds.[50] This would assure proper economic assessment because industry would be making it. Government subsidies would only be for risk-sharing in unforeseeable operation losses and for background R&D performed in the government research centers. Keck says that such a strategy is within the financial capabilities of the firms involved; he cites the small percentage of sales income it would amount to for Siemens and mentions that it is in line with previous expenditures on nuclear reactors.[51]

The market approach to technological policy-making sees technological choices as a function of economic and political factors, but it goes further to urge that market considerations guarantee more emphasis on innovation and hence better outcomes. Government policy which forces technology along a certain course almost certainly will backfire. The market approach, on the other hand, leads to a multiple-option, sequential, experimental strategy according to its backers, and this increases the chances for a project's success.[52] Industry thus is left to pursue the path it sees as best.

The Political-Organizational Approach

The advocates of the political-organizational approach to technological policy-making see technological choices largely as a response to pre-existing political developments. The two main developments to consider are (1) national political goals and (2) the way in which government priorities influenced the establishment of institutions which deal with a given technology. Political aims and organizational constraints are often treated separately in political science literature; we combine them in this approach, however, because for technological development they both reflect political choices which condition and shape the direction of a specific technology, and that is our focal point. When we speak of "political objectives" or "politics" for this model, we refer to the goals of the

state and institutional arrangements. Whereas the market approach viewed political factors as a source of distortion for technological development, here they serve as the context through which economic conditions are defined.

This approach emphasizes the historical aspects of specific technological projects, and it assumes an ongoing impact of politics. Relations between business and state sectors are defined less in terms of proper roles and more in terms of trade-offs. The distinction between stages of development is therefore much less sharp than with the market approach because the cumulative effect of national aims and institutional structure inevitably carries over into the commercialization stage.

In the market approach, we have seen that politics only referred to government actions and not to institutional impact; it had a negative role, was a means to clear the way for the market to operate efficiently, and thus was reactive to other conditions. In the political-organizational approach, on the other hand, politics has a positive role. It is seen as a continuing influence, not merely as periodic interventions or adjustments. The argument is that a truly free market cannot be attained and politics will not lose its significance since economic interests, however cloaked, also reflect political objectives.

A second point emphasized by this approach is the interaction of political and economic objectives. When industry turns to the government to create certain economic conditions, its actions are not only economic but also political. The firms involved in a given sector are eager to establish stability and control within their branch of an industry, and they are quite amenable to having their economic problems solved by political means. Most firms show little hesitation about discarding their market ideology when they stand to gain by government support. Similarly, objections to state planning can also be overcome quickly by firms when planning seems beneficial to them.

Such overlapping of political and economic objectives it not new. In fact, Gabriel Kolko has chronicled how the American railroad barons of the 19th century embraced regulation as a means to stabilize their industry and protect themselves from cutthroat competition.[53] The point is that industry and government are well aware of their interdependence, and hence any policy analysis of technological development should pay close attention to the interactions between the sectors.

Political Aspects of the Political-Organizational Approach. The political-organizational approach centers attention on the effect of politics on the sharing of

functions between business and state sectors (e.g., initiating projects, risk-sharing, profit-taking) and on the establishment of decision-making structures. Since politics is involved in the parcelling out of tasks among the relevant business-state sectors and in the way in which government is organized, political goals have a critical impact on technological outcomes. National security and national prestige are prime examples. According to this approach, military objectives steer developments in certain directions, and projects such as the Concorde are supported because of the supposed prestige they will bring. The interest in "national champion industries" during the late 1960s and early 1970s was very much a function of the so-called "technological gap" between Europe and the United States.[54] The assumption was that the national champion industries should be state-supported because otherwise they could not compete with large American firms. They had to be subsidized to uphold the honor of the state. The state backed technological development to further its own needs.

As we have seen, political factors often seemed of secondary importance in the 1950s and 1960s when the role of politics was obscured by an expanding pie of economic benefits. Now, though, the role is becoming more apparent. Henry Nau makes this point in his study of nuclear reactor development in Western Europe. The purpose of his study

is to show how nations have sought to accommodate civilian technologies to national aims, and he emphasizes the impact of national structures of interest on international technological and economic activity by examining how groups -- identified primarily along national lines -- behave in the development of big technologies.[55] The willingness to cooperate internationally is directly related to domestic strengths and weaknesses. Technological outcomes are seen as a response to pre-existent political developments; political choices condition and shape the direction of technology. Politics, in Nau's estimation, cannot be avoided in the new milieu of European technological relations.[56]

Two corollary arguments emerge from the claim that political choice is of prime importance in technological development. The first, represented by advocates of the "appropriate technology" school, is that political considerations may lead to the rejection of certain technologies. When Volvo, for example, replaced its assembly line successfully with 250 individual car carriers which permitted more personalized work, it demonstrated that low technology can be productive and can require as much engineering genius as high technology.[57] This view criticizes those who tend to believe in the inevitability of "grand technological solutions," especially concerning energy.

The second argument concerns the possible misuse of political factors in technological choices. John Kenneth Galbraith relates the problem to political alignments within society. Galbraith says that "massive and complex business organizations are the tangible manifestation of advanced technology," and these organizations are compelled to turn to the state for help because the problems of planning which arise inevitably with technology are beyond the reach of individual firms.[58] If society wants to reap the benefits of advanced technology, it has to bear the costs, and hence state support becomes an imperative of technology. The line separating public and private authority becomes blurred, and the state ends up promoting national goals which reflect the needs of the "industrial system."[59] The industrial system should no longer be regarded as separate from government because corporations are becoming part of the larger administrative complex associated with the state.[60] Galbraith assumes that political arrangements affect technological choices; his message is to be cautious about how these political arrangements are evolving.

Organizational Aspects of the Political-Organizational Approach. We should be cautious when we speak of the "government" or the "state" because the terms are so amorphous. Instead, there is a need to see which actors within the governmental process have an impact on technology policy. In addition, the stage at which they exert influence is also

critical. More attention should be paid to the process of reaching decisions to clarify how that process is an essential part of formulating policy.

W. Henry Lambright has presented this viewpoint cogently in his book Governing Science and Technology.[61] According to him, policy formulation should be studied in terms of both interest groups and organizational analysis. Too often, technological decisions involve coalition building rather than a rational search for solutions to public problems. Technological choices, hence, are important not only due to the technologies selected, but also due to the closing off of alternative options.[62]

The long development period for advanced technologies makes them particularly susceptible to organizational constraints. One reason for this relates to changing objectives and the struggle to keep coherent goals in sight. Milton Shaw, onetime head of R&D on the American liquid metal fast breeder reactor project for the Atomic Energy Commission (AEC), stated the problem clearly:

> Bringing to completion long-term technological projects is one of the toughest problems that a democratic society faces. The political process inevitably focuses attention on short-term payoffs, and long-range programs, whatever their promise, have a difficult time surviving.[63]

The momentum which large-scale technological projects gain is a second reason which underscores the relevance of organizational concerns. Part of the momentum derives from

the expenditures involved, but part of it comes from organizational alliances that evolve. Lambright points out that as nuclear critics grew in stridency and number in the late 1960s, "the technological partnership among the AEC, industry and the Joint Committee on Atomic Energy (JCAE) became a tight and closed political sub-system."[64]

The AEC is one example of how an agency can influence the policy process. In addition to regulating atomic energy, the AEC also assumed the role of chief promoter; it was the developers and marketers of nuclear energy (and not the regulators) who governed the agency. The AEC became so overly protective of the atom that one New York Times reporter said the agency "repeatedly sought to repress studies by its own scientists that found nuclear reactors were more dangerous than were officially acknowledged or that raised questions about reactor safety devices."[65] The consequence was that the AEC was not in a position to anticipate or even respond to growing public concerns; instead it fought change. Lambright draws a telling conclusion:

> Seldom has a federal agency pushed harder on a private industry to innovate a new technology. Initially, the AEC did so in the wake of a national mandate. It continued to do so even as the national policy climate changed. In the end the AEC itself was changed.[66]

This is a prime example of what Lambright labels "government-based technology" to show how the government is actively involved in the pace and direction of high

technology deployment. Those agencies which launch a technology usually retain a major influence on its subsequent deployment.[67] Another key facet of the government's role in technology decision-making is that where there is a policy vacuum, agencies will move in to fill the gap. NASA planners, for instance, had already chosen a lunar landing objective as one of their agency's major goals two years before President Kennedy made his historic decision -- and they were directing their program to that objective.[68]

Because organizational interests fit into a larger picture of interests, organizations can have a significant impact on technological outcomes. Bupp and Derian describe the organizational constraints caused by the activities of the AEC and JCAE. The authors say that the AEC and JCAE pursued institutional interests which were only distantly related to the public's interests, and they blame the 1946 atomic energy legislation for this because it established the JCAE as "a perfectly insulated, self-perpetuating organization with plenary power."[69] That virtually ensured many of the events of the next 30 years of American nuclear energy policy. According to Bupp and Derian, scientists had an intellectual stake in the success of nuclear power, politicians had a political stake, bureaucrats had an organizational stake, and businessmen had a commercial stake. Each side reinforced and amplified the others' claims: "The theology of nuclear power and the sanctification of

light water technology created an interlocking set of intellectual, political, and commercial interests."[70]

APPLYING THE FRAMEWORK TO GERMAN NUCLEAR ENERGY POLICY

The purpose of this thesis is to analyze how technological choices have been made in German nuclear energy policy and to consider what broader applications our findings may have. We focus on advanced technologies because it is here that the domestic and international priorities of the state are most evident and that the challenges to industry are greatest. This does not deny that ailing sectors, such as the coal industry, or low technology products (meaning that R&D amounts to a low percentage of sales) such as steel also provide challenges; still, advanced technologies involve more status and prestige questions, and they also have more open-ended policy options which enable us to look more carefully at why certain choices were made.

The market and political-organizational approaches to how technological choices are made provide the basis of our analysis. The two approaches should not be viewed as exclusive categories; we are not trying to decide which one explains policy-making better because they are related to each other. Our aim is to see (1) the relevance of each approach, (2) the relative significance of each approach at the various stages of technological development, and (3) the linkages between the two approaches. The questions become: with shifting objectives and leadership

roles in the promotion of a technology, which actor is able to exert maximum influence at which stage of development? Are there more or less optimal roles for each actor at each stage of development -- optimal with respect to advancing development of the project? Attention, in short, is directed to how the policy actors coordinate efforts over the course of development within and among the government, manufacturing and utility sectors.

The two approaches allow us to observe how political and economic objectives balance in German nuclear energy policy-making. The aspect of nuclear energy policy on which we will concentrate is the choice of nuclear reactor designs. Design refers to the type of reactor system -- meaning the light water, fast breeder and high temperature reactors for the Federal Republic. Of course reactor systems are complex and involve countless technologies, but the standard categorization of reactors is by overall design because reactor vendors have to convince potential customers to buy their line of reactors. The success of a reactor refers to the overall line.

Two Contexts for Applying the Two Approaches

In their extreme forms, the two approaches can be reduced to two questions: at the risk of oversimplification we can say that the market approach allows us to ask whether private industry can exert its will even under the best of

market conditions, while the political-organizational approach lets us test whether the state can control technological choices when it most wants to. German nuclear energy policy provides good contexts to examine each of these questions: the first question relates to the overall German context for nuclear energy policy; the second relates to the specific case of the high temperature reactor and the issues of national prestige inherent in it. The high temperature reactor example allows us to qualify the description of the overall policy context.

Starting with the overall case, we see that the nuclear energy policy context in West Germany is favorable for the market determination of technological choices for several reasons:

(1) The Germans renounced the use of nuclear energy for military purposes, and therefore there are no military priorities steering nuclear technology development.

(2) Given the bad memories of the strong Nazi state after World War II, the Germans opted for a decentralized decision-making structure which restricted the powers of the federal government.

(3) The Germans championed free market attitudes, especially until the late 1960s when the Social Democrats gained power, but after that as well.

According to the market approach, these conditions should have allowed private industry to play a maximum role in policy formulation, and they were propitious for pursuing several reactor design paths simultaneously. The state provided some funding for R&D work, but left the decisions

on narrowing options to the market. The nuclear industry decided which designs had commercial potential.

We will look at the extent to which the private sector did, in fact, exert its influence under such favorable circumstances. The utilities, for example, circumvented the government atomic program in the late 1950s and opted for the internationally available light water reactors (LWRs). The utilities felt that the LWRs had better market prospects and they preferred commercial reactors over experimental ones. The government had little choice but to go along with the decision.

At the same time, though, the second question leads us to consider the nature of government influence on a favored project such as the German designed and developed pebble bed high temperature reactor. The Germans take special pride in this design because their most original contributions to reactor design are embodied here. They see, for example, special advantages of the HTR in terms of safety features, the application of process heat, the saving of uranium, and the production of synthetic fuels. Several distinguishing features of the HTR have to be kept in mind: it is a "German" technology; there are no immediate prospects of commercialization; the reactor manufacturing firms and utilities involved are not the most important in their respective sectors; the strongest government support came from a Land, North Rhine-Westphalia, and not from the federal government.

This leads us to ask certain questions about the German HTR over the three stages of development:

--What role did national pride play?

--What role did cost calculations play?

--What was the main priority?

--Where did initiatives come from? Did the utilities have as important a role as with the LWRs?

--To what extent did the official government programs influence development?

--How did objectives change over the stages of technological development?

We want to analyze why the Germans initially decided to emphasize the pebble bed high temperature reactor and why they have continued to support it even in the face of almost no interest in ordering the design except inside the Federal Republic.

Our attempt in this thesis is not to prove that the market approach or the political-organizational approach is correct, but rather to look at the qualifications that have to be applied to each. The qualifications give a better sense of how political and economic objectives interact. They also direct attention to the need for the various policy actors in the business-state sectors to coordinate efforts.

As technological projects progress from the R&D stage to the demonstration stage to the commercialization stage,

the interests of the actors change, and so do the contributions which the actors can make toward technological choices. As we will see, government support can be most effective in the initial stage, the manufacturers' expertise is most essential for constructing prototype reactors in the demonstration stage, and the utilities as reactor operators exercise the most influence as commercialization comes closer. Increasingly, though, these stages must be integrated because the cost of technological development is so high and the time frame so long.

The advantage of focusing on German nuclear energy and the HTR is that we can examine one national context in detail, and then look at how it must be qualified. Peter DeLeon concludes in his comparative analysis of reactor development programs that the German program has been a success story because of its decentralized policy process.[71] Måns Lönnroth and William Walker reach the opposite conclusion in their report for the International Consultative Group on Nuclear Energy, arguing that the difficult political and economic conditions that have prevailed since the early 1970s have put countries with strong private sectors, such as West Germany, at a distinct disadvantage to those countries with strong government control.[72] We will return to this dispute in the last chapter; our analysis should shed light on why such contradictory conclusions arise.

Our focus is on the limits of explanatory power for the market and political-organizational approaches, and the intensive study of German nuclear energy policy should serve to clarify the nature of the limits. Understanding the coordination -- or lack of coordination -- within each sector and understanding the changes of leadership functions in the transitions between stages of development will be particularly important.

Of course the conclusions will be most relevant for the Federal Republic, but they also will be generalizable. First of all, they should add to our knowledge of how political, economic, social and technological factors affect each other. Second, even for countries that leave less scope to the business sector for decision-making, they should be instructive about how the business and state sectors are related. Third, nuclear energy in itself is a multi-billion dollar a year enterprise, and studies of how the policy process operates in the key producing countries should be welcome. Fourth, if nuclear energy does have a future, the high temperature reactor seems destined to play a significant role, and therefore its development in West Germany is important. It is the one reactor which has applications outside of the production of electricity. Japan, Switzerland and the United States are all quite interested in the long-range industrial uses of the German high temperature reactor even though commercialization is not feasible until the mid-1990s at the earliest.

Our analysis will proceed by looking at overall German nuclear energy development in the next two chapters. Then we will concentrate on the high temperature reactor to see the qualifications it adds to the general policy-making context.

NOTES FOR CHAPTER ONE

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PART II

TECHNOLOGICAL CHOICES AND THE OVERALL WEST GERMAN NUCLEAR REACTOR PROGRAM

The next two chapters examine the 25 years of post-war German nuclear energy policy. In contrast to the French and British programs which concentrated efforts early on a specific reactor, the German program began with many options which were only gradually narrowed down. We are concerned with what accounts for this approach, whether it can be called successful, and what we can learn about business-state relations by studying reactor design choices.

Chapter Two presents the argument that reactor types were not selected on the basis of market factors alone. It suggests that market factors are most important when a technology approaches commercialization, but that they have more limited applicability for the earlier R&D and demonstration stages. The chapter outlines changing objectives in the German nuclear program over the course of three time periods. It looks specifically at the light water, fast breeder and high temperature reactors.

Chapter Three switches the emphasis from the changing objectives in the nuclear program to the institutions involved with policy-making. It draws attention to the

political-organizational context which determine the impact of market factors on technological choices. The chapter, for example, explains why the utilities were so critical in the development of the light water reactor. The broad overview in Chapter Three focuses on the differences among the utilities, manufacturers and government in nuclear policy-making. The more specific examination of the high temperature reactor in Part III (Chapters Four to Seven) will consider differences within the individual sectors as well.

CHAPTER TWO

CHANGING OBJECTIVES WITHIN THE GERMAN NUCLEAR PROGRAM

In Chapter One we introduced two approaches for analyzing technological choices. The context we will use to test the applicability of the two approaches is German nuclear energy policy, particularly with regard to the selection of reactor designs. In setting out the framework for analysis in the last chapter we said that looking at how technological choices occur necessitates looking at the linkage of technology and public policy, or in other words, how different actors and multiple objectives are related over time. This chapter focuses on the changing objectives that have occurred in the 26 years of West German nuclear energy policy. The next chapter will focus on the individual actors and the institutional aspects of reactor design choices.

Our argument in this chapter is that although the market approach often explains how actors are motivated and how decisions are made, it does not give a complete understanding of the policy-making process. In order to show the limited applicability of the market approach, we will look first at three phases of development in German nuclear energy policy and then at three examples of reactor choices. The argument is that market factors are not

usually the determining factor in technological choices for German nuclear reactors, and when they are, they reflect narrow economic objectives and not the broader objectives which allow the market factors to be determinant. In the first section, we will demonstrate how the relationships among political, economic and technological concerns vary across the three phases of development. The second section applies these findings about the changing objectives to the choices made for three specific reactor designs -- the light water, fast breeder and high temperature reactors. This is not a detailed description of each reactor design but rather an overview of the factors that influenced the choices. The final section assesses the explanatory power of the market approach in the German nuclear policy context.

THE BACKGROUND FOR GERMAN REACTOR DEVELOPMENT

Nuclear energy has played an important role in the Federal Republic since 1955. The country today has the third highest nuclear capacity in the world, behind the United States and Japan; and it is the second major exporter of nuclear technology, behind the U.S.[1] In May 1955, the Paris agreements came into effect, allowing the Federal Republic to regain full sovereignty and consequently resume nuclear research. German reconstruction was proceeding so quickly then that its power demands had exceeded available resources. The reconstruction effort was

seriously threatened when Europe suddenly confronted an energy shortage in the summer of 1955. Consequently, the prospect of an additional energy source such as nuclear energy was eagerly welcomed by the Germans. The first atomic conference in Geneva in August, 1955 also spurred German developments, even though it showed the relatively weak position of German technology. In the 1930s, Germany had dominated nuclear science. The Federal Republic has apparently never entertained any notion of assuming such a dominant position again, but it certainly has recognized the significance of the nuclear energy sector. To the Germans in the 1950s, nuclear energy was a means to reassert their scientific and economic excellence, and the type of program developed was a demonstration of West German allegiance to the West. Matters of political, economic and technological prestige were all wrapped up in the advancement of the technology, and the Germans approached nuclear energy development with a great deal of commitment.

Several special circumstances had an impact on the resumption of nuclear research in West Germany. Domestic manufacturing firms which logically might have started a nuclear industry after the war were forbidden by the Allied Powers to conduct any research on nuclear energy until 1955. In addition, German technology was not linked to any military applications which elsewhere often guided research and funding. In West Germany, the whole notion of govern-

ment research support started with nuclear technology in 1955, and for several years the nuclear sector was the chief beneficiary of this policy. The Federal Republic, moreover, unlike France or Britain, adopted foreign reactor technology early in its development program. It came primarily from the United States. Finally, because of the abuse of power by the state under Nazism, the Federal Republic has always been wary of directing such sensitive technological developments nationally; this has increased the willingness to cooperate internationally. The German reactor program was not an outgrowth or continuation of wartime atomic research experiences; rather, it was initiated largely at the insistence of West German industries, utilities and scientists.

At one point in the late 1950s the Federal Republic was pursuing 13 different types of nuclear reactors, but eventually the choices were narrowed down to the three designs still being actively developed today -- the light water, fast breeder and high temperature reactors.[2] It is the process of how this narrowing down took place and why these designs were picked that is interesting because by the mid-1970s the fledgling German nuclear energy industry of the 1950s had become a showpiece of German economic and technological progress. Starting with licensing arrangements with U.S. firms and honing its skills through the construction of several light water reactors domestically, the

German nuclear energy industry quickly asserted its influence on world markets. The leading producer of nuclear reactors, Kraftwerk Union, had more orders in 1975 than all the U.S. vendors combined and America's monopoly of the market seemed to have been broken.[3]

Fortunes changed quickly, however, and KWU has not had another domestic order since then. The picture of the future is not much brighter for the nuclear industry either. Even though all the political parties advocate nuclear development according to their official statements, they also are reluctant to stir up the anti-nuclear forces again. There was even some speculation that the Federal Republic conceivably could be the one major nuclear power producer to curtail nuclear expansion following the Three Mile Island nuclear accident.[4] In April 1979 the Federal Minister of the Interior, Gerhart Baum, said, "We must ask ourselves whether nuclear energy really is unrenouncable in view of its risks, compared to those of other energy forms."[5]

THREE PHASES OF DEVELOPMENT

The development of the Federal Republic's nuclear reactor program can be understood better if we divide it into three phases. The phases are:

(1) an open-ended period of development in which debates inside the nuclear community about whether nuclear energy should be pursued were common,

(2) a period of consensus within the nuclear community that nuclear energy should be developed because of the benefits it brought the German economy, and,

(3) the present period of opposition to nuclear energy from outside the nuclear community while the community itself has closed ranks against the opposition.

The term nuclear community refers to the actors involved with producing nuclear energy. It includes the industry representatives (both suppliers and users), the government officials, the politicians, and the scientists involved with nuclear policy decisions. As the phases indicate, the internal relations of the nuclear community have fluctuated in the past 25 years, and external influences also have significance. Through this chapter and the next one, we want to discover how relations formed between actors who share objectives in certain stages of development are influenced when objectives change.

Phase One: The Open-Ended Period of Development

The first phase lasted from 1955 until 1963 and was marked by indecisions and uncertainty among actors over directions and objectives. The government did not assert much leadership despite its strong interests in nuclear energy. There was confusion whether the primary goal should be to provide energy or close the technological gap between the Federal Republic and other countries. The Bonn government wanted to prove its solid identification with the West and was not sure which nuclear policy most furthered this: should closer ties be established with

America or with Europe? The result of the confusion was essentially a compromise policy for the first years which sought to reconcile the different concerns of government and industry.[6] The new Atomic Law was therefore less directed to safety standards and liability regulations than to establishing Bonn's position in the Atlantic community.

Within the government there were clear differences of opinion about how to approach nuclear energy. The Chancellor and Foreign Minister leaned more to the French approach of state determination of atomic policy because they felt that the policy might contribute to European integration; the Economics Ministry strongly objected to such plans and sided with industry in insisting on private development of atomic energy.[7] The newly formed Federal Ministry for Atomic Questions also faced problems because so many other federal ministries were also involved with nuclear energy. In addition, the individual Bundesländer had carved out their own areas of competence, and hence the scope of action for the new ministry was quite narrow.[8]

The early years of this phase (1955-57) were characterized by unintended outcomes which resulted from the centrifugal forces affecting the policy process. It was not just the government which was divided. The Foreign Ministry and Economics Ministry had even sided with industry in opposing the formation of the new Ministry for

Atomic Affairs because they wanted to avoid introducing new actors into decisions on nuclear energy. Within the business sector, too, there was disagreement. At the beginning, the electrical utilities and the coal industry were opposed to developing nuclear power because they were oriented to traditional energy sources. In addition, although the reactor manufacturing firms were testing different options for reactors, government support of initial research took the edge off the competitiveness between designs.

Differences of opinion were also evident among the parliamentary parties and between the nuclear research centers. The SPD felt that the significance of nuclear energy required that it be placed under public control with long-range planning.[9] After its crushing 1957 defeat in the general elections, though, the SPD made its peace with the business sector and dropped any objections to private industry being involved with nuclear development.[10] Party differences on nuclear policy since then were essentially non-existent until the late 1970s. The major nuclear research centers were also in competition because during this phase the two largest centers at Karlsruhe and Jülich each adopted a major project to support, respectively, the fast breeder and high temperature reactors. Moreover, the Jülich center was the pet project of West Germany's biggest Land, North Rhine-Westphalia, and the federal government supported the center only grudgingly in these early years,

although government assistance for nuclear R&D projects was generous.

Some major issues remained totally unresolved: should industry invest in basic research or aim at producing commercial reactors quickly? what amount of government aid would be proper? how much international cooperation should there be? The situation changed, however, beginning in 1958. The energy crisis was replaced by an energy glut caused by cheap oil. At the same time, the very generous state subsidies for basically all aspects of nuclear R&D continued to reduce the incentive for firms to compete with one another.

For utilities, the need for new alternatives for traditional power supplies no longer existed once the energy crisis was over. They were therefore less willing to assume the investment risks which nuclear reactors entailed and which the manufacturing industries were trying to unload on them. The outcome of this and the fact that the utilities had been excluded for the most part from the government-industry policy-making process led to a greater independence on the part of the utilities. They worked directly against some government goals and instead pursued their own objectives. They focused on profits, low initial capital investments, and the availability of technology. These goals inclined them toward the American-made

light water reactors even though the government wanted to support domestic designs and preferred natural uranium fuel since it avoided dependence on American enriched uranium.

In contrast to the government, the utilities were clear about their objectives, especially after the energy crisis disappeared. By 1958, the debate was whether to continue in the experimental phase of reactor construction or build operational plants. The utilities still were prepared to invest in nuclear reactors but they opted for the operating plants course, and the government either had to go along with those plans or pour massive subsidies into the rest of the nuclear sector. Moreover, the utilities effectively sabotaged the government's first atomic program, the Eltville program, because they financed their own 15MW experimental reactor rather than go along with the government's proposed 100MW reactors which the utilities considered too large. The government had counted on the utilities to provide financing for the Eltville program; when they did not, the government proposed a supplementary "advanced reactors" program which did not rely on the utilities to place the orders.

Phase Two: The Period of Consensus

The second phase of development lasted from 1963-1973 and was characterized by a much greater consensus on objectives. This consensus on the direction of nuclear energy

development was based mostly on economic, technological considerations. Objections to building advanced technology reactors were minimal because the reactors showed promise of being economically successful in domestic and foreign markets. Following the lead of the electrical utilities, the actors in the nuclear community all accepted the economic priorities of development. Developing nuclear power as an additional energy source for a comprehensive national energy program was less important than the shorter term economic goals. Since nuclear energy seemed to promise economic success through more exports and more jobs, no one felt a need to criticize it or to keep a critical eye on reactor design decisions. For reasons not entirely technological, the light water reactor emerged victorious from the competition with other reactor types. Analyses of particular designs were usually carried out by the builders or eventual operators of the reactors, and the two reactors of the second generation -- the fast breeder and the high temperature reactors -- were never compared directly. This was a period of consolidation in German nuclear policy, and one author says it was at the end of this time that the "naive period" of development in German policy came to an end.[11]

The most striking feature of this phase is the close cooperation between industry and the state. One observer

of German nuclear energy, Robert Gerwin, says that the first seven years of development had been lean and improvised and that by 1962 the government wanted a more comprehensive program.[12] The first atomic program, the Eltville program, had not really been publicized. The second and third programs were issued more publicly in 1963 and 1968, and they tried to provide more of a guide to what could be expected of the government.

The basis of the second program was "a concentration and coordination of efforts and a strengthening of the means of public support."[13] The major goal of the program, according to the then Minister for Atomic Affairs, Hans Lenz, was to bring German nuclear research and technology in all areas up to par with world standards and to make all branches of the German nuclear sector competitive on world markets.[14] The major goals of the third program were to (1) maintain research at the international level it had achieved and to expand it further, (2) lower electricity production costs, and (3) increase the capability of the German nuclear industry to keep pace with the rapid international developments that were taking place.[15]

Even though German nuclear industry had become competitive internationally, the government made it clear that state support would be continued and increased substantially. Total state expenditures for the second program were DM 3.791 billion compared to DM 6.154 billion for the third

program. The amount set aside for reactor development was DM 584 million in the second program and DM 1.317 billion for the third program.[16]

The major developments of this phase were the economic breakthrough of the light water reactor and the concentration of government support on the high temperature and fast breeder reactors. The success of the light water reactor was clearly due to its development in the United States. It appeared successful there on the basis of several orders, and consequently the Germans were eager to jump on the bandwagon. One of the main goals of the second atomic program was to build two large demonstration reactors based on technologies already proven elsewhere -- i.e., light water reactors. Of course, the fact that German utilities preferred the U.S. LWRs due to their availability and due to the fact that German industry was working with American licenses influenced the decision. The fast breeder reactors were the major long-range focus of the second program, and by the third program the high temperature reactor had been elevated to equal status. This reflected the federal government's 1960 decision to fund the Jülich nuclear research center at the same level as the Karlsruhe center.

The driving force behind the government's program was its desire to be internationally competitive, and this

meshed with the objectives of nuclear industry. The industry itself was undergoing a consolidation process as firms backed out of it. Siemens, for example, had done all the work on the heavy water reactor essentially at government cost. In the long run the reactor proved uneconomical but the experiences which Siemens had accumulated were invaluable for other areas of application. And it was only the larger firms like Siemens which were able to pursue more than one line of research so that alternatives existed if one approach had to be dropped.

The most striking merger in the German nuclear industry was the joining together of Siemens and AEG to form Kraftwerk Union in 1969. The two firms were both among the largest firms in the Federal Republic and they had developed the two types of light water reactors: Siemens worked together with Westinghouse on the pressurized water reactor, and AEG worked with General Electric on the boiling water reactor. The impetus to merge arose from the recognition of how tough international competition was for reactor exports, and the government was supportive of the merger from the start. With the formation of Kraftwerk Union, Siemens and AEG had a virtual monopoly on the domestic light water reactor market, and they also controlled the fast breeder reactor development through their subsidiary firm, Interatom. In the field of high temperature reactor development the German firm Brown, Boveri and Cie

and BBC's American partner, Gulf General Atomic, had established similar dominance.

In sum, largely because of the role of the private sector, economic objectives were primary in the development of German nuclear policy in this phase. They were more significant than some other factors which might have affected policy. The Federal Republic was launching its Ostpolitik and was engaged in a domestic debate about whether to sign the Non-Proliferation Treaty, but it was also becoming a world economic power and that seemed to have the major impact on nuclear policy. The development of nuclear technology was a means to use the country's growing economic clout. Support for nuclear technologies was not fostered by urgent energy needs, but by desires to be competitive internationally. The late 1960s marked the high point for European fears of a "technology gap" with the United States. "National champion" industries were a common response, and the formation of Kraftwerk Union fits this category.

The differences of opinion among members of the nuclear community in the first phase of development disappeared in this second phase. Government officials, politicians and industry representatives all viewed nuclear energy in terms of how it would benefit the economy and found no reason to object to it. Nuclear energy policy in these years should

not be characterized as energy policy per se, but as "industrial structural policy" because it solidified a "nuclear energy coalition" among the actors involved.[17] This was not a conscious plan, but rather the result of fragmented decisions which were mainly profit-oriented. The heavy water reactor was dropped as a project by Siemens because its marketability seemed limited. The steam-cooled fast breeder reactor was dropped because international developments seemed oriented to the sodium-cooled alternative. German objection to the Non-Proliferation Treaty centered on the worry that the German nuclear industry would be handicapped in its international business.

In general, the background of world geopolitical stability allowed the military and civilian aspects of nuclear energy to be separated. They had been intertwined earlier, but the establishment and maintenance of international trust between East and West led to the liberal trading conditions and interdependencies of the 1960s and early 1970s.[18] Countries were not oriented to the political problems of nuclear fuel supply, waste storage and the proliferation of plutonium. These seemed less pressing at the time than they appeared a few years later. Until the 1970s, the unprofitable aspects of nuclear energy such as storage questions, reprocessing or accident research were only marginally considered.[19]

Phase Three: The Period of Opposition from Outside the Nuclear Community

The third phase covers the period from late 1973 to the present. One German analyst categorizes the time up to 1973 as the "depoliticization of nuclear energy" because so little attention was paid to the social consequences of the policy pursued.[20] The impetus of a politicized nuclear energy policy stemmed from the 1973 oil crisis which suddenly made energy needs the main priority of nuclear energy policy. For the first time the goal of nuclear policy related to a secure energy supply rather than to competitiveness of the nuclear industry.[21] On the one hand there was a shift in objectives and on the other hand new actors and new authorities seeking to regulate nuclear energy appeared in the picture. No longer was just the nuclear community involved. The movement against nuclear energy came as a surprise to the government and industry when it emerged in 1973-74 even though opposition had been evident in the United States before this. The first response of the government to the 1973 energy crisis was a nearly total embracing of nuclear possibilities, but since then responses have been more varied.

After 1973, the economic objectives which had characterized the development of nuclear energy policy were subordinated to political objectives. Energy supply was a major factor in these objectives and so too were efforts to defuse political protests. It is difficult to pinpoint

the reasons for the protests, but they related to doubts about the safety of nuclear energy, environmental concerns, objections to the constant orientation toward economic growth, and a lack of trust in the government given its long, close association with the nuclear industry.[22] The shift away from economic objectives as the main component of nuclear energy policy did not mean, however, that these economic objectives lost their importance. The effort became to incorporate them in other objectives.

Given the massive reliance on nuclear energy which the fourth atomic program envisioned in 1973, it is not surprising that new actors became involved in German energy policy. The plan was to increase nuclear capacity from 2,400 MW to 40-50,000 MW by 1985. That meant increasing the nuclear energy proportion of primary energy capacity from 3.1 percent to 15 percent and the nuclear energy proportion of electricity provided from 6 percent to 40 percent.[23] In the 1960s the investment decisions were made on an economic basis, and this narrow view of nuclear energy meant that certain problems were not foreseen. The electrical utilities had been particularly guilty of not considering the implications of site planning,[24] and with all the new reactors being planned, more and more people were affected. Not only individuals were expressing concern about the location of reactors, but also the Länder were protesting because the reactors raised water temperatures

of the waterways on which they were located. The public protest and Länder protest finally led the state to initiate some state-supervised site planning in the mid-1970s.[25]

The government presented its fourth atomic program in 1973. This was the first program that was actually prepared by the government (the Federal Ministry for Research and Technology) and not by the German Atomic Commission which the SPD disbanded in 1971 (although the German Atomic Forum, a lobbying organization for the German nuclear industry, was able to carry on most of the functions of the Commission which also reflected industrial interests).

The goals of the fourth atomic program were (1) a continuation and intensification of support for basic nuclear research, (2) the long-range guarantee of energy supplies which are affordable and not damaging to the environment, and (3) the further development of a competitive nuclear industry for the future.[26] In practice, this meant a continuation of former policies. In fact, over 80 percent of the new budget was already committed to on-going projects. This was the first government program that presented an overall concept of energy use, complete with goals and measures for energy usage and the expected contribution from different sources of energy.[27] In 1977 the government issued a program on energy research and energy technology. For all practical purposes, it amounted to a fifth atomic

program. It was a continuation of the fourth program, but it also was a response to criticism of nuclear energy and thus stressed the support for non-nuclear energy technologies. The ratio of nuclear to non-nuclear research changed dramatically from 78.9:1 in 1972 to 4.9:1 in 1975 to 2.7:1 after 1977.[28]

Not all the new actors involved in nuclear energy policy-making were anti-nuclear energy. Many were simply pulled in because of the increase in size of the nuclear sector. Within the government, agencies dealing with ecological standards, site-planning and the regulation of construction all became involved. Their impact did not replace the objectives of the old nuclear community, but rather was a factor added on top of the old objectives. Government control of nuclear policy became more, not less difficult.

The nuclear community itself responded to the protests by closing ranks. In effect, it lobbied for pressing forward with nuclear energy. The disagreements of the first phase of nuclear development dissolved completely and nuclear industry, the utilities and the government presented a united front at least in the first years of this phase. Some doubts began to set in, though, in 1976 following the German-Brazilian nuclear deal that aroused strong foreign protests because of the implications for nuclear proliferation. The safeguards issue was an especially sensitive

one following the 1974 Indian nuclear detonation, and other countries objected to the German sale because it involved the transfer of proliferation-sensitive fuel cycle technology.

The sale had been called "the nuclear deal of the century" because of the large sum of money involved (four billion dollars) and because nuclear fuel and reactor technologies had never been linked before in one transaction.[29] The significance of the sale for our purposes is that it shows the close linkage between government and industry. The agreement was signed by the respective foreign ministers; declarations concerning the agreement were signed by the ministers concerned with research and energy and they included detailed guidelines for the industrial commitments; and business representatives signed pre-contracts for the delivery of the first two reactors.[30] The problem internationally was quite simple: the Germans focused on the economic aspects of the Non-Proliferation Treaty and felt that it permitted such exports. Legally they were correct, but other countries, particularly the U.S., felt that such transactions went against the political intentions of the treaty.

By 1977 the Germans had acquiesced in part to the objections of their allies and agreed at least not to conclude similar deals in the future. The example remains

instructive, though, because it demonstrates the importance of economic interests and the problems of competing ministries in German nuclear policy. For the Germans, non-proliferation policy had become an economic concern.[31] Industry pressed the government to carry the deal forward, but they might have had less success if the German policy-making process had not made it so difficult to control corporate and bureaucratic actors.[32] An American, Edward Wonder, claims that "it would not be unfair to describe the agreement set before the German cabinet as a fait accompli, carried off by a coalition of corporate and government actors who went farther than the more diplomatically aware would have allowed had they been better informed."[33] The German who has done the most thorough account of the transaction, Lothar Wilker, claims that the communication problems revealed by the German-Brazilian negotiations resulted in the formation of the Nuclear Cabinet in 1977.[34] The Nuclear Cabinet provided the Administration (Bundesregierung) with a coordinating body in which to discuss nuclear issues, and it strengthened the Chancellor's role in policy formulation.

The German government is struggling with how to proceed with nuclear energy. Publicly it continues to emphasize the necessity of building more reactors, but practically it has halted development by holding up any construction permits. The 1973 projections of nuclear needs for the future

have been modified downward continually, but even so a number of new reactors will have to be built if the revised projections are accurate. The special Enquete Commission of the Bundestag reached a similar conclusion in its June 1980 report. The government finds itself not able to control nuclear policy except indirectly by providing more funding. Private industry has shown only limited willingness to participate in nuclear technological research unless the state supports it.[37] As a result, a partnership has evolved in which both sides need the other partner, but new questions have to be factored in -- concerning public objections and international objections -- to see what the goals of nuclear policy should be.

Conclusion

Phase one (1955-62) shows how nuclear policy in the Federal Republic was seen as a means to re-establish the country in the international political system. The idea of federal support for research started in the nuclear sector. The government wanted to boost German industry in world markets, restore lost prestige and confirm its alliance with the West. Economic factors were important, but so too were energy needs -- at least until 1958 -- and political goals. The government programs, first set out in the 1957 Eltville program, were important primarily due to the pattern of government support they established. Basically, the government supported all nuclear options, but

the scope of its decision-making was limited. It relied on the German Atomic Commission, comprised chiefly of industrial interests, for advice and program formulation. Government support was critical for nuclear energy development since it meant that early, hard decisions narrowing reactor options could be avoided. The government did have certain priorities such as emphasizing natural uranium reactors and domestic designs, but the nuclear industry and especially the utilities undermined these priorities. No real consensus on the direction of nuclear energy existed until the last years of this phase. Moreover, the nuclear energy programs represented support for a particular technology rather than a long-range energy program.

Phase two (1963-73) shows how the nuclear community united behind the development of the light water reactor as a commercial project and the fast breeder and high temperature reactors as research projects. There was not outside interference with policy formulation. The measurement for success of a project became its economic feasibility, but this was an odd measure given the massive state support for these reactors. Government cost assessments tended to be notoriously inaccurate. For a while, the justification for financing FBRs was that they would produce electricity more cheaply than LWRs. When that assumption proved untrustworthy, new rationales were sought.[38] European assessments of the LWRs were also inaccurate. The

European licensees adjusted their nuclear pricing to guarantee themselves a market share in the business.[39] Decisions for the LWRs were made more on mutually reinforcing hopes than on actual operating experiences.

The priority of the government was to be competitive internationally. Decisions were made very much with an eye to the international market. That explains why some reactor types were dropped (for example, the steam-cooled fast breeder reactor and the heavy water reactor), and why the LWRs were purchased. The problem is that using the market as a measure when the reactors are still in the R&D phase essentially guarantees that misinformation, or at least inaccurate information, will plague the decision. The German government was quick to accept the Karlsruhe Nuclear Research Center's figures justifying an accelerated FBR project in 1964, but the reactor manufacturing industry and the utilities were much more cautious. They felt that the economic utilization of fast breeders was not foreseeable, and hence they were not prepared to sink their funding in the project.[40]

Phase Three (1973-present) shows how the economic standards of the earlier years were replaced by new political objectives concerning energy supply and the response to anti-nuclear political protests. For the first time German nuclear energy policy was determined by energy needs.

Immediately after the 1973 oil crisis, the government anticipated a huge increase in the size of its nuclear program, but protests and indications that the additional amount of energy needed is far less than expected have caused major reductions in those plans. A wide range of new actors entered the nuclear policy-making scene, and the traditional nuclear community has tended to be critical of them and their calls to reassess objectives. The response of the government is ambiguous: it still insists on the need to press forward with nuclear energy, but it has brought about a halt to developments through its action. Patterns of industry-government cooperation have clearly been established in the past 25 years, and they will have an important impact on future policy. The government, for instance, in line with its market orientation originally expected only to support basic research, but government involvement is now a foregone conclusion. Economic factors alone have played less a part in nuclear policy as the process has grown more complicated.

REACTOR DESIGN CHOICES AND GERMAN OBJECTIVES

The three phases give a background for looking at specific reactor choices in the German program to see how well the market approach explains technological outcomes. The phases demonstrate that objectives shifted over the 25 years of development, and this affected the actors in the policy process and their relationships. But even in

the instances in which market considerations guided German policy, it is wise to see the background variables which permitted this.

Light Water Reactors

In a sense, the light water reactors are the most obvious choice for arguing that market factors determined reactor selection. When the German reactor program was launched, the expectation was that natural uranium gas-graphite reactors would be the major design backed because of the progress that had been made on them, especially in Great Britain, and because they would free West Germany from reliance on American enriched uranium. Nevertheless, by the early 1960s the Federal Republic had opted for the American LWRs. The major reason was that the electrical utilities preferred that design. To see how well the market approach explains this preference, we should look first at why the German domestic market selected the LWRs and next at why the United States supported them.

The German utilities were cautious about plunging into nuclear energy at the start. RWE, the largest domestic producer of electricity, was basically opposed to it in the beginning because it had its own coal supplies. Nonetheless, RWE also placed the first order for a nuclear reactor in West Germany -- a 15 MW experimental reactor, the Versuchsatomkraftwerk at Kahl/Main (VAK). RWE was

willing to develop a small experimental reactor because of the potential payoff, but it resisted the larger scale plans advocated by the government. From an economic standpoint, one could argue that the LWRs were chosen because of lower investment costs and quicker payoffs, but the simple fact was that the order placed by RWE was a direct challenge to the government's nuclear program.

One explanation of this direct challenge is that RWE wanted to show that a better development strategy was possible than what the government had chosen.[41] The utilities felt that foreign technologies should be relied on, that using enriched uranium was not problematic, and that the 100 MW plants envisioned by the Eltville program were far too big. A second account of why RWE worked outside of the government's wishes and program argues that the utility wanted to show that nuclear energy was uneconomical, and it wanted thereby to hinder the construction of larger reactors.[42] The difficulty with this second account is that it does not explain why RWE pushed ahead so aggressively with development plans.

In either case, RWE's attitude that the government should stay out of the business of selecting reactors is evident. In 1960, the chairman of the board of RWE, Heinrich Schöller, said:

> The state should occupy itself with research and development; this has always been its primary task. When we build the nuclear experimental plant Kahl, we are doing something that actually is not our task, but the task of the machine industry. And if I may be quite frank, my decision to order this plant was determined by the reflection that if the state already wants to engage in the follies of constructing plants prematurely, then we had better engage in similar follies ourselves in order to keep them under control.[43]

Schöller criticized the government for moving ahead with a nuclear program which supported reactors that his utility considered too large; and he felt that manufacturing firms, rather than the government, should be making decisions about which reactor to build. This reflects the traditional German approach to making technological choices: keep the government out of decisions; let the manufacturers (i.e. vendors) develop options, then let the utilities (i.e. operators) choose among options. With advanced technologies such as nuclear reactors, however, the long development times for reactor designs necessitate more coordination between the vendors and operators. RWE felt that the options being encouraged by the government were not what market considerations alone would have dictated; the utility felt that the governmental assistance was forcing nuclear policy along a certain path, and hence RWE pursued an independent path (referred to by Schöller as "similar follies") to keep policy developments under control. It is not clear whether the decision in favor of LWRs by RWE was made for economic or for uneconomic reasons.

In any case, the 1961 decision to build a 237 MW plant at Gundremmingen was a turning point in German nuclear development. The consortium of utilities involved, including RWE, selected a light water design over a British plan for a 300-400 MW gas-graphite plant. The utilities did not choose the LWR on the basis of a careful cost comparison with the gas-graphite reactor, but rather because Euratom would fund it. One reason was that only the LWR was eligible for assistance from the Euratom cooperative program. When the order was placed, no reactor of the size contemplated by the utilities was even operating in the U.S., but the decision convinced the principal German reactor manufacturer, Siemens, to reverse its own development priorities in favor of the American technology.[44] Moreover, the Germans were concerned about French hegemony over the Euratom Commission and this provided a way to escape the problem by developing an independent program. After 1962 the German program was already geared to the LWRs and it was the utilities who were responsible for this emphasis. The government had not expected this outcome, and we will see in the next chapter how the policy process played into the utilities' hands.

Thus, external conditions were more important than market considerations in determining LWR development in West Germany. Developments in the U.S. were especially critical. But in the U.S. too, market considerations only

partially explain why the LWR was pursued. The American decision was a function of (1) the LWR having been developed for nuclear submarines and therefore being available, and (2) American enriched uranium supplies. Milton Shaw of the Atomic Energy Commission said once, "If Admiral Rickover hadn't been so damned successful with the Naval LWR Program, the AEC might well have gone directly to the breeder."[45] The Americans also opted for the LWR in large part "because it was there."

The Americans persuaded the Europeans to order LWRs on the basis of hopes rather than actual operating experience.[46] Manufacturers were taking orders for plants six times larger than the largest one then in operation, and political leaders had essentially no credible, independent evaluations of light water reactors available to them.[47] Europe became a proving ground for American technology and this continued through the early 1970s.[48] One of the economic rationales for choosing LWRs was the supposed 15 percent cost advantage over gas-graphite systems, but in retrospect that appears small and insignificant given the habitual inaccuracies and cost overruns of nuclear reactors. The decisive factor in persuading the Europeans to accept the light water technology was not so much market considerations as a great job of marketing on the part of the U.S. firms.

The commercial break-through for LWRs occurred in 1963 in the U.S. and in 1967 for West Germany. It might be argued that German nuclear policy simply mirrored American advances, but that neglects some other key factors. During the early years of the 1960s, a serious debate took place in the Federal Republic about the advisability of developing LWRs. The debate pitted the German Atomic Commission against the utilities. After the utilities had opted for the Gundremmingen LWR and were showing signs of ordering two more, the Commission told them in 1964 that it could hardly recommend public support for the simple purchase of foreign proven reactors, especially when the Federal Republic already had such reactors.[49] Leading voices in the Commission such as the Chairman of the Board of Hoechst, Karl Winnacker, and the top person at the KFZ Karlsruhe, Karl Wirtz, made it clear that the further construction of American LWRs in West Germany worked against the German atomic program which emphasized German technology and natural uranium reactors.[50] The German program deserved protection according to these people.

The utilities, in contrast, showed no desire to engage in what they considered needlessly risky experiments. They did not feel that experiments, even when successful, contributed to reactor operating experience. They argued before the Atomic Commission that they should

adhere to the LWRs because proven reactors -- i.e. reactors which seemed to be already commercially viable -- were much less risky than new prototype models.[51] This was at a time when the "proven" LWR had one commercial order in hand worldwide. Eventually the Commission acquiesced to the utilities, and orders were placed for the Lingen and Obrigheim reactors. One reason the Commission gave in is that construction was wholly under the guidance of German firms -- in contrast, General Electric had been involved with the Grundremmingen reactor. A second reason, however, is that the Atomic Commission's sub-commission to deal with financing such projects as Grundremmingen, Lingen and Obrigheim never convened. It was in a strong position to oppose the projects. The chairman's decision, however, that meetings were "superficial" and his failure to call them essentially excluded the sub-commission from playing a policy role.[52]

Again the policy process worked to the advantage of the utilities. They themselves were influenced primarily by market considerations, but the political-organizational arrangements allowed them to push through their wishes. Within the government, the nuclear industry and the Atomic Commission, there were strong feelings against an over-commitment to the LWRs but the utilities overcame this.

Fast Breeder Reactors

In the case of fast breeder reactors in West Germany, market considerations were also less instrumental than other factors -- most significantly, the pressures of international competitiveness. The competition was to develop FBR technology to the point that the German design could capture a substantial share of the international FBR market when the reactor went commercial. The policies of the German government were not based on careful market analyses of the reactor's potential, but on responses to developments in other countries. The U.S., France, Japan and the U.K. were all supporting their FBR projects generously, and consequently the Germans felt compelled to do the same. According to Winnacker and Wirtz, the breeder reactor became "a classic example of how the state is nowadays financially and organizationally involved in technological development."[53]

In the Federal Republic the initiative for the FBR came from the Nuclear Research Center in Karlsruhe. Industrialists and the responsible Working Group of the Atomic Commission gave it a sour reception because they felt that design and engineering work should be given to industrial firms, and they doubted that the structure of the KFZ Karlsruhe would permit this.[54]

Government officials were also in favor of the project, and the then Minister for Atomic Questions, Balke, recommended a commitment to the fast breeder in March 1958, just a few months after discussions had begun at Karlsruhe.[55] German scientists had been prompted to look at possibilities of the breeder reactor by discussions at the U.N. Geneva Conference in September 1958; they decided to seek American assistance partly because they wanted to avoid the military overtones of French and British programs, partly because they felt that the potential for American assistance was higher, and partly because they wanted to avoid the French and British pattern of centralized nuclear research and instead give more responsibility to industry.[56]

The course of the German program was almost always determined by competitive factors. At the beginning, the FBR development was a function not of a "sober anticipation of economic need," but of a "supposed competition with foreign state-financed programs."[57] The rivalry with France and the relationship with Euratom were especially pertinent. The Federal Republic was determined to establish parity with France, and thus it was wary of relying on central Community institutions or French institutions for cooperation.[58] It also felt that it had to compete directly with the French for Euratom FBR funds, but to do so required supporting FBR development

to the same degree as the French. This led to the decision of the KFZ supervisory board in May 1961 to increase efforts on the FBR project, even though the Working Group had given the project a cool appraisal a few months earlier.[59] Starting in 1962, the fast breeder became the main task of the Karlsruhe center. Other firms involved with German nuclear policy had little objection to the FBR emphasis because their own support was not curtailed at all.

Competitive concerns also determined the response to General Electric's 1964 annoucement that it would offer a commercial reactor within ten years. The Karlsruhe group was startled by the American firm's announcement which implied that rapid progress had been made by General Electric, placing it far ahead of other reactor vendors. Instead of questioning the Americans' claims (which subsequently proved over-optimistic), the Karlsruhe people felt compelled to push ahead with the German program faster than planned in order not to leave the international market to the Americans. This meant moving immediately into the prototype construction phase, but since the Germans had not chosen between the sodium-cooled and steam-cooled versions of the reactor, they decided to build both, despite the high added costs. The government accepted Karlsruhe's justification for increasing support of the FBR project: it related to the

vast commercial potential of the reactor and the pressing international competition. The leading reactor manufacturing industries and utilities, however, were not convinced enough by the economic utilization arguments to pour additional money into the project. They regarded the Karlsruhe cost projections "as a numbers game which was not to be taken seriously."[60]

By 1968/69 the steam-cooled design was given up. Internationally, all the interest centered on the sodium-cooled design, and the Germans did not want to be left out of the international market. The U.S. had just cancelled its steam-cooled experimental project. The German government told AEG, the industrial firm involved, that no more government money would be forthcoming to cover the increased costs of an isolated national program. AEG was willing to terminate work both because it had lost some of its interest in nuclear power[61] and because it had an arrangement with Siemens which protected it from too many losses.[62] The unusual element in all this was that the 1966 decision by the Atomic Commission to support the two designs equally had gone against international opinion. Only the Americans had even a small steam-cooled project, and furthermore the May 1966 fast-breeder conference clearly recommended giving up the steam-cooled for the sodium-cooled design.[63] The Germans, by moving too quickly to the prototype stage

of the reactor development and retaining two expensive options, pushed reactor development too fast and ended up adding significantly to the costs. If cost calculations had been heeded more than international competition, development would probably have taken place more slowly and cheaply; as it was, the utilities were the only actors to urge some delay in FBR construction aside from the licensing authorities.[64] Their own cost estimates were more pessimistic than those of the government.

In sum, it is the government which has mainly determined FBR policy, and its decisions have been influenced significantly by the Nuclear Research Center at Karlsruhe. The objective of policy has been international competitiveness. Even the late 1960s' initiative toward broader international cooperation for the FBR can be explained in large measure by the Federal Republic's desire to protect the reactor's commercial prospects from the potentially adverse effects of the non-proliferation treaty which was being discussed then.[65] German industry was concerned that there might be discriminatory applications of the treaty by the U.S., but within an international consortium German industry would be less vulnerable to such applications. As a result, the Belgian, Dutch and German governments announced agreement in October 1967 to construct a common 300 MW prototype plant.[66] Although the utilities are engaged

actively in the FBR project, for example in the construction of the SNR-300 demonstration reactor, their share of the funding amounts to only seven percent of the costs.[67] In addition, the utilities showed little inclination to support the project until the funding for the other 93 percent of costs was assured.

Keck maintains that the state has been too active in the determination of the FBR. It is unable to assess prospects for a new technology as well as industry can because its economic calculations are inaccurate. Keck's recommendation is for the government to make further steps toward commercialization of fast breeders dependent on whether supplier and user firms are prepared to finance these steps with their own money; only then will there be a realistic economic assessment and a better awareness of time-cost trade-offs.[68] The fast breeder reactor, in short, was not determined by market considerations, although Keck argues it should have been.

High Temperature Reactors

The determinants of the HTRs appear to be quite different from those of the light water and fast breeder reactors. We will only consider them here briefly since a more detailed analysis will be presented in Part III. First, the German pebble bed HTR was hardly determined by American technology since the Americans have focused

on the distinctly different block design. There was, though, a brief flirting with the American technology in the early 1970s when the Gulf General Atomic block HTR seemed destined for commercial success. But after the commercial contracts fell through, the emphasis in the German program returned to the pebble bed reactor. Second, the German HTR was also not pursued because a commercial breakthrough for the design seemed imminent. Although the steam cooled FBR was cancelled because it did not seem marketable, work on the HTR has continued despite the lack of any commercial orders in the past or foreseeable future.

Third, the Germans (meaning one manufacturing firm and the nuclear research center in Jülich in this case) insisted on developing the HTR on their own. As with the fast breeder, they were afraid of having their program swallowed up by more advanced national programs. The 15 MW AVR experimental high temperature reactor was thus developed independently of the supranational Dragon project located in the United Kingdom. The federal government also adopted a rule of thumb for its overall nuclear program which stipulated that "whatever one did internationally, one must do at home on at least twice that scale."[69] The government was also unwilling to sub-contract its work outside of the Federal Republic. Since 1975, the Federal Republic has been the only country carrying out a full program on the HTR.

Fourth, the domestic situation of the HTR is also noteworthy and different from the situation for LWRs and FBRs, but it does not reveal why support for the reactor has continued at a high level. The reactor manufacturing firm behind the HTRs, Brown, Boveri and Cie, does not have the dominant status that the major German reactor vendor, Kraftwerk Union, and its parent firm, Siemens, command. In addition, the utilities behind the HTRs have tended to be the small regional and communal ones. Until 1966, even the federal government was lukewarm in its support, but since then the project has been thought of as just as vital as the FBRs. Through the years, though, the Nuclear Research Center in Jülich and the government of North Rhine-Westphalia have staunchly backed the HTR, but the rationale presented to the federal government and the public has varied. At one point the HTR was characterized as an interim project between the LWRs and FBRs; then it was put on an equal footing with the FBRs as a second generation nuclear reactor; now it is even considered by many as an alternative to the FBRs since the breeder reactors have been so controversial while the HTRs have shown promise as the only reactors with a wide range of non-electrical applications.

It is hard to find any point at which market considerations have been the major determinant of the German pebble bed reactor's course of development. Rather, the

development has been steady, consistent, and at times downright slow -- the THTR was originally scheduled for completion in 1976, but now 1984 is the earliest expected date. The high temperature reactor has also aroused remarkably little controversy in either the public or political circles. In Part III we will examine whether the treatment accorded to the HTR has differed from that given other reactors and whether its status as a German-developed technology has been important.

CONCLUSION

The effort in this chapter has been to evaluate the progress of the German nuclear energy program and specific reactors in it to see to what degree market considerations account for the technological choices made. Although such considerations have steered reactor development at certain points, usually some other aspect of the policy process accounts for why this is possible. In addition, when the market factors do seem to determine outcomes, they sometimes prove to be unreliable guides in the long run as we saw with the FBRs.

Market considerations in the German nuclear policy process are most relevant for the utilities. The utilities, in turn, have had an impact on policy-making mainly because the government and industry left a policy vacuum for the utilities to fill, which they gladly did. The

vacuum arose because of German thinking on the role of the market: commercial orders were the key measure of success for nuclear reactors, but the government and industry left the orders in the hands of the utilities. The utilities were not included as equal partners in planning nuclear policy -- for example, their role in the German Atomic Commission was minimal -- but the other policy actors expected the utilities to accept their policy recommendations. The utilities, however, had their eyes on reactors which could be ordered commercially, and thus moved quickly when commercial LWRs became available. For us, the key point is that the structure of the policy process permitted this to happen.

The Federal Republic subscribes to a market ideology, at least outwardly, although in practice it has moved away from a strict adherence to market principles. When Andrew Shonfield wrote Modern Capitalism: The Changing Balance of Public and Private Power, he cited the United States and West Germany as the two countries out of the mainstream of modern capitalism because they left so much control in the hands of the private sector.[70] After the war the Germans set out deliberately to reduce the power of the state in managing the economy. Ludwig Erhard, the Minister of Economics and later Chancellor, fervently defended private enterprise against government power.[71] The hallmarks of the "social market economy" of the 1950s

were private ownership of the means of production, free entrepreneurial initiatives, unrestricted competition and the guarantee of a certain social stability by the state.[72]

Since the German nuclear sector grew up in this environment, one might have expected it to be a prime target for market attitudes. In reality, though, market principles were not carried over into practice. In the first place, the market existed only to a limited degree in the nuclear sector. In the second place, to the extent that it did, it was not very relevant for determining policy because the market mechanism comes into play following the research and development and demonstration stages of reactor development, but the initial steps taken in these years were all still in the R&D stage.

There are several indications that no free market existed in German nuclear policy. Even in 1955 as the Ministry for Atomic Questions was being set up, it was clear that the other ministries had already staked out their positions and expectations with respect to atomic problems.[73] These were important for steering national development. In addition, the German Atomic Commission was effectively a planning commission for nuclear energy, not only for technical planning but also for financial planning.[74] An editorial in the Frankfurter Allgemeine Zeitung in 1959 after a nuclear energy conference for

European industries related that foreign participants "could barely suppress smiles" as a German participant spoke of the German nuclear energy industry being entrenched in the market economy.[75]

The West German business and government leaders made a pretense of operating under market conditions, but in practice they ignored the market (as with HTRs) or used it as a rationale either to drop projects (e.g., the steam-cooled FBRs or the heavy water reactor project) or to cover up other objectives. The LWR case demonstrates this last point: market analyses alleged that the LWR was the best alternative, although the differences with the British gas-graphite reactors were minimal. A better explanation for why the LWRs were chosen is that American business used superior marketing skills to convince West Germany and Europe to order them. With the fast breeder reactors too, the claims of marketability were highly inaccurate, but they provided the basis for the policy followed.

Nevertheless, market thinking did have an impact on German policy because the expectation was that future decisions on commercializing reactors would fall to the market. Thus, at the start of its nuclear program the government maintained that it would support only the basic research stages of development, but the light water reactors

are clearly beyond that point now and government assistance is still increasing. Market principles, however, have not proven to be a very good gauge of what to do in reactor development. In the first place, measures of cost-effectiveness cannot be applied very well when massive domestic and international support of certain technologies is involved. None of the reactors could be deemed profitable were it not for state aid. Economic assessments of reactors also vary widely depending on where costs are attributed, and many of the long range costs such as waste storage are ignored.

Secondly, market criteria are not widely applicable to the R&D phase of advanced technological development. The commercial breakthrough for LWRs in the Federal Republic came in 1967. All the nuclear construction before then was essentially part of the research and development phase. We saw how the German utilities opted for available American light water technology in the early 1960s; they were not interested in taking a gamble on still undeveloped German technology. Their narrow economic objectives prevented them from seeing larger political objectives despite the pleas of the German Atomic Commission not to order more American LWRs. The market is not a good guide to R&D projects because it evaluates them from only one perspective; it may therefore overlook national objectives, research priorities, military concerns,

and even longer term economic goals. In both the U.S. and the Federal Republic, the LWRs were chosen not because of market considerations but because they were available at the right time.

Market considerations are sometimes used as rationales for why specific reactor designs should be pursued, but these rationales usually manifest larger political objectives. For us, the important issue is how the larger political objectives are formed and how they affect technological choices. This leads us into the structural features of the policy process, and these will be discussed in the next chapter.

NOTES FOR CHAPTER TWO

1. Concerning nuclear energy capacity see World Energy Conference statistics cited in Thomas Connolly et. al., World Nuclear Energy Paths (New York and London: The Rockefeller Foundation and the Royal Institute of International Affairs, 1979), p. 391 -- U.S. has 52.2 GW_e capacity, Japan 14.5 GW_e, West Germany 8.9 GW_e; concerning exports, see Lothar Wilker (ed.), Nuklearpolitik im Zielkonflikt (Cologne: Verlag Wissenschaft und Politik, 1980), pp. 77-102.

2. Lydia Martin Edingshaus, "Vom Atom-Ei bis Brokdorf," Bild der Wirtschaft Vol. 14/4 (1977): p. 127.

3. Joskow, "International Nuclear Industry Today," Foreign Affairs Vol. 54 (July 1976): pp. 788-803, here p. 793.

4. Elizabeth Pond, Christian Science Monitor, May 14, 1979.

5. Quoted in International Herald Tribune, 10. April 1979.

6. Herbert Kitschelt, "Kernenergie und politischer Konflikt," Leviathan Vol. 4 (1979): p. 602.

7. Ibid., p. 603.

8. See the then minister's description of the limitations in F.J. Strauss, "Der Staat in der Atomwirtschaft," atw Vol. 1 (1956): pp. 3ff.

9. SPD Program 1957, cited in Hans-Joachim Bieber, "Die politische Entwicklung der friedlichen Kernenergienutzung in der Bundesrepublik Deutschland," in Wolfgang Lienemann et. al., Alternative Möglichkeiten für die Energiepolitik (Opladen: Westdeutscher Verlag, 1978), p. 132.

10. This was part of the SPD's Bad Godesberg program which marked an accommodation of social democratic ideology to market capitalism.

11. Kitschelt, "Kernenergie und politischer Konflikt," pp. 602-6.

12. Robert Gerwin, Atomenergie in Deutschland (Düsseldorf: Econ Verlag, 1964), p. 35.

13. Bundesminister für wissenschaftliche Forschung (ed.), Atomprogramm der Bundesrepublik Deutschland 1963-67, reprinted in W. Cartellieri et. al., Taschenbuch für Atomfragen 1964 (Bonn: Festland Verlag, 1964), p. 164.

14. Bundesminister Hans Lenz in Bulletin No. 79, May 7, 1963, p. 697.

15. Bundesminister für wissenschaftliche Forschung (ed.), 3. Atomprogramm der Bundesrepublik Deutschland 1968-72 (Bonn, 1968), pp. 14, 24.

16. 3. Atomprogramm, Chart 1; see also BMFT, Viertes Atomprogramm der Bundesrepublik Deutschland 1973-76, (Bonn: 1973), pp. 21, 23. In fact, the figures for reactor development in the earlier program are slightly inflated because they include expenditures for reactor safety which are listed separately for the later program.

17. Kitschelt, "Kernenergie," p. 609.

18. Lönroth and Walker, Civil Nuclear Industry, p. 7.

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CHAPTER THREE

INSTITUTIONAL ASPECTS OF THE GERMAN NUCLEAR PROGRAM

Chapter Two described the objectives of German nuclear energy policy and showed how these changed over the three phases of development since 1955. To gain a more complete understanding of how technological choices were made in this case, however, we must also examine the institutions involved and see how their interrelationships changed over time. This chapter deals with the structural, or institutional, aspects influencing technological choices for German reactor designs and analyzes how the structure of the German policy process influenced technological outcomes. Structure refers to the patterns of control and interest that exist among institutions in the policy process.[1] It serves as a mediating variable between domestic and international pressures and the responses of policy actors. Structural factors are a key attribute of the political-organizational approach outlined in Chapter One.

In analyzing the structural aspects of decision-making we will consider: (1) how institutions first became involved with nuclear energy policy and (2) how responsibility was divided among the government, manufacturing

and utility sectors in each of the three phases. These two considerations are important because, as we will see, initial patterns of cooperation often significantly affect subsequent political behavior, and policy leadership varies across the three phases. The considerations will allow us to see why the utilities were so instrumental in directing early nuclear policy, why the government deferred to nuclear industry in planning initial nuclear programs, and why the manufacturing firms were not a critical factor in stipulating the course of nuclear development.

Whereas the last chapter pointed out the limitations of the market approach alone for explaining the path of technological choices in German nuclear policy, this chapter shows how our understanding is increased when the political-organizational approach is added. Both organizational and political aspects are relevant. Policy leadership shifts among the actors as a technology develops: not suprisingly, utilities as reactor operators (who place orders) are especially important in the commercial stage of reactor development. Still, the importance of the utilities in German LWR policy was not just a function of LWRs being close to commercialization, but also of the context left to the utilities by the government and manufacturing sectors.

The first part of this chapter evaluates the policy influence of the major federal government institutions concerned with German nuclear energy; the second part focuses on the division of responsibilities between the business and state sectors, particularly regarding the role of the electrical utilities.

INSTITUTIONAL ARRANGEMENTS

The main responsibility for nuclear energy policy on the federal level lies with the Ministry for Research and Technology (BMFT -- Bundesministerium für Forschung und Technologie), originally established as the Ministry for Atomic Questions. An industry-dominated group called the German Atomic Commission (not equivalent to the U.S. Atomic Commission) was instrumental in guiding the ministry's formation and early policy. In contrast, the Bundestag played a very insignificant role in nuclear energy policy-making. This section examines these three institutions. It concentrates mainly on the conditions surrounding their establishment for, as we will see, the way in which an institution initially enters the policy process often accounts for its subsequent role.

The Federal Ministry for Atomic Questions

From the beginning, the Ministry for Atomic Questions had a limited role inside and outside of government and

was oriented largely to economic objectives. Set up in 1955, it was immediately swept into the middle of competition between industry and other federal ministries. The Foreign Office sought to guard its own responsibilities in the nuclear field and wanted guarantees that it would still represent German interests in such international meetings as the 1955 Geneva Conference on the Peaceful uses of Atomic Energy. German industrialists, on the other hand, were anxious to use the new ministry to exclude the Foreign Office from decisions on the supply of nuclear materials and the construction of research reactors.[2] Industry did not favor a strong ministry but did want a centralized place in the federal government for nuclear policy. Through the offices of the industry-dominated German Atomic Commission the industrialists made their wishes clear: the new ministry's functions should be limited to dealing with the legal aspects of nuclear development, preparing budgets and facilitating cooperation; everything else -- above all, decisions on reactor designs[3] -- should be left to industry.

German industrialists were closely involved both with planning the new Ministry for Atomic Questions and formulating its policy once it was established. As a result, the ministry emphasized economic considerations. This was augmented by the fact that many of the

responsibilities taken over by the new ministry were of an economic rather than a foreign policy nature. Ludwig Erhard, the economics minister at the time, neither saw the importance of nuclear questions nor was convinced that a new ministry was needed at all. Erhard went so far as to say,

> What do I care about nuclear energy? That's all physics and all nonsense. Why do we need an atomic ministry? We don't have a steam ministry.[4]

Because of this indifference, Erhard readily transferred responsibility from the energy section of his economics ministry to the new ministry.

Franz Josef Strauss, the first Minister for Atomic Questions, described the tasks of his ministry as follows: (1) to prepare a nuclear energy law; (2) to prepare a law protecting the population against radioactive materials; (3) to draft a coordinated research program; (4) to establish a manpower training program; (5) to coordinate international negotiations.[5] Strauss saw the ministry's goals as overcoming West Germany's 10-15 year lag in nuclear energy and making German industry internationally competitive.[6]

The scope of the ministry changed several times after 1955 and nuclear issues had to compete with a wide range of other issues even within the ministry itself. In 1957

it became the Ministry for Water and Atomic Questions, in 1962, the Ministry for Scientific Research, in 1969, the Ministry for Education and Science, and in 1972, the Ministry for Research and Technology.[7]

The ministry also had to cope with several changes in leadership and style. Strauss remained in office only one year. He was succeeded by Siegfried Balke, a scientist with little political experience or ambition who said he had no particular goals except to enable the younger generation to practice science without interference from the state or politics.[8] In 1962 a political move by Chancellor Adenauer brought in Hans Lenz, a scientist himself with little interest in nuclear energy or politics. Both scientists and industrialists were skeptical of him, and for over two years he never even called the German Atomic Commission into session.[9]

In sum, from the very beginning the Ministry for Atomic Questions had to fight for its right to make nuclear policy. An industrial interest group, the Physical Study Society, made the initial suggestions for the ministry in order to counter the role of the Foreign Ministry. Winnacker and Wirtz, who were part of this industrialists' group, write that the problem of competition with the Foreign Office has always been present.[10] This has been especially true concerning non-proliferation matters: the

balancing of non-proliferation questions and economic interests has been important over the past 25 years, and the tensions between non-proliferation and the peaceful use of nuclear energy have still not been politically resolved.[11]

Especially in the early years before the federal government assumed a more major role in nuclear policy, the atomic ministry was relatively weak, with only 38 nuclear experts and a total of 130 employees in 1957 in contrast to the more than 200 expert advisers of the German Atomic Commission.[12] Although industry wanted the new ministry, it did not want strong new decision-makers in the field and so it sought to circumscribe the role of the ministry. Strauss, for example, was specifically required by the Federal Cabinet to listen to the views of the Atomic Commission on all essential questions.[13] But Strauss' views were also very much in line with those of the nuclear physicists and industrialists.[14] He was convinced that a country could not be a leading economic power in the future without a nuclear basis.[15]

The German Atomic Commission

The German Atomic Commission was set up as an advisory body to the ministry in January 1956. Although it reflected a business, especially a manufacturing, point

of view, its members were not bound by traditional German business beliefs: their major objective was to establish a competitive German nuclear industry even if that occasionally involved sacrificing adherence to free market beliefs. The Commission, for example, was prepared to engage in long-range economic planning. The Ministry for Atomic Questions depended on the Commission to shape nuclear policy at least until 1967 when the Grand Coalition between the Christian Democrats and Social Democrats came to power.

As with the Ministry for Atomic Questions, German industrialists were active in establishing the German Atomic Commission. In fact, the Commission was essentially a continuation of the Physical Study Society which the industrialists had organized. Strauss had made it clear after he became minister in October 1955 that such a commission would be formed with a wide-ranging scope.[16] Although the name of the Commission paralleled that of the U.S. Atomic Energy Commission, its role was more limited.[17]

There was some controversy about whether the Atomic Commission's role in the policy-making process should be official or unofficial. Several members of the Commission demanded that it have a legally defined role, but the majority opposed this because they wanted to limit the state's influence in such an important field; the memories of the state's

monopolistic position during the Third Reich were still present.[18] Even without a legal role, the Atomic Commission was probably the strongest state actor in nuclear policy until it was disbanded in 1971. Actual leadership of German nuclear policy fell to it and not to the ministry.[19] The Commission was responsible for formulating the Federal Republic's first three atomic programs from 1957-1968. Jürgen Peter Pesch has done the most thorough analysis of the Commission's role, and like Keck, Radkau and Christian Deubner, he had access to the minutes of the Commission's meetings which were secret at the time.[20] He found that the Commission's recommendations were followed nearly without exception by the government, and that for all practical purposes the federal government was an "executive organ" of the Atomic Commission.[21]

Interestingly, the Commission never shied away from advocating a type of central planning even in the early 1960s when West Germany stood ideologically opposed to such planning. The Commission called for "genuine economic planning on a large scale" and industry did not condemn this approach.[22] The Commission was supposed to be comprised of neutral experts, but these experts came primarily from industry; initially the Commission had 27 members: 15 from industry, 8 scientists, and 2 each from the government and the trade unions.[23] The criticism

can thus be made that national policy was being made by those for whom the policy was designed. Because the Commission looked like an interest cartel and because the early German nuclear program financed essentially every firm that made a proposal, accusations were made that the policy amounted to "give me an accelerator and I will give you a nuclear reactor."[24] In other words, the industrialists on the Commission looked after each other.

Within the Atomic Commission at the start, though, there were some hesitations about the orientation to nuclear energy. Two interest groups -- the Ruhr coal companies and the electrical utilities -- had reservations. The coal companies did not want to lose their traditional position as primary suppliers of energy, and the utilities were concerned about costs and risks. Both groups were able to slow the rush to nuclear energy. However, both -- especially the utilities -- eventually dropped their opposition for reasons which we will explore in this chapter.

The utilities and coal companies were not particularly influential in the Atomic Commission which represented mainly the manufacturing industries. After 1958, though, the Commission lost much of the initiative in the Federal Republic's nuclear program to the utilities.

The shift was due not to any change in the Commission's relationship to the federal government, but to changed conditions arising from the end of apparent energy shortages and internationally available technologies. A rivalry between the manufacturers and utilities with their different perspectives seemed inevitable.[25] The Commission favored a reactor development program which would establish an internationally competitive industry, whereas the utilities favored proven technologies. The Commission wanted to bolster domestic industry, but the utilities preferred to order foreign reactors which were already available.

Gradually, the federal government developed its own expertise in nuclear energy and thus could rely less on the Atomic Commission. The Commission was responsible, though, for the formulation of the government's first three atomic programs. Only the fourth program completed in 1973 was done by the federal ministry. According to Winnacker and Wirtz, the contacts between industry and government started breaking down when the Grand Coalition came to power in 1967.[26] Eventually the Atomic Commission was disbanded in 1971 because the Social Democratic government felt that a tighter advisory system was needed. German industrialists still sponsor an organization called the German Atomic Forum, but it lacks the influence the Commission had and is more of an industrial lobby.

The Parliament

The role of the Bundestag in nuclear energy policy has been limited. This may be inevitable in a parliamentary system since initiatives are expected to come from the individual ministries. The Bundestag lost any chance to steer nuclear policy when it lost its regulatory control over nuclear developments through the Atomic Law of 1959.[27] After that, the Bundestag demonstrated little interest in nuclear affairs, and the parties differed very little in their positions until the late 1970s when anti-nuclear groups appeared within the SPD and FDP. The one form of control which the Bundestag has is that it must authorize budgetary expenditures each year, but it has made no serious attempt to use this tool.

The SPD had major differences with the ruling CDU in the 1950s about nuclear policy, particularly regarding state control, but these disappeared after the Bad Godesberg program in 1959.[28] Debates within the parties over nuclear energy did not take place until 1977.[29] Parliament had been involved with the formulation of nuclear safety regulations in the 1950s, but the only expert witnesses it called to testify at hearings were members of the Atomic Commission.[30] The regulatory function was transferred out of Parliament's hands with the enactment of the Atomic Law in 1959, and after that debates in the Bundestag took place before practically empty benches.[31]

The members had almost no information about the government's nuclear programs. In the third legislative session the only information which the members of the special committee on nuclear affairs received from the responsible ministry consisted of two short presentations by Minister Balke at their request in 1958 and 1960; in the fourth session Balke made one similar speech in 1962, and the only hearing on the government's Second Atomic Program in 1963 involved three civil servants, two parliamentarians, and a total of five questions; in the fifth session there were no discussions of the government program at all.[32]

The committees were also unable to exert control because the responsibilities of the committee changed often and the members did not have much technical expertise. The special committees in Parliament had areas of competence in line with those of the ministries. Hence, as the responsibilities of the ministry shifted to include water, education or research, so too did the responsibilities of the committee most connected with nuclear energy: in the third and fourth legislative sessions the committee also had to deal with water regulation; in the fifth and sixth sessions, with press concentration, space travel and the preservation of national monuments; in the seventh session, with research and technology policy as well as postal and telecommunication

policy.[33] The committee was always dominated by farmers or educators, never by scientists.[34] Moreover, the individual legislators operated essentially without legislative assistants most of the time, and the "legislative research service" (Wissenschaftlicher Dienst) which normally supplied information to the members was not technically oriented or competent.

Parliament has not been a source of initiative in nuclear energy policy-making. Ironically, it may well be that the one-man campaign of the Frankfurter Allgemeine Zeitung's science editor, Karl Rudzinski, against the cancellation of the steam fast breeder reactor in 1969 was more influential than the actions of the Bundestag.[35] The cancellation of that reactor, the development of strong state support for developing nuclear power reactors, and the broadening of the government's atomic programs to detailed policy tools all occurred without the participation of Parliament or the public. Pesch terms this a "short-circuit" in the public opinion-making process.[36]

The evidence of the 1970s does not show a reversal of tendencies even though the Bundestag did hold up budgetary allocations for the fast breeder and high temperature reactors briefly in the mid-1970s. The reasons, though, were linked to regional disputes among

parliamentarians who felt that the advanced reactor program was tilted away from the reactors they favored and which were being developed in their regions of the country.[37] The total government program was not called into question and funds were eventually released. Likewise, the Enquete Commission on nuclear energy which was formed in 1979 and reported its findings in June 1980 was not steering policy so much as justifying decisions already made.[38]

DIVISION OF RESPONSIBILITIES IN GERMAN NUCLEAR ENERGY POLICY

In the previous section's examination of how the federal government became involved with nuclear energy policy in the Federal Republic, we saw that no comprehensive plan guided the establishment of institutions. Policy-makers and industrialists alike simply wanted to close the gap with other countries as quickly as possible. Through its first atomic program (the Eltville program), the government made clear its intention to support virtually any nuclear reactor design. It did not feel competent to choose among reactor design possibilities and did not worry particularly about long-term technological choices which it expected would be a function of market factors.

Market factors were, in fact, instrumental in steering the course of German nuclear policy and they became important

far earlier than the government had anticipated. As we saw in Chapter 1, the stage of development of a technology plays an important role in determining which policy actors exert leadership in making technological choices. This section examines how leadership shifted from the government and its agencies to the electrical utilities as the focus changed from research and development to commercialization. The change occurred sooner than expected because of international developments, namely the availability of light water reactors. Because of their availability, the German utilities narrowed the options for reactor development more quickly than the government had anticipated. The government policy-makers had assumed that the utilities would support the wide-range of reactor technologies which the government was subsidizing through the Eltville program, but the utilities circumvented the government's plan by concentrating on light water reactors. The utilities' emphasis did not correspond either to the government's wish to be independent of foreign enriched uranium or to support domestic technologies.

This section highlights the important relationship between the stage of development for a given project and the policy leadership for that stage. The focus is on the utilities, especially on their role within the Eltville program, and their influence indicates how

significant the prospect of commercialization of a technology can be for a project's development. The section serves to tie together the points raised in the last two chapters with the theoretical framework of Chapter One: it demonstrates how the stages of development of a specific project are related to both the institutional arrangements and the leadership exerted in a given stage. We deal first with the utilities themselves and second with the significance of the utilities within the Eltville program.

The Electrical Utilities

German electrical utilities assumed an unexpectedly important role in nuclear policy-making after 1957. The government and the Atomic Commission did not anticipate the policy-making significance of the utilities, but their attitudes fostered it. The government and Commission expected to support nuclear research at the early stages of development and then leave further decisions to the market. This favored the utilities because they placed the commercial orders, and therefore the rest of the nuclear industry had to keep the utilities' interests in mind. Pesch claims that the German utilities are the "controllers of the entire energy program."[39] There are over 300 of them and it is imperative to look at their priorities. One official from the Federal Ministry for

Research and Technology complained that the ministry has "no control" over such firms; especially with research and development work the ministry responds to utilities' decisions, but it is very hard for the ministry to take its own initiatives.[40] In contrast to many other European countries, West Germany has an electricity industry which is more decentralized, mixed publicly and privately, and subject to communal and state participation. For all practical purposes, though, it is organized and oriented as a private industry.[41]

In addition to having power because they place the commercial orders, the utilities also preferred to move forward from the research stages more rapidly than the government and Atomic Commission; given their private nature and own resources, they were able to do this and thus again direct initiatives. The minutes of the Commission in May 1958 reveal that even Commission members recognized that the initiative had shifted from developmental groups within reactor construction industry to the utilities.[42] It should be remembered that early views about the application of nuclear power went beyond just the electricity sector to the chemical industry, the metal industry and the powering of nuclear ships. That explains partly why the utilities were not fully integrated into the Atomic Commission.

West Germany's nuclear program was torn in the early years between the wish for a wide-ranging experimental program encompassing several reactor types and the pressure for operating power stations supplying usable electricity. The manufacturing industry was not inclined to move beyond the experimental phase since the nuclear projects of every firm were supported by the government. The utilities, on the other hand, were impatient to move beyond the research phase because they felt they had only to look abroad to find reactor types that met their needs. The utilities were quick to look at internationally available technology whereas the government and Atomic Commission wanted to foster domestic designs. Heinrich Mandel of RWE urged the Atomic Commission in 1956 not to shy away from a program relying on enriched uranium even though that implied a dependence on the U.S.A.[43] He recommended that three of the five experimental reactors in the government program be of the light water type. It is interesting that although other scientific and technical experts advanced technological justifications for their choices, Mandel argued for his primarily on the grounds of lower initial investment costs.[44]

For the government, it was important that the utilities place orders for the whole range of reactors being developed, but the government had no special influence on the utilities.

Both the largest utility, RWE, and a group of small utilities, AVR (Arbeitsgemeinschaft Versuchsreaktor e.V.), set up study groups on nuclear energy in 1956. The utilities, though, with their different and more cautious conceptions of how to proceed with nuclear energy, felt that the government's plans to build 100 MW plants involved too large a risk. The utilities argued that plants should be as small as possible to minimize costs, but as large as necessary to gain relevant technical experience.[45] The advice of the utilities was for 15 MW plants. The Atomic Commission had different ideas since it regarded the development of an internationally competitive domestic industry as the main priority; it felt that the utilities had a premature and over-stressed bias toward economic aspects.[46]

Nonetheless, industry and government had little choice but to accommodate themselves to the wishes of the utilities because of the dramatic change in the energy situation beginning in 1958. Suddenly there was an overabundance of conventional energy supplies. It became clear through this energy glut that the utilities would only order nuclear reactors if they were enticed to do so by the government subsidies. The manufacturing firms were somewhat surprised by the need to woo the utilities. The minutes of the Atomic Commission show that the leading manufacturing firms had expected that the government would

be able to convince utilities to order the reactors being developed by German domestic industry.[47] German laws and the composition of the supervisory boards (Aufsichtsräte) of the utilities also contributed to the companies' influence and autonomy.[48] The public nature of the utilities required diverse representation on the supervisory boards. Through these appointments, interests tended to neutralize each other, thereby leaving considerable freedom to the board of directors.[49]

German utilities played a key role in determining the route of nuclear energy development. The next section on the government's first atomic program outlines how the utilities supported the light water reactors. One major reason they could do so was the situation created by the German government and Atomic Commission. Free market attitudes were not very important for regulating nuclear markets, but they were pervasive enough to increase the influence of the utilities insofar as the government believed that the decisions following the early stages of reactor development would still depend on market competition. Subsidies were considered appropriate for the early stages, but not for the later ones.

The utilities played a significant role in the early years of nuclear energy policy-making through their support

for light water reactors, but they were less instrumental in steering policy for the more advanced high temperature reactors. Commercialization possibilities for the HTRs were more remote, thereby reducing the willingness of the utilities to make a full commitment to the technology. With the LWRs the utilities were influential partly due to the stage of technological development and partly due to the role left to them by the other policy actors.

Opinion on the role of the utilities in German nuclear policy varies. Otto Keck, in his analysis of German nuclear energy policy, concludes that German policy-makers have not sufficiently appreciated the importance of the utilities in decisions. If government policy alone had determined which strategies to follow, the results would have been disastrous according to Keck: pressurized water reactors, which were eventually the most successful design in West Germany, might have never been developed because early government programs did not feature them.[50] Keck praises the decentralized decision-making in the Federal Republic. He feels that the decisions by the utilities were the key to the success of the German effort, and the fact that they were independent of government programs -- and sometimes even against them -- shows that the development of high-risk technologies such as nuclear power plants is not beyond the capability of business enterprises.[51]

Klaus Traube, on the other hand, criticizes the utilities for the power they exert. Traube, formerly a leading nuclear industry executive and now an opponent of nuclear energy, attacks the utilities for controlling policy developments under the guise of "free market" decisions.[52] He maintains that the utilities, by claiming to protect the consumer from state planning but in reality advancing their own interests, subject the consumer to an even more insidious form of planning.[53] Traube is referring to the utilities in his warning that "In the free market economy, some have a more equal chance than others."[54]

The Role of the Utilities within the Eltville Program

In contrast to most other countries, the German government preferred not to exercise exclusive control over nuclear policy. German scientists did not distrust the private sector as French scientists did; indeed, they realized that their own success depended on encouraging eventual industrial sponsorship of reactor development programs.[55] The scientists believed that they could best advance German industry. A pattern of cooperation between industry and science was established early in the nuclear development program.

Certain disadvantages of this link soon became evident, however, once the debate on nuclear policy had subsided in the later 1950s because the need for nuclear

power was less urgent. Neither government nor industry was prone to look critically at what was being done. It became common practice that reports evaluating specific reactors were only issued by the firms building or operating them. Laymen and even experts found it nearly impossible to make comparisons among reactors, and overall analyses from supposedly neutral authors almost never compared designs.[56] For example, no comparative analyses were done for the second generation fast breeder and high temperature reactors. Radkau suggests that the involvement of the two major nuclear research centers, Karlsruhe and Jülich, contributed to this because they wanted to keep their projects separate and independent.[57] Likewise, in the German Atomic Commission, Siemens and AEG suppressed any critical comparison of their light water reactor lines, the pressurized and boiling water reactors, even though the designs were parallel.[58]

By late 1956 German industry had gained some nuclear experience through the research reactors imported after 1955, but it was eager to move forward to the design and construction of working reactors. The task of proposing an actual program fell to the working group on nuclear reactors (Arbeitskreis II-III/1, "Kernreaktoren") of the German Atomic Commission. The working group consisted of three representatives of the manufacturing industry, three

from the chemical industry, three from universities or research centers, and one from the utilities. This program was labeled as the Eltville program after the small town on the Rhine River where concrete plans were formulated in early 1957. Eventually it was referred to as the first German atomic program after the government formulated other "atomic programs" in the 1960s. The Eltville program supported the design and construction of five 100 MW nuclear power plants by five different companies. Total installed capacity was to be 500 MW, scheduled for completion by 1965. The five reactors supported by the program were: (1) a light water reactor to be built by AEG; (2) a gas-cooled high temperature reactor using enriched uranium to be built by BBC and Krupp; (3) a gas graphite reactor similar to the advanced Calder Hall type using natural uranium to be built by the German Babcock and Wilcox; (4) an organic reactor to be built by Interatom; and (5) a heavy water reactor using natural uranium to be built by Siemens.

Industry wanted to obtain state support for the development programs and to avoid open competition. The Eltville Program essentially staked out the exclusive domains of the firms involved. No hard choices between projects were made; the program supported every project which German industry had undertaken.[59] No firm had to give up anything, and actually the program even made

provisions for one firm, Interatom, which still had to be founded.[60] The Eltville program encompassed ongoing projects and, to the extent that industry had been more attached to commercially viable designs beforehand, the program also reflected favoritism to market considerations. Originally, the intention of the German nuclear policy was to rely exclusively on natural uranium, but the apparent commercial chances of light water reactors caused reconsideration.[61] Earlier it had seemed that German efforts would concentrate on the heavy water reactor using natural uranium, but in the Eltville program it became just one project among several.

The significance of the Eltville program was that it created a new division of responsibility between the state and industry. The notion of state support for the design and construction of high technology projects was embodied in the program, and that was far more important than the program's electrical production. The 500 MW figure had been adopted as a kind of index for the first stage of the reactors, but it did not reflect industry estimates of need; it was merely intended to map out the extent of the work required.[62] In the long run only 340 MW of the proposed 500 MW were installed and only DM 250.6 million of the expected expenditure of DM 600 to 800 million were spent.[63] Most of the money spent (DM 225.9 million) went

to the unsuccessful heavy water plant while only DM 6 million of government and utility funds went to the successful light water reactor.

The Eltville program was important for the development of nuclear energy and business-state relations in Germany because it confirmed that the state had a role to play in technological development. At the same time, it also expressed the largely industrial and cautious bias of German initiatives. In contrast to the French and British programs announced in 1955, "Eltville encouraged a variety of reactor designs and emphasized quality and experimentation rather than quantity and series construction."[64] The Germans kept their options open, perhaps because of an uncertainty over whether to stress their national interests (e.g., technological pride or the need for independence from enriched uranium supplies) or commercial interests. In all events, the pressures which drew the government into supporting the nuclear industry continued to grow in subsequent years.

The Eltville program was not successful, and the major reason was the opposition of the electrical utilities. As we saw earlier, they stressed that their decision whether to build a reactor would be made on the basis of market considerations and not the requirements of the Eltville program. The program ended up being too general to appeal

to the manufacturing firms or the utilities. Several factors contributed to the problems of the Eltville program: it tried to support too many projects; the electrical utilities were wary of the project; the Ruhr coal mining industry was adamantly against nuclear energy and the 500 MW program; and the changed energy situation after 1958 took away the urgency for developing nuclear reactors.[65] Although the Eltville program may have been a failure from the point of view of achieving what was planned,[66] it did have a lasting impact on nuclear policy in the sense that it brought the government officially into the nuclear sector. Industry and utilities complained that sufficient public incentives to spark private undertakings were lacking in these early programs, but German authorities were increasingly drawn into more active involvement.[67]

Even the Atomic Commission conceded that the Eltville program had failed.[68] According to one government official, "It was a time of stagnation; . . . there was no body to place an order for construction."[69] The government responded by urging the Atomic Commission to set up a joint program with the reactor building industry for the development of 10 to 30 MW advanced experimental reactors. This "Program for Advanced Reactors" also supported every firm interested in nuclear reactors. One firm, Maschinenfabrik Augsburg-Nürnburg AG (MAN), had been turned down by the working group of the Atomic Commission

for its request for design work support of a 5 MW pressurized water reactor of the horizontal type. The working group argued that the design was licensed abroad and was not a domestic development. Nevertheless, the ministry overruled this advice and financed 50 percent of the design work in subsequent years.[70]

The program for advanced reactors was not markedly different from the Eltville program regarding reactor designs, except it did not seek any collaboration from the electrical utilities. The program stressed developmental aspects and new technical ideas rather than commercial aspects, and the design phase could be started immediately since funds were appropriated directly to the manufacturing industry.[71] Again, the actual implementation of plans was not important -- only three of the five proposed reactors were built. The same federal official mentioned in the previous paragraph characterized the program as "somewhat like an emergency assistance measure or a stopgap program for industry."[72] As with the Eltville program, the most important result of the advanced reactor program was the additional funding it provided for the nuclear industry, but in this case with less reliance on the utilities.

Clearly the links between industry and the state were close at the start of Germany's nuclear program, and this

established patterns of cooperation and structural arrangements that have continued to have an impact on policy. In West Germany science and industry worked together, and the role of the government in supporting "big science" grew continually. The Physical Study Commission, formed by industry, was closely connected with the establishment of the German Atomic Commission, and the Commission's role was openly acknowledged by the government in establishing the Ministry for Atomic Questions. Moreover, industrial interests played important roles in the committees of the Atomic Commission too; for instance, working group IV (AK IV, "Economy and Industry") had close ties with the German manufacturers association, the Bund der Deutschen Industrie (BDI).[73]

The utilities -- which Hans Jarass calls "the third column in the nuclear energy picture" along with the federal government and the small number of reactor firms[74] -- were not fully integrated into these structures. Nuclear energy was seen in broader applications than mere electricity production and the utilities themselves were cautious about nuclear commitments. The exception was Heinrich Mandel from RWE who was always a staunch supporter of nuclear energy. His influence and the influence of RWE were important in later years for the positive attitude of the utilities toward nuclear energy.

The trend toward more government involvement in the nuclear sector began immediately with the Eltville and advanced reactor programs. Federal contracts still left primary responsibility for technical and managerial control to the industry.[75] On the government side, the trend was to more federal involvement rather than state involvement due to the huge funding requirements. The Nuclear Research Center in Jülich originally received 50 percent of its funding from the Land North Rhine-Westphalia, then 25 percent, then 10 percent. On the industry side, firms relied increasingly on government support for development. Industry had been actively involved with the development of the Karlsruhe Nuclear Research Center, but it could not meet the additional financial needs of the research reactor (FR2) being built there. Rather than accept a minority position in line with a reduced financail contribution, industry forfeited its DM 30 million share as a gift to the government. In return, two industry representatives were retained on the center's supervisory board for the next five years.[76]

The informal network of associations between scientists and government officials allowed the government to work behind the scene and keep a low profile. To a large extent, the German Atomic Commission coordinated these efforts.[77] At the outset, when the German nuclear program

was weak, an open orientation to the outside was favored. West Germany tended to measure its capabilities against France's. Gradually, West Germany's position became stronger and policy changed because general competitive concerns toward outside powers acquired new priority.[78] These competitive concerns were manifested in West Germany -- and elsewhere -- by a concentration process, most notable in the merger of Siemens' and AEG's nuclear interests to form the subsidiary of Kraftwerk Union. KWU not only built reactors but also controlled many fuel element interests. Naturally, this concentration facilitated cooperation with state authorities, especially on a federal level, because of KWU's dominant market position and link to German prestige in the field.

CONCLUSION

When the German government was allowed to resume nuclear research in 1955, it did not want to assume too much of a leadership role. This restraint was due partly to the decentralized nature of the state, partly to its own lack of expertise in atomic energy, and partly to its belief in market principles. The government certainly felt, though, that it was essential for the Federal Republic to develop a nuclear capacity. Initially, energy needs were seen as the paramount reason for pushing nuclear energy; later economic motives were more salient. At certain times security needs have also been important, mainly in terms of

how the Federal Republic can be integrated into a European nuclear deterrant.

In any case, the government favored keeping a low profile regarding nuclear policy. It chose to work primarily in conjunction with industrialists involved with nuclear energy. The German Atomic Commission, comprised mainly of industrialists, assumed considerably more significance than the Ministry for Atomic Questions. The electrical utilities were included only peripherally in the industrialists' group at least in part because nuclear energy then was seen to have several applications besides the generation of electricity.

The first atomic program of the Federal Republic, the Eltville program, was prepared by the Atomic Commission and it basically supported all the reactor designs which the German reactor manufacturing industry was pursuing. The government wanted to provide R&D support, fearing that otherwise the firms might not be willing to undertake the risks involved. Several designs were expected to move into commercial development; the utilities were expected to place orders for such designs.

It is at this point that the government wrongly assessed the workings of the market process. The utilities simply were not amenable to staying in the experimental

phase for as long as the government and the Commission anticipated. The utilities wanted working reactors and when they saw an available technology -- the light water reactor -- which provided them what they wanted, they opted for it. Their calculations were economic, not political or nationalistic as were the calculations of the Atomic Commission. The government never told the utilities not to choose the LWRs, but it certainly had expected that a narrowing of options would come much later. The structure of the policy process left the decision-making power to the utilities by default.

The government had always expected that market forces would determine the direction of the nuclear program, but these forces became relevant sooner than anticipated. The manufacturing firms did not play a critical role because their government subsidies meant that their need to narrow options was minimized. Moreover, by the late 1950s and early 1960s the energy and security reasons for developing nuclear energy were less significant than the economic reasons -- i.e., supporting domestic firms and promoting exports. In short, both the institutional aspects of nuclear policy-making and the domestic conditions affecting decisions worked in favor of the utilities. They took the lead in opting for light water reactors and no one opposed this move.

We should realize that the evidence in this section relates mainly to the light water reactors which were close to the commercial stage while these policy deliberations were taking place. The situation is different, though, for the advanced reactors such as the fast breeder and high temperature reactors. Before we draw conclusions about the role of economic factors or utilities in determining technological choices, we should look more closely at what happens when economic pay-offs are not readily available. In the next chapters we will examine how technological choices have been made for the pebble bed high temperature reactor.

NOTES FOR CHAPTER THREE

1. This is the definition presented by Zysman in his study of the importance of structural arrangements for industrial policies in France. See his book, Political Strategies for Industrial Order, p. 11.

2. Winnacker and Wirtz, Nuclear Energy, pp. 66-7.

3. Bufe and Grumbach, Staat und Atomindustrie, p. 60.

4. Edingshaus, "Vom Atom-Ei bis Brokdorf," p. 114.

5. Strauss, "Der Staat in der Atomwirtschaft," atw Vol. 1, (1956): p. 4.

6. Bulletin, No. 242, Dec 28, 1955, p. 2087.

7. See Edingshaus, "Vom Atom-Ei bis Brokdorf," and "Wie Deutschland zur Kernenergie kam: Stopp auf halbem Weg?" Bild der Wissenschaft Vol. 14, No. 5 (1977): pp. 92-104.

8. Edingshaus, "Vom Atom-Ei bis Brokdorf," p. 126.

9. Ibid., pp. 130-1.

10. Winnacker and Wirtz, Nuclear Energy, p. 67.

11. See for example Wilker, Nuklearpolitik im Zielkonflikt, p. 146.

12. Bulletin, Nr. 191, Oct. 12, 1957, p. 1754.

13. Minutes of the German Atomic Commission, Jan. 26, 1956, p. 5, cited in Pesch, Staatliche Forschung, p. 28.

14. Bieber, "Kernenergienutzung," p. 19.

15. Strauss, "Der Staat in der Atomwirtschaft," p. 2.

16. Bulletin, No. 205, November 3, 1955, p. 1733.

17. Winnacker and Wirtz, Nuclear Energy, p. 56.

18. Ibid., p. 68.

19. Bufe and Grumbach, Staat und Atomindustrie, p. 67.

20. Pesch, Staatliche Forschung.

21. Ibid., p. 90.

22. R. Schulten, A. Schuller, "Der Staat als Partner," atw (1963): p. 4.

23. W. Cartellieri, A. Hocker and W. Schnurr, Taschenbuch für Atomfragen 1959 (Bonn: Festland Verlag, 1959), pp. 209-211.

24. Pesch, Staatlich Forschung, p. 74.

25. Keck, Fast Breeder Reactor Development, p. 107.

26. Winnacker and Wirtz, Nuclear Energy, pp. 212, 300. These two authors, who were involved at every stage of German nuclear policy, provide a readable, balanced account of nuclear development in their book Nuclear Energy in Germany -- except for their impassioned defense of the Commission.

27. Pesch, Staatliche Forschung, p. 85.

28. As we mentioned in Chapter Two, the Bad Godesberg program was the SPD's formal acknowledgement of the acceptance of market ideology.

29. Bieber, "Kernenergienutzung," p. 140.

30. Pesch, Staatliche Forschung, pp. 36-41.

31. Bieber, "Kernenergienutzung," p. 74.

32. Pesch, Staatliche Forschung, pp. 37-43.

33. Ibid., p. 21.

34. Ibid., p. 22.

35. Rudzinski argued that the steam-cooled system had important advantages over the sodium-cooled one, and he was critical of both the ministry and Karlsruhe nuclear research center. See Keck, Fast Breeder Reactor Development, p. 263 for a listing of 16 articles by Rudzinski.

36. Pesch, Staatliche Forschung, p. 90.

37. See comments by W. Schmidt-Küster in Energy Daily, May 16, 1977.

38. The Commission dealt primarily with fast breeder reactor development, not with HTRs.

39. Pesch, Staatliche Forschung, p. 73.

40. Interview 4 with BMFT Official, May 1979.

41. Winnacker and Wirtz, Nuclear Energy, p. 120.

42. Radkau, "Lernprozess," p. 203.

43. Minutes of the German Atomic Commission, May 6, 1956 cited in Ibid., p. 207.

44. Ibid.

45. Keck, Fast Breeder Reactor Development, p. 82.

46. Ibid.

47. For AEG, see minutes of the German Atomic Commission: Schuller to the Geschäftsführung Aug. 11, 1958; Schuller to Wirtz, Nov. 1, 1960; for Siemens, see criticism of cooperation between the government and the electrical industry, Nov. 9, 1966. Cited in Radkau, "Lernprozess," p. 205.

48. See Hans D. Jarass, "Formen Staatlicher Einwirkung auf die Energiewirtschaft," Der Staat Vol. 17 (1978) pp. 517-22.

49. German firms have both a supervisory board (Aufsichtsrat) and a board of directors (Vorstand). The supervisory board, which has no counterpart in Anglo-Saxon or Latin countries, is supposed to protect shareholder interests in management decisions. In theory there is supposed to be a complete "separation of powers," but in practice the power of the managers (Vorstand) is increased. That was the case with the utilities mentioned here. See Shonfield, Modern Capitalism, pp. 247-8.

50. Keck, Fast Breeder Reactor Development, p. 121.

51. Ibid., pp. 126-7.

52. Klaus Traube, "Der Mythos vom 'unverzichtbaren' Atomstrom," Der Spiegel, October 1, 1979, pp. 55-70.

53. Ibid., p. 63.

54. Ibid., p. 70.

55. Nau, National Politics, p. 93.

56. Radkau, "Lernprozess," p. 216; see his literature review, "Atompolitik ohne Alternative?" Neue Politische Literatur Vol. 22 (1977): pp. 308-45 and pp. 442-83 (parts I and II). As an example he cites a book by Gerhard Schmidt, Kernenergie: Fakten und Prognosen für Industrie und Wirtschaft, Medizin, Technik und Forschung (Berlin; Safari Verlag, 1970) in which the chapter "Comparison and Prognosis of Reactors" amounts to two pages.

57. Radkau, "Atompolitik," Part I, p. 320.

58. Ibid.

59. See Bulletin Nr. 229, Dec. 11, 1957, p. 2109.

60. Keck, Fast Breeder Reactor Development, p. 79.

61. Minutes of the German Atomic Commission, Jan. 11, 1957, contribution by Wirtz, cited in Radkau, "Lernprozess," p. 201.

62. Winnacker and Wirtz, Nuclear Energy, p. 121.

63. Ibid., p. 127, and Keck, Fast Breeder Reactor Development, p. 93.

64. Nau, National Politics, p. 86.

65. Bufe and Grumbach, Staat und Atomindustrie, p. 116.

66. Keck, Fast Breeder Reactor Development, p. 92.

67. See e.g. comments by Siemens representative, Mannheimer Morgen, Nov. 19, 1958 and AEG representative, FAZ, May 1, 1961, cited by Nau, National Politics, p. 86.

68. Minutes of the German Atomic Commission, Feb. 9, 1961 cited in Pesch, Staatliche Forschung, p. 40.

69. Joachim Pretsch, "10 Years of Nuclear Energy Policy in the Federal Republic of Germany," in Johannes Sobotta (ed.) State, Science and Economy as Partners (Berlin: A.F. Koska Verlag, 1967), p. 141.

70. Keck, Fast Breeder Reactor Development, p. 98.

71. Ibid., pp. 94, 98.

72. Pretsch, p. 141.

73. Pesch, Staatliche Forschung, p. 24.

74. Jarass, "Formen Staatlicher Einwirkung," p. 517.

75. Nau, National Politics, p. 87.

76. Winnacker and Wirtz, Nuclear Energy, p. 106.

77. Nau, National Politics, p. 87.

78. This argument is presented by Nau, Ibid., 257.

PART III

TECHNOLOGICAL CHOICES AND THE DEVELOPMENT OF THE HIGH TEMPERATURE REACTOR

The next four chapters center on the development of the pebble bed high temperature reactor in the Federal Republic. The first part of the thesis, Chapter One, set out ideas about how technological choices are made. It stressed that although economic factors often seem compelling for explaining the path of technological development, one should pay attention to the underlying political-organizational factors because the economic context is often defined by the political context. To study technological choices, the focus should be on the phases of policy development for a technology and on the roles of individual actors and changing objectives within these phases.

Part II used this framework to look at overall German nuclear policy since 1955. Chapter Two proposed three phases of development in the German nuclear reactor program and looked at the changing objectives over these phases. Chapter Three focused on the institutional side of German nuclear policy-making in terms of (a) how the institutions were established and continue to have an impact on policy, and (b) how responsibilities are divided among the manufacturing, utility and government

sectors. For the first generation of nuclear reactors in West Germany -- i.e., the light water reactors -- the utilities played an especially significant role. We saw, however, that the reason for this was not that economic interests are necessarily the best determinant of reactor choices, but that the government and manufacturing firms unwittingly conceded a scope of activities to the utilities which the utilities gladly filled. The market may determine the choice of reactors in certain stages of development, but it is not a good measure for the R&D stage because economic considerations are limited in their applicability then. Part II gives us several assumptions to consider for nuclear policy subsequent to the first generation LWRs.

Part III, therefore, uses the framework of Part I and the assumptions from Part II to look at one second generation nuclear reactor in depth, namely the HTR. In focusing on one technology, we can be more specific in our analysis and see better the development within each of the sectors, not just among them. We can also focus more on the relationship of the stage of a technology and the policy choices made. Given the complexity of advanced technologies, it is nearly impossible to keep the involvement of actors distinct for certain stages. The distinction between the R&D and commercialization stages of technological development is not particularly meaningful

because the two are so closely linked. It makes no sense to argue that economic factors should determine technological choices once commercialization nears because by then political factors have influenced development to such an extent that they will not disapper. Political factors have a lasting impact. The key to technological choices for advanced technologies lies in seeing how the actors interact and adapt to conditions.

The organization of Part III parallels that of Part II: Chapter Four gives an overview of HTR development; Chapters Five, Six and Seven look at the roles of specific actors and the interactions among the manufacturing, utility and government sectors. Part III strengthens the conclusion from Part II that the market is not a good gauge on which to rely for technological choices; here the reason is not only due to the developments that occur in the R&D and demonstration stages preceding commercialization but even more importantly due to the wealth of HTR options which were available. Cost comparisons of diverse technological possibilities proved to be very difficult. For the HTRs, economic calculations were used more to decide when to drop certain options than to decide which ones were best. We argue that the important issue with technological choices is not to identify the "best" or most "economical" technology, but to see how choices are narrowed. The biggest challenge for

the policy actors is to cooperative effectively to narrow the choices and concentrate developmental efforts.

Chapter Four presents the changing objectives which have influenced the HTR. Commercialization has always been more remote than it was with the light water reactors, and that affected the perspectives of the various actors. The actors gradually learned that they would have to work together to develop the HTR, given the lack of any possible international partners, if the reactor were to stand any chance of success.

Chapter Five explores the development of the first experimental HTR, the 15 MW AVR. The focus is on the struggles within each sector about early HTR development, on the individuals involved, and on the special significance of the Land North Rhine-Westphalia. The role of the utilities was less significant for the HTR than for the light water reactor. In addition, the claim that the Germans insisted on developing the pebble bed HTR alone is shown to be overstated. Some national pride was involved, but there were also circumstantial reasons why the Germans were not involved in an international partnership. The early years of HTR history are important because they still have an impact on present working relationships.

Chapter Six focuses on the 300 MW prototype thorium high temperature reactor (THTR). Construction for the reactor began in 1971 but is not scheduled for completion until 1984 at the earliest. Development has been plagued by political problems, licensing problems and an inability to narrow options concerning a THTR follow-up project. In the late 1960s, the actors involved with HTR policy saw the need to narrow HTR options, but they tried to do so unilaterally, i.e., within their own sectors. The disputes within the manufacturing sector were especially significant. Outcomes -- or the lack of outcomes -- were determined more by industrial strategy than by technological strategy.

Chapter Seven deals with HTR policy since 1975. The post-1975 period represents a radical change of attitudes on the parts of the HTR actors. After the Americans dropped out of the HTR market in 1975 because of Gulf General Atomic Company's failure, the market was left to the Germans, and the actors knew that they had to cooperate. For the first time, manufacturing firms and utilities began working together -- both within their own sectors and among sectors. The federal government played an important role in facilitating communication. Nonetheless, the willingness to cooperate does not guarantee success, and the attempts to move to a narrowing of technological options and the possibility of commercialization

still present problems. The actors, however, have learned certain lessons about reactor development strategy, for example that it is best to proceed incrementally and stress practical projects rather than more sophisticated R&D projects which take too long to realize.

CHAPTER FOUR

THE H.T.R: CHANGING OBJECTIVES AND MARKET CALCULATIONS

After 1955, the German government and industrialists wanted to make the German reactor industry internationally competitive. Given the success of the American light water reactors in the mid-1960s, however, the Germans decided that they could not match skills with the Americans for the first generation LWRs. Instead, they placed emphasis on the next generation of reactors, namely the high temperature and fast breeder reactors. The HTR, at least in the pebble bed design pursued by the Germans, was a solely German design. Because of this and because of the German wish to be internationally competitive, the HTR provides an example of a technology in which we might expect the government's stakes in the technology's success to be high. The questions that interest us are to what extent is it true that the government had a special interest and what influence can the government exert in such a situation?

The last two chapters on overall German nuclear policy indicated how German attitudes toward the market determination of technological development and the commercial possibilities of LWRs combined to limit the government's influence. The HTR example allows us to see how applicable

these limitations are when governmental interest in a technology is seemingly high. To examine this issue, we need first to examine carefully the nature of the government's interest to see if it is indeed high; then we have to look at the interactions of the policy actors, not only between the business-state sectors, but also within them. To put the issue in terms of our theoretical framework, we will be looking again at the balance of market and political-organizational factors, but the analysis will dwell more on disputes and agreements within individual sectors. Specifically, we want to see how market factors have affected decisions about the HTR since commercialization has always been more distant than it was for LWRs.

In this chapter we will first explain what the high temperature reactor is and why it is attractive to the Germans. Then we will outline several reasons why the HTR is a good case study for seeing how technological choices are made. Finally, in the major part of the chapter we will relate HTR developments to overall German nuclear policy by seeing how applicable the three phases of development from Chapter Two are for HTR policy. With commercialization possibilities more remote than with first generation LWRs, the HTRs are less subject to market considerations. We want to see how this influences the decisions of policy actors. The

utilities, for example, have not been as instrumental in steering HTR development as they were with LWRs, but the eventual success of the HTRs may still hinge on greater utility commitments because they are the potential funders. The HTR case offers an opportunity to see how technological choices are affected when development in the R&D and demonstration stages lasts longer than it did with the LWRs. The LWRs moved rapidly to the commercialization stage.

Like Chapter Two, this chapter focuses on changing objectives in German nuclear policy, but it lets us see the effects of such changes when development stretches out over a longer period. This chapter also reinforces the argument that the market approach is an inadequate guide for explaining how technological choices are made; market factors are critical for development at a certain point, but that point often comes late in the development of a technology. This chapter stresses that market factors have to be understood in the context of political-organizational factors. The three chapters following this one go into greater detail to show how the political-organizational factors became relevant and how they shaped overall policy.

DEVELOPMENT OF THE HIGH TEMPERATURE REACTOR

The development of the high temperature reactor in

the Federal Republic is closely associated with the nuclear research center at Jülich (KFA) and the Land North Rhine-Westphalia. Industrially, the primary actors are Brown Boveri and Cie as the reactor manufacturer and a group of small electrical utilities as the orderers and operators. The reactors in the German HTR program are a 15 MW experimental reactor, the AVR (Arbeitsgemeinschaft Versuchsreaktor), at the KFA and a 300 MW demonstration reactor, the THTR (thorium high temperature reactor), being constructed at Hamm-Uentrop. Discussion continues within government, industry and the nuclear research centers about the next phase after the completion of the THTR. Both the AVR and THTR have utilized the German-developed pebble bed reactor design, and this design has continued to receive support, at least until late 1981, at all levels -- government, science, reactor construction industry, utilities -- despite the lack of any serious interest in ordering the pebble bed HTR outside of the Federal Republic.

The 15 MW AVR reactor is the only experimental high temperature reactor still in operation in the world. The other two experimental reactors, the 20 MW British Dragon reactor and the 40 MW American Peach Bottom reactor, have both been shut down. Two HTRs beyond the experimental stage have been or are being built: the 330 MW reactor at Fort St. Vrain, Colorado was constructed in a

remarkably short time between 1968 and 1974, but was then plagued with operating difficulties which have finally been overcome; the THTR-300 has been under construction since 1972 in the Federal Republic but will be completed in 1984 at the earliest. For several years the THTR has been within three years of completion, but new licensing requirements keep delaying any further progress. The AVR, in any case, has been in operation since 1966 and it has been remarkably successful.[1]

High temperature reactors were just one of many reactor systems being considered in the 1950s. Nearly every reactor system had been discussed by pioneering scientists in the 1940s and the attributes of a good system were widely recognized. According to Edwin Shaw, an analyst from the EEC:

> There was no secret about the attributes that should be looked for. In addition to being self-sustaining as far as the basic chain reactor was concerned, a good power reactor would have a high temperature outlet fluid, an economic use of neutrons so that the majority of spare neutrons could be used to produce new fuel, high burn-ups of fuel to minimize fuel handling costs, compact and simple engineering design, stability of the materials employed, and no supply problems.[2]

The HTR, in fact, was developed as an improvement on Great Britain's Calder Hall type advanced gas reactors (AGRs). The Calder Hall reactors had the disadvantages of low steam temperatures and very large dimensions which were necessary because of the use of natural uranium and graphite.

The AGRs demanded large capital investments, and their low efficiency made them uncompetitive with conventional power plants.[3]

The high temperature reactors, on the other hand, were designed more compactly, achieved higher gas outlet temperatures, and used nuclear fuel more efficiently. A 1977 International Atomic Energy Agency report cited the potential advantages of the HTR:[4]

> (1) It also shows great flexibility in the mode of fuelling, allowing an adaptation to various boundary conditions such as availability or non-availability of highly enriched uranium, existence or non-existence of a closed fuel cycle, etc.
>
> (2) The HTR system offers a good potential for adoption to very strict safety standards.
>
> (3) The HTR system permits using either the indirect steam cycle or the direct cycle with a closed helium turbine. Dry air cooling can be employed without major economic penalties, especially in the case of the direct helium cycle.
>
> (4) The HTR system has the unique and proven potential to supply helium of 950-1000°C, and of even higher temperatures if the necessary materials become available. This permits the direct use of nuclear heat for the production of gaseous or liquid secondary fuels from coal and other fossil fuels. On a more extended time scale thermochemical water splitting seems a realistic goal, opening an enormous new market for nuclear energy.

The development of the HTRs suffered somewhat because of the early success of the LWRs and the expected future role of the fast breeder reactors, but starting in the

1970s the possibility of process heat and coal gasification applications had made the HTRs more attractive again. Such applications would allow HTRs to contribute to more than just electricity needs; the importance of these additional uses is particularly relevant to the post-1975 era.

The question remains, though, why the Germans chose to focus on the pebble bed design rather than on block fuel-elements. The German-designed HTRs used pebbles for nuclear fuel; elsewhere, in HTRs relying on block fuel-element designs, prismatic fuel was used. The main differences in the design of the pebble bed and prismatic cores are the loading and unloading systems and the control rod systems.[5] Each system has certain advantages: the prismatic core reactor allows better accessibility to the individual fuel element and it has a more conventional control rod system; the pebble bed reactor can be refueled without shutting it off, it gives great flexibility in the types of nuclear fuel it can use, and it has the potential of reaching higher outlet temperatures with a fixed maximum fuel temperature.[6] This opens the way for other uses in addition to electricity production.

Several German nuclear experts felt that the Dragon and Peach Bottom experimental HTRs in the U.K. and U.S. were overly influenced by light water reactor developments,

and that the German AVR was designed from a more logical overall point of view.[7] German HTR experts, however, have never claimed that their pebble bed reactor is better or worse than the block fuel-element designs. They have preferred to welcome the development of both reactors. In brief, the Germans do not maintain that there were significant reasons for emphasizing the pebble bed design. They made a choice, but the choice could have been different.

No one was convinced that the pebble bed was the ultimate reactor or the only course to follow, but it was seen as a suitable technical alternative for the Federal Republic. The Germans felt that they trailed other Western nations so much in terms of first generation light water reactors that the best strategy for catching up would be to concentrate efforts on second generation reactors like the HTRs. When the AVR project was launched, it was independent of any other HTR work elsewhere in the world.[8] Moreover, the technological gap caused the reactor manufacturers, BBC/Krupp, to follow an innovative strategy -- for instance, (a) the fuel load system used pebble-shaped balls, (b) the transfer of heat to the steam cycle was done through conventional steam generators, and (c) the fuel cycle relied on ceramic materials rather than metal coating so that efficient operation would not be dependent on reprocessing.[9]

USING THE H.T.R. AS A CASE STUDY

The high temperature reactor is a technology in which the Germans have placed high hopes for over 25 years. The pay-off has yet to be realized. Support in other countries has dropped to almost nothing, but the German interest continues. Since 1979, however, the government (through the Ministry for Research and Technology) has been demanding that some hard choices be made about the future of the HTR. The government has put pressure on the manufacturing industry and even more on the utilities to decide what future steps will be taken by the private sector to support the HTR. The government feels that the technology is set to move beyond the demonstration stage of development and hence should be less dependent on public funding.

The justifications for the reactor have changed over the course of its development. National pride was especially important at the outset because the Germans wanted above all to be internationally competitive in high technology areas such as the construction of nuclear reactors. The competition in the Federal Republic was not between designs, but between industrial actors trying to establish themselves. By 1968 and the government's third atomic program, federal support was primarily directed to advanced reactor designs such as the HTR. The HTR, however, suffered from having too many options, both

domestically and internationally. The challenge has always been to narrow these alternatives. Still, as the justifications for the HTR shifted from national pride to economic reasons and then to the reactor's applications beyond the production of electricity, the number of options has increased. This has complicated development. At the same time, though, the HTR has developed in a context relatively free of international influences; in the early years the government guarded against too much international involvement for fear that German ideas would not have a chance to be expressed; later, the German project was the only one being seriously pursued internationally. International factors were not responsible for any major turning points in the German HTR program as they were for the LWR program -- except between 1971-1975 and the decisions from that period have now been reversed.

For these reasons, the HTR is a good case study of how technological choices are made for an advanced technology; moreover, the HTR case can be distinguished from the LWR case for several reasons:

-- The HTR case allows us to see the role the government plays when its interests in a project seem to be high.

-- It indicates how market forces operate when the number of technological options is high.

-- It provides an example of how a technology develops when commercialization is distant.

-- It lets us assess the role of domestic considerations carefully because the German HTR developed relatively free of intervening international variables.

The paterns set out in Chapters Two and Three for the LWRs are not necessarily generalizable to West German HTR development. There were specific reasons why the utilities played such a key role for the LWRs. The HTR example demonstrates again that both the stage of development of a technology and the policy leadership in a given stage are important: the shifts between stages and between policy leaders have to be considered carefully. Market factors have not been the primary shaping force on HTR policy because the technology has not yet reached the commercial stage; the LWRs had reached that stage so the utilities could be more influential. Nonetheless, it is important to examine HTR development to see how political-organizational decisions of the past 25 years are affecting the context in which market factors will eventually be significant. It is necessary to examine the particular German circumstances which led the government, industries and utilities to work together after 1975. The HTR case provides a good example of how these three sectors interact in the light of differing and changing economic, technological and political objectives.

THREE PHASES OF DEVELOPMENT APPLIED TO THE H.T.R.

In examining overall nuclear energy policy in the

Federal Republic, we suggested three phases of development since 1955: (1) an open-ended period of development from 1955 - 1963 characterized by debate and uncertainty about objectives and directions; (2) a period of consensus from 1963 - 1973 in which market considerations guided relatively frictionless development of nuclear energy; (3) a period of opposition to nuclear energy from outside the "nuclear community" starting in late 1973 which forced a closing of ranks within the nuclear community.

These phases were utilized in Chapters Two and Three to indicate what role market considerations played in the development of overall nuclear policy. The phases have to be distinguished for the high temperature reactor, however, because market considerations have usually been subordinate to other factors. We will look specifically at the HTR case in relation to each of the phases to see how objectives have to be distinguished for HTR development. In phase one, personal relations linking firms, the research centers, the utilities and the government were important; in phase two, market factors were used to decide when to drop certain options, but they were not used to decide which options to favor; in phase three, the key motivation brining the policy actors together was a recognition that the entire HTR development might fail unless cooperative efforts were made. Technological

choices for the HTR have not been made primarily because of market considerations -- although perhaps they should have been, and perhaps the immediate next steps in development need to be made on the basis of the market.

Phase One: The Open-Ended Period of Development

The early years of nuclear energy policy in the Federal Republic were not characterized by industries and utilities making careful cost determinations of which alternatives to follow. Rather, there was a scramble to become involved with new projects so as not to be excluded from future developments. Established industries and utilities were moving into a new field which had new ministries, new laws, new research centers, new research orientations which had not been allowed by the Allied military occupation a few years earlier, substantial financial support and a competitive mood. In these early years personal relationships played a key role in determining policy -- much more than was possible later after firmer working relationships and patterns were set. The special relationships which Rudolf Schulten, the "father" of the HTR, developed with the utilities, manufacturing firms and Land government in North Rhine-Westphalia proved to be very significant for HTR development in the Federal Republic.

The motivation of the utilities to back the HTR

design arose because certain utilities saw the HTR as a means to protect their share of the electricity market. This led them to set up working relationships which then continued to influence HTR development. The utilities that first supported HTRs were not the largest German utilities. The Stadtwerke Düsseldorf, a municipal utility, played an instrumental role in ordering the AVR experimental reactor. The Stadtwerke Düsseldorf then convinced several other small municipal utilities that HTRs suited their needs: the reactors would not be as big or as expensive as LWRs.[10] These utilities were concerned about the expected shortage of coal and its rising cost. They also felt threatened by the larger utilities, such as RWE, which surrounded them and had their own lignite coal reserves.[11] Moreover, the Stadtwerke Düsseldorf was involved with the KFA Jülich from the center's outset because the utility operated the MERLIN and DIDO research reactors there. A close relationship between the municipal utility and the KFA formed early and has continued.

Industrial decisions too were often a function of the working relationships which were established. The municipal utilities had begun discussions about ordering an HTR with the German firm Babock and Wilcox which had direct connections with the British firm Babcock and Wilcox. In line with similar reactors being developed in England,

the German Babcock and Wilcox offered the utilities a 40 MW natural uranium gas-cooled graphite system. The utilities were also in contact with BBC Mannheim about acquiring a turbo-generation plant for their reactor, and it was through these contacts that the utilities first heard of the pebble bed system.[12] BBC had long been involved with turbo-generators through its parent firm in Switzerland. BBC's interest in the pebble bed HTR arose because Rudolf Schulten, one of its scientists, convinced the firm that his pebble bed design was superior to the British Calder Hall design. BBC was attracted to Schulten's proposals and was able to persuade the utilities to choose the pebble bed HTR over the Babcock and Wilcox offer.

As we will see in detail in the next chapter, government support for initial nuclear reactor designs was generous. Manufacturers and utilities wanted to establish footholds in the reactor market; for them, too, it was a new area. Government subsidies permitted the business sector to get started on nuclear R&D without having to worry about which designs were most cost efficient. The business sector was not even in a position to conduct such studies considering the newness of the field. Just as we observed with LWRs, German firms and utilities involved with HTRs relied on already established ties for developing their reactors.

Phase Two: The Period of Consensus, 1963-1973

A seeming consensus marked overall German nuclear policy for this period. Business and state sectors shared the notion that developing nuclear energy would bring benefits to the German economy, and decisions were made without any debate or disagreement. This harmony, however, did not apply on the more specific level of HTR development. The 1963-73 period of HTR development is characterized by the completion of the experimental AVR reactor and the decision to go ahead with the THTR-300 demonstration reactor. Despite the consensus among actors in the overall nuclear sector, this was the major period of competition within the German HTR sector. Decisions had to be made by both industry and utilities about reactor designs and whether to develop the reactors alone or internationally.

The role of the market for HTRs was not to decide which design was most economical, but to decide when to turn away from certain options. Firms and utilities already had their attachments to specific designs; their goal was to achieve the fastest breakthrough to commercialization. The expectation was that the race to HTR commercialization would be determined on a "winner-take-all" basis, as with the LWRs. Firms had too much self-interest to compromise on their own efforts. To the extent market factors were heeded, they were used to evaluate

individual nuclear options rather than broad overall policy. The Germans -- and this includes the government as well as the industries and utilities -- were not using market factors to select between reactor systems. They were not even that eager to use them to differentiate between the competing lines of high temperature reactors. They were willing, however, to evaluate individual approaches, such as GHH's effort to develop a direct-cycle high temperature reactor, from a market perspective. GHH eventually dropped this line of development when it proved uneconomical. GHH had agreed to build the reactors at a fixed cost, but they had seriously underestimated the technical difficulties and the expenses of producing a new fuel element.[13] GHH had moved too quickly in offering a fixed price contract, and when the economic losses became apparent, they dropped out of the HTR manufacturing field. Market considerations contributed to the turning away from options.

The key for the business sector was always what the prospects of commercialization were, but the causes of commercialization remained unclear. The Europeans held the lead in HTR research in the 1960s, but it was the U.S. firm Gulf General Atomic Company (GAC) which launched the most serious efforts at commercialization in the early 1970s. The GAC example indicates clearly how quickly the German business sector could shift

priorities when the possibility of commercialization was perceived. Gulf Oil Company joined in a partnership with the General Atomic Company in 1967 and proceeded to push the HTR vigorously in an effort to overcome the lead of the American reactor manufacturers outside the HTR field.[14] European experience in the HTR field was greater than the American experience -- e.g., in the area of gas graphite technology -- and the Europeans had all the resources necessary to commercialize the system, yet the separate countries drew back from commercialization or went to the U.S. for help.[15]

The Germans formed a partnership with GAC. One part of the explanation for this is that a replacement partner was needed for Krupp in the BBC-Krupp partnership after Krupp's financial problems forced it to drop out of the nuclear reactor area. But another part of the explanation is that BBC was lured by the chances of commercialization even though its previous efforts had not been focused on the prismatic fuel design of GAC. In any case, opting for partnership with GAC clearly meant proceeding with the prismatic design. Gulf General Atomic's success stemmed from a number of letters of intent signed in the U.S. with several utilities in 1971 for reactors ranging from 770 MW to 1160 MW.[16] The Germans had not yet completed their 300 MW THTR prototype, but they looked enviously at the Americans who already had commercial

orders. The Germans too, in their new partnership, proposed to build a 1160 MW HTR of the American design.

In retrospect, as we will see in Chapter Six, GAC far exceeded its competence in proposing to build so many high temperature reactors. When this became clear and all the orders were cancelled in 1975, the worldwide confidence in the HTR was shattered. But the failure was an industrial one rather than technological.[17] The cancellations were linked to the world-wide recession which forced utilities to cut back their growth plans, but they were also linked to the poor performance of the Fort St. Vrain reactor in Colorado. Utilities began to doubt whether large-scale HTRs were feasible. GAC had tried to more ahead too ambitiously and, in doing so, set back the possible commercial break-through for HTRs.

The lesson from this is that the timing for moving on to the next stage of technological development is critical to the technology's success. Firms and utilities were quick to jump at the prospect of HTR commercialization, but that did not mean that they were thinking in rational economic terms for the specific step being taken. Rather than relying on market calculations, GHH and GAC, for example, attempted to bulldoze their way into the market through aggressive marketing of their THR designs. When it became clear that they had overstretched their

capabilities, however, so that orders had to be cancelled, the designs themselves fell into disrepute. A reactor system cannot be successful just because of its theoretical advantages or financial potential; the timing of its development is also essential.[18] Following the GAC debacle, German interests returned to the pebble bed HTR. Its development had been slowed down but not set back irretrievably by the German interest in the prismatic fuel HTR.

The GAC failure was a reprieve for the pebble bed HTR, and the post-1975 period shows how decisions were reached in government, business and utility circles about how to proceed with HTR development. There was increasing awareness at every level that market or technical considerations alone did not determine the course of technological development.

Phase Three: Opposition and the Closing of Ranks in the Nuclear Community

Although overall nuclear energy development in the Federal Republic was directly affected by the rise of anti-nuclear groups after 1973, the situation differed for HTR development. On the one hand, ongoing projects like the THTR were slowed down considerably due to new and changing licensing requirements. On the other hand, though, the degree of coordination among the various sectors of the nuclear community increased significantly, not because of nuclear opposition but because financial

constraints on the firm level and state level forced close consultations about technological developments. The types of decisions that had to be made related to technological factors that did not arouse public opposition. They involved decisions such as what type of cycle to use and how and when to include process heat applications.

It was not the 1973 oil crisis directly which led to this new coordination, but rather the 1975 GAC failure which compelled the Federal Republic to ponder whether the HTR should be pursued at all. All the relevant actors seemed to be more aware of the complexities involved in developing the HTR technology, and thus they were willing to pay more attention to the timing and practical feasibility of subsequent stages. Technological coordination on a broad level was carried out for the first time; the actors recognized the need for common approaches. Instead of stressing self-interest or attempting to calculate which approach was most economical, the actors were prepared to decide with one another what technological choices to make. HTR development has benefitted from this coordination.

The basic thrust of the post-1975 period has been to develop a common strategy for the HTR. For several years, the various actors had been aware of the problem confronting

the HTR system: there were too many options. The actors, however, had tried to remedy the situation unilaterally. On the industry side, BBC decided that partnership with Gulf General Atomic Company was the best route -- it meant focusing on the U.S. prismatic fuel design. A BBC report in 1972 claimed, "All other firms in Europe which have been suggested as partners would be unable to contribute anything to the expansion of present knowledge at Hochtemperatur-Reactorbau" (the name given to the BBC-Gulf General Atomic Company subsidiary which succeeded BBC-Krupp after Krupp's withdrawal).[19] The utilities had also responded to the HTR commercial sales in the U.S. by joining together in a company, Euro-HKG, with other European utilities to study the HTR's economic prospects, but this move came too late to enable European industry to regroup for winning commercial orders.[20] The federal government made an effort to consolidate projects by using its Third Atomic Program in 1968 to encourage BBC-Krupp and GHH to merge efforts in the HTR field. The government was also willing to support the BBC-Gulf Atomic Company partnership, even though it curtailed chances for the pebble bed HTR, because the government recognized the need to narrow the number of HTR projects.

After 1975 the different sectors were able to coordinate their desire to narrow options. Industry, the utilities, the government, and the KFA Jülich sat down together

to work out future plans. Several factors were essential for this relationship. In the first place, the energy situation after the 1973 oil crisis changed the orientation of the government's nuclear policy. In the federal government's Fourth Atomic Program in 1973, energy needs were stressed over the need to make the German nuclear industry competitive for the first time.[21] In the second place, the government made it clear that funding for all the HTR alternative projects would not be continued. Third, the HTR became more attractive because of its applications beyond electricity production. There was more talk of the relationship between "Kohle and Kernenergie" -- i.e., coal and nuclear power.

Fourth, on the industrial side, BBC was joined by the dominant nuclear manufacturing group, Kraftwerk Union, which had developed its interest in the HTR through process heat applications. Since the HTR development after 1975 focused both on electricity production and process heat, the BBC and KWU industrial groups could pursue their interests without directly competing with each other. A direct working relationship was set up between the BBC and KWU groups (i.e., including their subsidiaries) so that the HTR line is now being developed jointly by them.[22] The inclusion of KWU was not totally welcomed by BBC, but BBC had to accede to licensing their know-how because the utilities wanted the stronger financial backing of the

KWU group for the support of the line of reactors since the reactors were new.[23]

The coordination among the actors started as a result of a governmental initiative in 1976 from the Ministry for Research and Technology (BMFT). After the GAC pull-out from the HTR development, the BMFT wanted to accelerate the decision about what to do next. The ministry wanted to decrease its financial involvement and rely more on the private sector, but it was dissatisfied with the progress being made by the utilities regarding the next step. On February 23-24, 1976, the Ministry sponsored a meeting at Dernbach about the future of the HTR. The group decided that (1) HTR development should be continued, (2) the construction of the THTR-300 prototype should be completed, (3) a viable reactor manufacturing industry should be maintained, and (4) there should be agreement on one unified concept for future HTR work.[24]

This Dernbach meeting was a critical turning point for HTR development in the Federal Republic. Industry and the utilities welcomed the BMFT's initiative. The Ministry drew on its own expertise -- unlike the early years of nuclear development when it had relied primarily on the advice of industry -- and it was willing to play an active coordinating role. For example, the Ministry

set up the "Projektträger HTR"[25] which facilitates work on the HTR and reports directly to the BMFT. The Ministry was able to force the utilities to support HTR development by threatening to withdraw all support if no interest was shown by the utilities in the reactor. At first, the utilities were not willing to talk to one another or to the other actors, but gradually everyone realized how they were benefitting from the experiences of the others.[26] For example, the experiences of the utilities with not only nuclear reactors but also with conventional power stations were particularly valuable because even small details, such as cable location for servicing, turned out to be important for the overall reactor design plans. The cooperation led to some critical decisions: (1) the market introduction of an HTR system for both process heat and electricity production as a long term goal would be the focal point of development, but (2) there would be a compromise on the THTR successor to use a steam-cycle design (rather than the helium gas-turbine design) with no process heat application.[27] In other words, a balance was struck between demonstrating how far advanced the technology was (with all the accompanying licensing problems) and minimizing risks of not being able to complete the project.

In this third phase of nuclear energy policy, then, market objectives were incorporated into a larger framework

which showed a better understanding of the complexities of technological development. Many of the options were feasible, but the question was which ones to emphasize. The failure of the Gulf General Atomic Company in 1975 highlighted for the German actors that a new orientation or development strategy for the HTR was necessary, and this orientation had to be agreed upon by the actors. The actors became more aware of the uncertainties involved with the development of advanced technologies and, thus, they were more amendable to sharing the risks. Moreover, as the applications beyond electricity production became more practical, the coal and gas companies as well as the chemical industry developed more interest in the HTR. This made coordination even more imperative, but it also increased the possibilities of success for the HTR.

CONCLUSION

Economic factors were less critical for HTR development in the Federal Republic than for LWR development, for commercialization was not imminent and thus the policy actors, especially utilities, were less inclined to "jump on the bandwagon" to place orders as they had done for LWRs. HTR development in West Germany was influenced more by domestic factors than by international conditions which had been most critical in LWR development. The HTR is a reactor still in the R&D stage, and hence the effect

on the marketability of specific designs has been less determinative. Market factors were more important in decisions against certain options than in making choices for the overall path of development. They also were used more for assessing individual technologies than for making comparative analyses.

Overall, the period of development for the HTR since 1955 has been a learning experience in which reactor manufacturers, utilities, the KFA and the government have recognized the need to work together. Genuine cooperation first became evident after the 1976 Dernbach meeting convened by the BMFT to discuss the future of the HTR. During this period, the actors have learned that it is rare that a unique technological choice appears: more often, there are several feasible options. The problem is deciding how to concentrate efforts, and market factors alone do not suffice for this because they do not solve the problems of which reactor design, which nuclear fuel, which control rods, etc., should be pursued.

The actors gradually came to recognize that choosing a common strategy was more essential than trying to identify the best technological or economical alternative. The actors saw the need to narrow their options, but at first they attempted to do this unilaterally -- i.e., within their own sector. The importance of the Dernbach meeting

was that it provided a forum in which the actors could coordinate efforts and reduce the options across sectors. The sobering effect of GAC's setback made the actors amenable to this coordination. Government, industry, utilities and the research institutes worked together to decide what the next step of HTR development would be. They did this on the basis of balancing priorities between designs exemplifying the highest state of technological advance and designs which were more feasible to build and license. The critical decisions since 1976 about the next step after the completion of the THTR have been made by the various actors working together.

The priority of making the German nuclear industry internationally competitive was stated explicitly in the first three "Atomic Programs" of the Federal Republic. Only in the fourth program of 1973 was the priority of energy needs given more weight. Throughout the 1960s economic assessments were made only for individual options but not for comparing systems. Firms and utilities were mainly interested in keeping their options open and jockeying for position so that when the possibility of commercialization appeared they could move quickly. The problem here was that too little consideration was given to what would bring about commercialization. With LWRs, the impetus came from the United States. German firms and utilities -- and other European ones too -- seemed to be

waiting for something to happen again, and indeed the first moves to commercialization did come from the U.S. The Europeans had a lead over the Americans concerning HTR technology, but they left commercialization to the Americans. Unfortunately, Gulf General Atomic Company, the American firm, moved too quickly with its plans.

The hint of commercialization, however, created a quick rush by the French, British and Germans to the GAC design. Both the GAC case and the GHH case in the Federal Republic in the late 1960s show that the move to commercialization is often more a function of aggressive marketing than of anything else. The GAC case taught the Germans a lesson about how to make technological choices. After GAC's failure, the government moved quickly to bring all the HTR actors together to coordinate subsequent efforts. The call for the meeting at Dernbach was not startling in itself, but the actors were finally prepared to work together because they recognized that the complicated nature of HTR development required this.

We see that a learning experience took place in which firms and utilities, after an initial period of keeping options open for HTR development, decided that the time had come to narrow options. The government, i.e., the BMFT, had started with little expertise and thus could play only a limited role in the early years, but it

too had the capability of being more actively involved after 1975. In sum, a main tool needed to explain how technological choices are made is an understanding of what underlines the decision to begin narrowing options. This chapter has shown that market factors alone do not explain this. Subsequent chapters examine the process in more detail and clarify what other factors are involved.

NOTES FOR CHAPTER FOUR

1. The goals of the AVR are outlined in detail in Chapter Five, but basically the AVR was successful because it showed the feasibility of the pebble bed HTR, the high availability of the reactor, and the high outlet temperatures which could be achieved.

2. Edwin Shaw, The Three Virtues: A History of the Dragon Project, manuscript prepared for the European Commission, Brussels, September 1979; p. 54.

3. Rudolf Schulten, "Entstehungsgeichichte des AVR - Reaktors," atw (May 1966): p. 218.

4. Karl Heinz Beckurts, P. Engelmann and D. Erb, "The Gas-Cooled High Temperature Reactor," in Nuclear Power and Its Fuel Cycle Vol. 1 (Vienna: IAEA, 1977): pp. 349-67, here p. 352.

5. Ibid., p. 354. The spherical fuel elements are continuously added through pipes from the top and withdrawn through special holes at the bottom of the core (on-load refuelling). The control rods in both cases are moved into the core from the top. Stronger forces have to be applied to the control rods in the case of the pebble bed core, however, because the rods are driven directly into the bed of spherical fuel elements. Control rod guide tubes are not possible as they would perturb the flowing behavior of the pebble bed. Large-scale testing has proven the feasibility of both designs.

6. Ibid., p. 355.

7. W. Mattick and J. Bugl, "Die Hochtemperaturreaktorlinie," atw (Oct. 1973): p. 455.

8. Shaw, Three Virtues, p. 276.

9. H.W. Müller, F. Schweiger and W. Stürmer, "Probleme bei Planung und Bau des AVR-Versuchsatomkraftwerks," atw (May 1966): p. 224.

10. Interviews with Rudolf Schulten and Chrysanth Marnet, KFA and Stadtwerke Düsseldorf, Jan. 1980 and April 1981.

11. Interview with Egon Ziermann, April 1980.

12. Shaw, Three Virtues, p. 66.

13. K. Müller, "Der Hochtemperatur-Reaktor," FAZ May 28, 1970.

14. Nau, National Politics, p. 208.

15. Shaw, Three Virtues, p. 409.

16. W.F. Schilling, D. Stölzl and W. Tegen, "Das 1160-MW-Hochtemperatur-Kernkraftwerk-Project," atw (Sept./Oct. 1972): p. 520.

17. Wolfgang Müller, "Was wird aus dem HTR?" atw (Nov. 1975): p. 555.

18. Ibid.

19. See "Zur HTR-Politik in der BRD," Hochtemperatur Reaktorbau GmbH, Bericht No. 72/10, Cologne, October 6, 1972, cited in Nau, National Politics, p. 210.

20. See Shaw, Three Virtues, p. 402 and Nau, National Politics, p. 210-11.

21. E. Baust and G. Wittchow, "Der Hochtemperaturreaktor -- Ergebnisse und Perspektiven," atw Vol. 24 (March 1981): pp. 147-8.

22. See, for example, atw News, No. 7, July 1978.

23. Interview 9 with government official.

24. FAZ Blick durch die Wirtschaft, March 5, 1976.

25. "Projektträger" are coordinating agencies set up by the Federal Ministry for Research and Technology to provide expertise on individual projects without having to expand the ministry's permanent staff. The agencies are an administrative extension of the ministry, but they are also integrated into a nuclear research center. More details are given in Chapter Seven.

26. Interview 9.

27. Projektträger für Hochtemperaturreaktoren (PTH), Program Status of the High Temperature Reactor Development in the Federal Republic of Germany (Report prepared by the PTH for the BMFT, Jülich, November 1979), pp. 1-6.

CHAPTER FIVE

DEVELOPMENT OF THE FIRST EXPERIMENTAL H.T.R.

This chapter and the following two chapters parallel Chapter Three in purpose, but here the subject is the high temperature reactor rather than overall policy: these chapters will examine the structural determinants behind policy by focusing on how arrangements between the institutions, actors, etc., were set up and how responsibilities were distributed. Each chapter corresponds to a specific stage of development of the HTR:* this chapter looks at how decisions were made about the 15 MW experimental high temperature reactor, the AVR (Arbeitsgemeinschaft Versuchsreaktor); Chapter Six concentrates on the demonstration 300 MW thorium high temperature reactor (THTR); Chapter Seven deals with the efforts after 1975 to determine what the follow-up project to the THTR should be.

The benefits of looking at the HTR case in detail are threefold. First, we can differentiate the HTR case from

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* It should be remembered that the three stages of development are R&D, demonstration and commercialization. The three phases of development outlined in Chapter Two are not necessarily the same as the stages. For the HTRs the phases and stages are essentially similar, but they are not for LWRs. That explains why we used the mechanism of the phases for overall development. Our point is that technological choices are influenced markedly by the stage of development of a project, and therefore the patterns from the LWR example should not be generalized too quickly.

the apparent patterns we saw in overall German nuclear policy. For example, the utilities which developed the HTR were not the most influential ones in the Federal Republic. In addition, the utilities lacked the international technological options which they had had for light water reactor commercial orders. Second, instead of describing merely the struggles among sectors, we can see the struggles within the sectors themselves. We will consider the significance of the fact that the HTR was developed initially by a manufacturing firm which did not dominate the market, by small utilities, and by one region of the country (North Rhine-Westphalia) in the early years. Third, in comparing the HTR case with overall nuclear policy, we can examine whether it was important that the pebble bed HTR was a purely German technology. In many respects, being a "Land technology" (i.e., the special project of North Rhine-Westphalia) was more critical than being a German technology.

The first part of this chapter looks at the background for the AVR experimental reactor. The main part of the chapter then examines the structural conditions underlying AVR development on a sector-by-sector basis. The pattern of technological choices for HTRs does not differ too much from the pattern for overall nuclear policy in the AVR stage, but distinctions are already visible. The divergence will become still more evident in the following periods which are covered in the next two chapters.

AN OVERVIEW OF THE A.V.R. DEVELOPMENT

The milestones in the history of the AVR can be sketched out easily. The order was placed for the reactor in 1959 by the utility group which developed the experimental reactor. This followed two years of planning, first by BBC and subsequently by a consortium between BBC and Krupp. During these two years the emphasis was on basic research and the problems associated with this new technology -- e.g., concerning fuel elements, coolants, etc. The small utilities in the AVR group also started their cooperation in 1956 and in 1958 their interest was drawn to the pebble bed reactor. The number of utilities affiliated with the group increased from nine to 16 in the 1956-59 period.[1] It was the Federal Government's agreement in 1959 to assume a major share of the financial responsibility for the reactor which stimulated the order placed by AVR. Construction on the property of the KFA Jülich could not be begun, though, until August 1961 because of legal and administrative difficulties. Both the German Atomic Law and special legal ordinances (Atomanlagenverordnung) had to be passed first. Efforts to involve Euratom in the AVR project began in 1962, and finally in April 1964 an association including Euratom, the KFA and BBC/Krupp was formed.

The 15 MW reactor went critical in August 1966 and first supplied electricity on December 17, 1967. The

goals of the reactor were to:

-- demonstrate the feasibility of HTRs with a pebble bed core;

-- test out certain main components, especially fuel elements, under HTR-specific conditions;

-- demonstrate the reliable and safe operation of high temperature reactors.[2]

Once in operation, the AVR proved extremely successful. Through the end of 1976 it achieved a strikingly high time availability of 78 percent, including the inevitable lower availability of the initial phase and shut-downs necessary to the AVR's experimental program.[3] 1976 marked the best year of operation for the AVR: availability reached 92 percent. Another significant accomplishment of the AVR was the raising of the gas outlet temperature from 750 degrees centigrade after seven years of operation to 950 degrees. Fission products in the cooling gas still remained at a low level, showing the feasibility of the HTR for both direct cycle operation and nuclear process heat.

Technological Purpose of the AVR

The AVR was an experimental reactor and the utilities which placed the order were aware of this. The utilities were looking for a reactor to test which was suitable to their needs, but they did not have a set of ideal conditions in mind. One AVR official said the decision for the HTR rested partly on fears that RWE, the largest German

utility, would swallow up the smaller firms and partly on a "fascination with the newness of the design."[4] Werner Cautius said that the decision was not just for a reactor type, but whether the utilities were going to support nuclear energy at all.[5] He felt that the Stadtwerke Düsseldorf and other municipal utilities should be involved in the development of the new technology, even though costs were not predictable. Through early involvement, the utilities could develop the expertise and personnel necessary eventually to operate the reactors.[6]

The basic development of the AVR design took place from 1956-1958 at a time when the British Calder Hall type reactor was the dominant model. The AVR attempted to overcome some of the shortcomings of the Calder Hall reactor such as the low operating temperature and the problems with seals which necessitated large container vessels for the reactor.[7] In contrast to the Dragon and Peach Bottom experimental HTRs, which focused respectively on basic HTR technology without electricity production and on the generation of electricity at a steady rate, the AVR focused mainly on fuel elements, the irradiation behavior of the fuel, and the high availability of an HTR.[8] Because of this, it was advantageous to be able to load and unload the elements while the reactor was still in operation.

In short, the pebble bed design, which allowed this, meshed particularly well with the experimental goal of the AVR. Coincidentally, being able to load the reactor continuously turned out also to have important applications in neutron physics concerning high conversion or breeding factors for nuclear reactors, but this was not foreseen at the time.[9] In contrast, the design of the reactor containment vessels ended up being unnecessarily complicated. A second container surrounded the primary container due to the danger of emission of contaminating gases, but the development of "coated particles" in the U.S. obviated this problem. The development of coated particles came too late for the AVR, however, even though construction did not begin until 1961, because design plans were already too far advanced to allow for a simpler vessel system.[10] The contract for the design study was placed by the AVR utilities with BBC/Krupp in April 1957, and the study was completed in April 1958.

The mood influencing nuclear energy in the Federal Republic was affected by the Second Geneva Atomic Conference in 1958 and by the end of the oil shortage in the same year. The surplus of oil meant that the urgency for developing nuclear technology vanished. The Geneva conference highlighted that the initial optimism about nuclear energy's competitiveness with conventional sources was overstated.[11] In addition, the Germans present in

Geneva felt that the gap separating German nuclear technology and other countries' technology had grown larger.[12]

The results of the changed conditions were that: (1) the utilities were even less willing to order nuclear reactors since they were not needed; (2) the coal industry argued against moving to nuclear energy too quickly; (3) the manufacturing firms claimed that more government guarantees were needed before they would go further with nuclear technology; and (4) the government ended up increasing its support for nuclear energy dramatically to protect its interests. The Ministry for Atomic Questions doubled the amount of operating losses it would cover for each of the five reactors in the Eltville program from DM 50 million to DM 100 million per reactor. It also made DM 400 million available for their construction, and DM 70 million available for the construction of two foreign reactors, again with operating losses up to DM 100 million to be covered.[13]

German industry was subject to criticism in these early years for lack of support for nuclear energy. According to Chrysanth Marnet of the AVR group and the Stadtwerke Düsseldorf, the Minister for Atomic Questions, Balke, urged German firms at the annual meeting of the German Atomic Forum in 1961/62 to show more initiative in the energy field.[14] Marnet also relates that the president

of Euratom, Heinz Krekeler, reproached the German industry in a speech for showing too little interest in new reactor techniques.[15] Wolf Häfele, then the project director for the fast breeder reactor at the Karlsruhe nuclear research center and now the chairman of the board at the KFA Jülich, was not as directly critical of industry, but he claimed that a new approach to technical development was needed. Instead of relying on competitive projects to determine technologies to pursue, industry, government and the research sector should work together "to establish a concentration of men and means."[16] Häfele criticized the exaggerated pessimism of the 1958-59 period, and he especially blamed the coal interests for their worries about holding their prices down.[17] In view of the special circumstances in the nuclear energy field regarding personnel, financing, organization and politics, Häfele was willing to have the state join in as a direct partner to industry and the universities.[18]

The German priority at this time was to develop the international competitiveness of its own nuclear industry. There was more emphasis on the organization of technical know-how than on energy. Even though industry may not have taken the initiatives which the government wanted, and even though the utilities showed no interest in ordering the large 100 MW experimental reactors called for in the Eltville program, the people developing the pebble

bed HTR were optimistic and pleased with their work. Schulten said in 1960, "The idea of the pebble bed HTR was born in Germany. We will be doing everything possible in the future to retain the lead we now have in the development of the HTR."[19] Schulten was not attracted by an unofficial offer by Euratom at the 1958 Geneva conference to join the Euratom project because he had too much "joy and enthusiasm" for his own project.[20]

The Isolated Development of the AVR

Although considerable work was being done on HTRs internationally, and although other German firms were quick to tie themselves into industrial arrangements with foreign partners, BBC and Krupp carried out their own HTR efforts basically only as a national project. There was little international collaboration. The Geneva Conference and a follow-up conference on gas-cooled reactors in October 1958 at the Oak Ridge National Laboratory in the U.S. revealed how much work was being done internationally on HTRs. Details were given on Oak Ridge's gas-cooled reactor, General Atomic's helium cooled reactor with metal clad fuel elements, and a pebble bed design in the U.S. for which the Battelle Institute was investigating different methods of manufacturing the fuel balls.[21] In November, the U.S. Atomic Energy Commission announced that, in response to its invitation, an order with the Bechtel Corporation and General Atomic as prime contractors had been placed for a prototype 30-40 MW HTR.[22]

In every other area of nuclear reactor development German firms aligned with American firms. These alignments involved not only Siemens and AEG with their long-time partners Westinghouse and General Electric; in addition, GHH and MAN were linked with General Atomic while Demag and Babcock were linked with Atomic International.[23] With BBC, however, the firm's involvement with advanced turbines and its Swiss parent company contributed to BBC's not having an international partner. BBC's interest in nuclear reactors turned logically to the HTR from the very start because the company was involved in the most advanced steam turbine developments and only the HTR allowed the application of this technology.[24] LWR turbines, in contrast, were based on technology which had been available since the turn of the century.

Brown Boveri in Switzerland shared interests with BBC, but the industrial situation in Switzerland was quite different. The Swiss firm decided to focus on the production of turbines. It intended to provide general engineering skills and rely on firms such as Siemens or General Electric for nuclear parts of the reactors. This did not work for BBC because it was in direct competition with Siemens in the Federal Republic and thus could not rely on competitors for a major component of its own product.[25]

BBC felt compelled to switch its interests to other reactor lines. Initially, the firm was involved with the English Babcock and Wilcox, but the shortcomings of the British reactors convinced BBC to pursue another course. The Germans were more willing to use highly enriched uranium for their HTR line, but the fuel had to be obtained from the U.S. The British wanted to avoid the enriched uranium fuel in order to insure British independence in military applications of nuclear energy. Because the German HTR was to use highly enriched uranium, it could be much more compact in design than the British natural uranium CO_2-graphite moderated reactors. BBC was convinced that its reactor line was better; therefore, it cut its relationship with the German Babcock and Wilcox (through which it had access to the British Babcock and Wilcox) and instead formed a partnership with Krupp.[26]

BBC ended up without international partners largely because arrangements with the most logical partners fell through. This was compounded by some gross miscalculations of the time and money required for developing the HTR line. One BBC official says that he doubts that the HTR direction would ever have been followed if the costs had been accurately foreseen then -- and he adds that the same is true for the fast breeder reactor.[27] Moreover, it was expected that the progress from the AVR experimental reactor to a prototype reactor to commercialization

would go quickly. These miscalculations led to Krupp's leaving the partnership in 1971.

The Germans, indeed, were not actively interested in international cooperation. The Bonn government concentrated its interest and funds on the Karlsruhe center, and it paid little attention to HTR development. Within the HTR project itself there was surprising lack of knowledge about similar work being done abroad. Chrysanth Marnet, then a physicist working for the Stadtwerke Düsseldorf and now a member of the Board, recalls that the first time he learned there was a British high temperature gas-cooled project was on a visit to Harwell, England for discussions in mid-1958 when he saw the drawing of one on the wall.[28] The German team at Jülich was only conscious of the Dragon project after the agreement had been signed and the members were asked to nominate staff to work on it; Schulten did not meet some of the key figures on the Dragon project, such as Leslie Shepard and George Lockett, until the 1958 Geneva Conference.[29]

In sum, the German HTR project remained a strictly national one mainly because of industrial decisions and not because of any particular political decisions. The government was eager to foster domestic technologies and it emphasized this in its 1957 atomic program, but

it took no steps to hinder other international cooperative agreements arranged by German firms. National pride in the pebble bed technology did not strongly influence the decision to develop the project on a domestic basis: not only did the federal government display little interest in the HTR project, but it also voiced little objection when another "German" technology, the Siemens heavy water reactor, was dropped. The federal government knew almost nothing about the AVR until the research study plan was completed and requests were made for federal funding assistance in the construction of the reactor.

The interests of the Land North Rhine-Westphalia appear to be more critical than national interests for explaining the pebble bed reactor's progress. The Land felt itself in competition with the federal research interests in southern Germany. Some NRW officials were upset and envious that much of the nuclear research was being carried out south of what they called the "Weiss-Wurst" (white wurst) equator.[30] The northerners, in other words, felt better qualified to lead German research. Moreover, North Rhine-Westphalia had been the birthplace of German industrialization, remained its industrial heartland, and the NRW government wanted very much to guarantee its role for the future. The Land consequently encouraged the HTR actively both

through funding and through providing a site for the new Jülich research center including the first experimental reactors.

STRUCTURAL CONDITIONS UNDERLYING THE A.V.R. DEVELOPMENT

The imprint of certain people and firms on the early phases of the AVR is striking. They were responsible in large part for establishing the working relations that persist to the present. The possibility of such an impact existed because the high temperature reactor technology was so new -- as were the attitudes and arrangements within the Federal Republic. Later, when policy directions were more defined, individual actors could not exert similar influence. As an acknowledgement of the role played by individuals, the nuclear industry brochure published to commemorate 10 years of service by the AVR even begins by listing on its first page four key personalities affecting the AVR development: (1) Rudolf Schulten, the present director of the Institute for Reactor Development at the KFA who is not only the father of the pebble bed reactor, but also the person who has guided its development for 25 years; (2) Werner Cautius, the managing director of the AVR utility group and one of the directors of the Stadtwerke Düsseldorf (the Düsseldorf municipal utility); (3) Leo Brandt, the state secretary of North Rhine-Westphalia who was always the strongest proponent of the

HTR in Bonn; and (4) Wilhelm Engel, general director of the Stadtwerke Düsseldorf (and friend of Leo Brandt) who also supervised installation of the two research reactors at the KFA.[31]

Schulten developed the idea of a German pebble bed reactor. Formerly a student of Werner Heisenberg, the scientist who conceived the present idea of the structure of atomic nuclei, Schulten had been one of the first scientists working on reactor development at the Max Planck Institute in Göttingen. When the Federal Republic was permitted to resume nuclear research in 1955 he had moved on to work on reactors for BBC. Similarly, Siemens and AEG also turned to the Max Planck Institute group for the scientists to head their research.[32] Other scientists who were affiliated with the Göttingen group and who subsequently played important roles in German nuclear policy included Karl Heinz Beckurts and Wolf Häfele.

Although Winnacker and Wirtz in their book on German nuclear energy credit Schulten with "the initially surprising idea of a high temperature reactor,"[33] he was not the first to propose a pebble bed design. The United States considered the concept in the 1940s, and the U.S. Bureau of Mines considered applications of process heat in the early 1950s. The Oak Ridge National

Laboratory even took out a patent on the pebble bed reactor shortly before the West Germans were able to begin nuclear research again. The problem was that there was also a debate concerning whether to follow the pebble bed or prismatic design. In contrast to the Germans, the U.S. concluded in the late 1950s that higher temperatures could be achieved with the prismatic design so it was selected as the focus of the HTR program.

British consideration of the HTR started with Stefan Bauer's ideas in 1948-49 about a gas-cooled reactor with a fuel bed of beryllium oxide balls coated with uranium and recoated with beryllium oxide. Along more conventional lines, there were evaluations for the Navy of a helium-cooled graphite-moderated reactor as a possible submarine propulsion unit. This research, with modifications, led to the decision to build the Calder Hall reactors.[34] Nonethless, even though the pebble bed HTR was not just Schulten's idea, he has always been the key figure involved with the German project, first as a scientist at BBC, then as one of the two managers in the BBC-Krupp partnership, and then as head of the HTR project at the KFA Jülich.

Cautius was the motivating force behind the utilities. He was connected with the Stadtwerke Düsseldorf which was engaged in a quarrel between small and large

electrical utilities about how electricity should be produced. The large utilities felt that it was cheaper to ship coal a long distance and then produce electricity whereas the small utilities advocated producing electricty at a local utility and then transporting it. Cautius was eager to prove that the small utilities could be competitive. Thus, under his guidance the Stadtwerke Düsseldorf took the lead in 1956 in bringing together several small utilities into the AVR group. Their interest was in the British Magnox reactor, but Schulten convinced Cautius that the pebble bed HTR would be preferable to the Magnox reactor. Schulten had spent time in Harwell England observing the natural uranium reactor there, and he felt that several improvements were needed which he set out to achieve with the pebble bed design. In Schulten's words, Cautius was smitten with "love at first sight" for the HTR.[35] Cautius immediately agreed to proceed with Schulten's pebble bed design, and a warm friendship between Cautius and Schulten ensued. This was at a time when, according to the Mannheimer Morgan, very few experts placed any confidence in the HTR.[36]

Leo Brandt, in the meantime, recognized the significance of the HTR and became its chief political backer both in North Rhine-Westphalia and Bonn. He was a man who, according to the German financial news-

paper, Handelsblatt, "contributed more to the support of research than anyone in any other German Land."[37]

> Minister-Presidents of the Land changed, but Leo Brandt remained and simply changed ministries. First in the Ministry for Economics, then in the Ministry for Cultural Affairs, later directly under the Minister-President, he had his "working group for research" which -- if one is permitted to say so -- was a combination of the most honorable, selfless and effective lobby in Germany.[38]

Although Leo Brandt was an SPD man, he really was viewed as above politics by all the German parties. A CDU Minister-President of North Rhine-Westphalia, Karl Arnoldt, was responsible for bringing Brandt into the government in the mid-1950s. Brandt, who during the war had worked on the development of German radar systems for Telefunken, had been the head of one of Düsseldorf's two municipal companies, the Rheinbahn, before he joined the Land government. Wilhelm Engel was the head of the other company, Stadtwerke Düsseldorf, and he and Brandt continued their close working relations for several years. The ruling parties in NRW changed often, but every government kept Leo Brandt in office. He was extremely open-minded about innovative ideas, and it was with him that the Land's tradition of supporting industrial research in NRW began. He also is responsible for involving NRW's universities with the research center in Jülich so that each university did not feel obligated to construct its own expensive reactor.[39]

Brandt had negotiated the research reactor agreement with the British that brought the DIDO and MERLIN reactors to Jülich; they were initial equipment for the planned nuclear research center there. He made it clear that North Rhine-Westphalia, the largest and richest Land in the Federal Republic, intended to play a special role in the atomic field.[40] After Schulten and Brandt discovered their shared interests, the focal point of this special role for North Rhine-Westphalia became the HTR.

These individuals played a key role in initiating the working relationships among business, the government and the scientific community. The links between the people were not inevitable, but they were based on personal friendships and common interests. Nuclear energy was a totally new field in the Federal Republic, and everyone was pondering which directions to take. Still, individuals alone did not make policy because the major institutional actors also had interests at stake that merit consideration.

The Electrical Utilities and the AVR

The utilities in the AVR group were interested in a simple design which they could afford to build and operate. The HTRs represented one possibility which seemed particularly appropriate for reactors in the 100-300 MW range favored by the smaller utilities. One can

ask why the largest utilities, especially RWE, never adopted the HTR. Part of the answer relates to the advantages of the already established LWRs which the large utilities saw, but another part of the answer had nothing to do with technological assessment.[41] In fact, the then chancellor, Konrad Adenauer, influenced the decision somewhat. As the former mayor of Cologne, he had a special interest in the small municipal utilities comprising the AVR group. He had long familiarity with their problems since he came from the area. In the mid-1950s the German railway system, the Bundesbahn, was being electrified, and some of the technical decisions which had to be made carried political impact. A decision had to be made whether the electricity should be 50 herz or 16 2/3 herz. If 50 herz had been selected, only RWE could have produced the electricity. The choice of 16 2/3 herz meant, however, that the federal railway could build its own electrical network in which the smaller utilities would play a role.

The decision for 16 2/3 herz was made on the basis of a joint offer by the Stadtwerke Düsseldorf and the German Bundesbahn for a power station along the Rhine in Düsseldorf. Acceptance of the offer implied that subsequent development would all be 16 2/3 herz. RWE was not happy with the decision, which Adenauer and Leo Brandt helped to push through, even though some had

expected Adenauer to favor RWE because the father of his son-in-law was chairman of the board at RWE (H. Werhahn). One person affiliated with the HTRs since their start claims that RWE's "angry reply" was to build the 15 MW boiling water experimental light water reactor at Kahl. Another person with similar HTR experience maintains, however, that the RWE decision was a more reasoned one: RWE was not happy and that might explain why they did not negotiate for HTR rights, but the decision really persuaded RWE to look for a better market strategy. RWE aimed for better marketing approaches and commercial attitudes and hence settled on the boiling water LWR for RWE's own experimental reactor because management saw better operating possibilities throughout the world for it.

The people doing the technical work on the pebble bed reactor were not even aware of the controversy, but some of them still feel that it led to a hostile stance on the part of the large utilities toward the HTR which persists to the present. In any case, the large utilities did place their interests in the LWRs while the smaller utilities opted for the HTRs because they felt the cost and size better met their needs. The AVR decision, though, was not a long thought-out process with a careful weighing of options -- no one saw it as the only way to go. Rather, it was a personal decision by

Cautius who viewed it as a feasible project which favored smaller facilities. One scientist who has been affiliated with the AVR from the start said flatly that the utilities did not believe that the HTR was the best technological alternative, but it had high potential and was economical on a small-size level.[42]

The interests of the Stadtwerke Düsseldorf fit naturally with the HTR on several levels. Cautius and his "love at first sight" for the HTR accounted for one level, but another level concerned the ties of the Stadtwerke Düsseldorf with the Jülich research center: the utility was installing the British research reactors. More significantly, the Stadtwerke Düsseldorf was concerned about the expected shortage and rising cost of coal because it was surrounded by bigger utilities, notably RWE, with large lignite reserves.[43] This was the major reason why the Stadtwerke Düsseldorf felt compelled to undertake a project developing an alternative energy source, and given their own small size, they preferred setting up a joint project. They felt that nuclear energy would be more economical than coal, and thus the contract for a design study was placed in April 1957 with BBC/Krupp for a 15 MW plant.

The point to note concerning the electrical utilities is the differentiation within the sector itself. There

are local utilities, regional utilities and the interconnected grid utilities which have a network across the country. (The Germans call the interconnected grid utilities the super-regional utilities.) On the regional and local level most utilities are distributors, not generators, of electricity. Some companies, however, do generate their own electricity but have no access to an interconnected grid. These companies belonged to an association -- the S.V.S., Studiengesellschaft für Verbrauchende Stromerzeuger -- of which the Stadtwerke Düsseldorf was a member. When BBC was looking for utilities which might be intrigued by the HTR, it turned to the Stadtwerke Düsseldorf because the two had had a good partnership for conventional power plants. The Stadtwerke Düsseldorf then asked the other 19 members of the S.V.S. association how many would be willing to place a design contract with the BBC. Altogether, 15 of the utilities were willing and the AVR e.V. was formed.[44]

The energy supply sources of the various utilities have an important impact on their policies. RWE is not only far bigger than any other electrical utility; it also is unique because of the soft brown coal supplies it has. As one non-RWE utility official said, "RWE's bread and butter is brown coal. Why opt for nuclear energy when you have brown coal?"[45] RWE was only willing to pursue the nuclear route when the pay-offs seemed clear. This also explains partially why RWE's interest in the HTR has

always been limited: it has enough other sources of electricity. In contrast, VEW -- another large utility although only one-fifth the size of RWE -- has a totally different energy supply. It has had to rely on Dutch gas and expensive German hard coal. This puts VEW at a disadvantage which continues today to hamper their development policies.

The situation for utilities in northern and southern Germany has always differed. The southern utilities lacked coal, and therefore they did not have the access to cheap base-load electricity which the northern utilities had in the early years of the Federal Republic. Either they had to have higher cost levels for their areas or they had to buy base-load electricity from RWE.[46] With the advent of nuclear research and the cheap oil prices which came in 1958, however, two new lines were available to the utilities: they could build oil-fired or nuclear power stations. The decisions of the various utilities should be analyzed in the context of their own resources: RWE did not want its position weakened so it was lukewarm toward nuclear reactors; the AVR utilities were anxious to establish some independence from RWE;[47] Badenwerk from southern Germany was investigating the organic-moderated reactor because of the utility's lack of coal, but the reactor did not prove feasible.

The Manufacturing Industry

On the industrial side, too, it was not the largest firms such as Siemens and AEG which became involved with the HTR, but rather medium-sized Brown Boveri & Cie through its subsidiaries. These included Brown Boveri/ Krupp Reaktorbau GmbH (BBK) -- which started off with Schulten as one of the two managing directors -- and Hochtemperatur-Reaktorbau GmbH (HRB) established in 1971 after the break-up of BBK. The subsidiaries were set up primarily for legal and tax purposes. In examining the industrial involvement with the HTR, it is more important to ask what relations were arranged between the large industrial firms and the government than to ask why BBC was involved with the pebble bed reactor. As we saw earlier, BBC had prior experience with turbogenerators; that, combined with Schulten's work on pebble bed reactors, steered them in the direction of the HTR. The LWR turbines were not sophisticated enough for BBC to be interested. Since government programs financed so much of the initial R&D work, BBC faced a relatively costless venture and that spared the firm from having to make some hard choices about the reactor's long range prospects.

One question is why BBC brought Krupp into the HTR development. A former BBC official claims that BBC felt that it could not manage the project alone because of the

costs and risks involved. The head of BBC consequently approached one of the directors of Krupp, Dr. Kallen, who accepted the idea of partnership. Krupp was singled out because it specialized in steel which was important for the construction of the reactor. No other firm was contacted.[48] A contrasting interpretation of Krupp's involvement -- and simultaneously a criticism of the course of development of the HTR -- is that Krupp was brought in at the behest of Leo Brandt.[49] Brandt wanted the HTR project to be a North Rhine-Westphalia development; hence, he wanted a local company to be involved with BBC. Brandt pushed Krupp onto BBC which had little choice but to accept it since North Rhine-Westphalia was providing such extensive support for the HTR. The two firms were equal partners and that in itself almost killed the project because of the policy conflicts that arose.[50] The same person who criticized Krupp's involvement claims that the differing philosophies of the firms delayed HTR development significantly: BBC had Swiss ties and an "international elegance" whereas Krupp was rooted in old traditions and knew nothing but the steel business.

One key aspect to note, regardless of whether the above accounts are accurate, is that common practice in German industry essentially mandated a partnership. The standard approach for building conventional power stations

had always been to order different parts of the plants such as containers or turbines from different firms. The idea of "turnkey-contracts" in which one firm is responsible for delivering a completed reactor was introduced by U.S. firms such as Bechtel.[51] BBC in the early years was hardly prepared to fill this role. It needed a partner with the kind of experience which Krupp had in producing heavy components. Together, BBC and Krupp thought they could break through to a new market, but they were unsuccessful.

Governmental support for nuclear industry in these early years reduced the need for individual firms to compete with one another and take large financial risks. The construction costs of the AVR were estimated at DM 40 million at the start of the project with the federal government and the AVR utilities each agreeing to pay DM 20 million and the government and BBK sharing overruns on a 4:1 basis. The eventual cost, however, amounted to DM 113 million so that the federal government paid DM 78.4 million, the AVR utilities DM 20 million, and BBK DM 14.6 million.[52] We saw in Chapters Two and Three that the government supported essentially every nuclear reactor proposal and thereby relieved industry from having to calculate whether it was profitable to pursue specific designs. The priority of industry in the 1955-57

period was to establish a "division of labor" between basic research supported by the state and industrial development.[53] Industry accomplished this goal primarily through its influence on the formation of the Ministry for Atomic Questions and the German Atomic Commission and, through them, on the first governmental atomic program, the Eltville program.

In sum, the way the government provided support affected subsequent developments. The uncertainty surrounding the new technology was so great that some assurances were appropriate. Government support, though, was not concentrated on increasing energy supplies per se, but rather on fostering nuclear technology. Decisions about the wisdom of certain technological possibilities were therefore left to industry rather than the government, and the government was left with administrative details.[54] Although these practices are not necessarily bad, they do mean that nuclear energy policy was not part of an overall energy policy but rather was a policy geared to the structure and demands of industry. In short, in the early years during which the AVR was being discussed and ordered, the German program adhered to the notion that technical developments are the responsibility of industry, even for nuclear energy technologies. Development was oriented to an essentially "engineering approach," and new technologies were viewed "in terms of

the realization of complete plants or customer-directed products."[55] For industry, there was a wide scope of action and a reduced incentive to narrow reactor choices.

The Government's Role

As the above section indicates, the government's influence was limited to general overall support for reactor projects. Probably the first time that the federal government in Bonn -- and, in fact, the Ministry for Atomic Questions -- was made aware of the nature of the AVR project, according to an analyst from the European Community, was in 1957 when the government was approached for assistance in funding after the AVR-commissioned design study had already been completed by BBC/Krupp.[56] The reactor was then estimated to cost only DM 40 million. A major reason for this lack of knowledge about the project was the independent status of both the Länder and the industrial organizations. Moreover, the federal government was concentrating its support on the Karlsruhe research center rather than on Jülich which Bonn viewed as an unwelcome step-child of North Rhine-Westphalia.

In the Federal Republic the independent actors and the federal structure of the administration worked against the establishment of a well-defined national policy.[57] Rather than developing in a linear fashion, policy developed

as a series of parallel activities. Government did not seek to impose a specific direction to technical development; instead, it offered support to the industrial firms which it felt had the best machinery for determining the soundest commercial lines of development.[58]

The Eltville program envisioned support for a 100 MW high temperature reactor to be built by BBC/Krupp. In the Eltville program, every firm or consortium interested in reactor construction was offered financial support and no firm had to give up anything. But not all projects were carried out under the auspices of the Eltville program: this was true for the heavy water reactor research done by Siemens and for the AVR. Because the AVR utilities (and RWE) felt that 15 MW reactors rather than 100 MW reactors should be constructed, they placed their order for the smaller design study at practically the same time that the Eltville program was devised. Government officials then stressed that the reactor would not be considered part of the program, and the design contract was given without government support.[54] Eventually, though, the utility group received the support of the government for the construction of the AVR because no orders were being placed for the larger reactors. Originally the AVR plant was intended to yield experiences to aid in the construction of a 100 MW plant along the lines of the Eltville program,

but the delays resulting from technical problems precluded this.[60] Eventually, the 300 MW THTR became the follow-up project to the AVR.

The Role of the KFA

The Landtag of North Rhine-Westphalia approved the construction of a nuclear research facility in December 1956 and in November 1957 Jülich was chosen as the site. Leo Brandt was responsible for both decisions. Not until February 1961, however, was the title Nuclear Research Center Jülich (Kernforschungsanlage Jülich e.V.) given to the facility. Although the center was involved with HTR activities from the outset, it was not really until 1966 when Rudolf Schulten was made director of the institute for reactor development at the KFA that the HTR became the clearly defined main task of the center. Thus, the influence of the KFA on the HTR in these early years was minimal, but the center offered a means for North Rhine-Westphalia to concentrate research on the HTR. The KFA has never tried to guide HTR development, but it offers a center for expertise on the reactor and has always been an effective lobbying force for HTR interests.

The Impact of the Discovery of Coated Particles

For all the differences in the HTR development on

a domestic and international level, there is one element of the HTR which drew the projects together -- coated particles. The coated particles prevent the emission of fission products of the HTRs. Both the pebble bed and the prismatic HTRs had to find complicated design solutions to overcome the danger of such emissions. The pebble bed reactor had a second container vessel -- the AVR is an example -- to protect against emissions, while the prismatic fuel HTR had a special purification loop for ventilation.

The development of coated particles was essential if HTRs were ever to become operational. Otherwise, the high level of radioactivity would have eliminated any practical applications of the reactor. The countries involved with HTRs recognized this and therefore established cooperative arrangements. For example, the KFA, the Federal Republic, the Dragon project and Euratom set up a special project on coated particles in 1959-60 and this made the links between the projects much stronger.[61] All these experimental HTRs -- Dragon, Peach Bottom and AVR -- were designed to operate without coated partciles. The breakthrough on the particles came in 1962 from U.S., British and Austrian sources.

For the Federal Republic the cooperation on coated particles was a means to increase contact with other HTR

projects. Much of this contact came through Euratom. The Germans concluded an order with Union Carbide in the U.S. in May 1964 for the fabrication of the coated particle core for the AVR.[62] The Germans were not pleased with the U.S. Atomic Energy Commission's demand for maximum technological information and know-how generated by the AVR facility. The Americans were resistent to the inclusion of Nukem, a German firm, in the fuel fabrication. The U.S. AEC wanted to put in a full core under completely controlled conditions for testing fission-product release. Eventually the Germans decided to go with a private American fuel supplier rather than the AEC, and the Germans also dropped demands to include their firm Nukem.

The development of coated particles forced the German project out of isolation.[63] At the early stages of the pebble bed design development, the Germans felt the fledgling design had a better chance to succeed as one of a few unique German designs than one of many Community projects.[64] As of 1958, estimates gave the German concept a nine month edge over British and American high temperature programs, but this had disappeared by 1960 because of the work on coated particles.[65] The Germans were compelled to join in the cooperative efforts on coated particles.

Delays in the Construction of the AVR

The design study for the AVR was completed in 1958 and the order for the reactor was placed in 1959, but construction did not begin until 1961. In 1961 it was projected that the reactor would be completed by 1964, but construction took until 1966.[66] Some of the delays were technical but others were political.

After the order for the reactor was placed, BBK needed a license for construction. The Germans had not yet passed a new law governing atomic energy so the old Allied provisions still were in force. After the new law was finally passed in December 1959 and the complementary legal statutes enacted in April 1960, the initial efforts which BBK had taken had to be started over completely.[67] The site for the reactor in Jülich could not even be opened until the summer of 1960. Then the coal companies with brown coal interests in the surrounding area threatened to hold up construction indefinitely through legal suits unless very detailed conditions for the building foundation were met.[68] Thus, the delays in the start of construction were caused by legal requirements -- which we saw in Chapters Two and Three arose because the parties worried about the nuclear defense implications of the new atomic law for the Federal Republic -- and by demands from the competitive coal firms.

Once construction began, delays arose more for technical reasons which is not surprising given the first-of-its-kind nature of the AVR. According to an article in the 1962 German Atomic Forum publication atw, BBC-Krupp had intentionally set off in creative technological directions for the HTR (e.g., regarding the way in which the reactor was fueled the fuel itself, and the heat transfer system) to try to catch up with HTR progress elsewhere.[69] Overcoming the problems of these new technologies was a learning process which necessitated continual adaptation of the AVR construction plans.[70] The main problems encountered were with the heat exchanger. which had to be rebuilt and with helium in the gas circuit, a problem which necessitated the rebuilding of all the valves.[71] The German regulatory officials were also gaining their first practical experience with the HTR and were therefore particularly demanding.[72]

The coordination of the AVR project with Euratom activities caused additional delays. Euratom was essential to the AVR at first because all arrangements for the highly enriched uranium which fueled the reactor had to be made through it. Euratom subsequently also became an important funding source for the AVR, both to supplement immediate resources and to guarantee financial support over a longer time period (five years) than German federal grants which were only annual.[73] Additional

funds were requested in 1964 from Euratom, for example, when the problems with the heat exchanger arose.

The decision to approach Euratom for funding coincided with the German government's desire to redress the low percentage of Euratom contracts placed in the Federal Republic, and although the request for an association agreement was made in 1962, a formal contract was not made until May 1964.[74] Henry Nau describes the situation on the basis of personal interviews he conducted with German and Euratom officials:

> The negotiations which took place between these dates were difficult and complex . . . . Government negotiators deferred to the influence of private German groups, especially industry; government and industrial parties dealt bilaterally with the USAEC as well as U.S. industry as a means of exerting leverage on Euratom; and German industries carefully safeguarded potentially valuable commercial information. The purpose of these policies, as in the fast reactor and participation negotiations, was to secure Euratom funds without compromising industrial freedom or becoming too dependent on what was perceived as a French-dominated Brussels bureaucracy.[75]

This attitude fits with the traditional German notion (described in Chapter Two) that technical developments should be led by industry, and nuclear energy, at least in these early years, was not an exception. The government did not try to impose specific directions on technical development, but rather to support and coordinate private industrial efforts.

In terms of delay, it should also be noted that the influence of certain people was also important. Minister Balke, for example, was more interested in the application of process heat to chemistry than in the use of thorium as a fuel for the HTR; his attitude was that the Germans had the money to finance their HTR project alone, and hence he did not favor Euratom participation.[76] One top official involved with the AVR accuses one of the other top officials of being a "fat-head" who held up work unnecessarily.[77] Altogether, the problems of obtaining rights to use highly enriched uranium, working out arrangements with Euratom and resolving personal difficulties caused two to three years of delay in the AVR at a cost of probably DM 3 million.[78] Technical problems alone did not slow the progress on the first German HTR.

CONCLUSION

This chapter on the AVR has examined the early years of HTR development and related them to overall nuclear energy policy in the Federal Republic. The HTR case differed in several important respects from the overall development. It is most striking that the utilities did not play the exclusive role they played in LWR development, although their involvement was still essential. With commercialization further off in the future and no internationally available technology competing with German

ideas, the German utilities were more willing to participate with industry in development projects.

By focusing on the development of one reactor, we also can see more the dynamics of development within each of the sectors rather than just among them. The differences of opinion among the utilities, the manufacturing firms, the research centers, and within government circles were critical for determining the direction of technological development for the HTR. It is also important to recognize which firms, utilities and areas of government ended up supporting the HTR; it was neither the largest manufacturing firms, nor the biggest utilities, nor the federal government (at least at the start). For the actors involved with the HTR, the HTR design in many ways represented an alternative to the major designs being pursued by RWE (the largest utility), Siemens and AEG (the largest reactor manufacturers -- later they combined efforts to form Kraftwerk Union), and the nuclear research center at Karlsruhe upon which federal efforts were concentrated. The structural factors outlined in Chapter Three concerning the German Atomic Commission, the Ministry for Atomic Questions, Bundestag, etc. are still relevant for HTR development, but the HTR case has to be differentiated from the overall case and the LWR case because it allows us to see how German attitudes and structural factors affected

nuclear policy in a context involving more advanced reactor technologies.

The AVR was one of several reactors being developed in the Federal Republic in the late 1950s, and the aim of initial government programs was to encourage all feasible designs. National pride was not automatically linked with the pebble bed HTR even though the reactor was often referred to as a pure German technology. The Siemens' heavy water reactor was also a German technology, but no efforts were launched to salvage it when Siemens switched its interest away from the reactor line. National pride, to the extent it existed for the HTR, came later. We should recognize, though, the important involvement of North Rhine-Westphalia in HTR development. Regional pride may well play a more significant role than national pride for the HTR. The reason for NRW's interest is closely linked with the Land's coal industry, and this link between coal and nuclear energy has continued to remain important. The HTR might well have been discontinued long ago were it not for the support of North Rhine-Westphalia.

NOTES FOR CHAPTER FIVE

1. Mannheimer Morgen, January 9, 1960.

2. 10 Jahre Stromerzeugung mit dem Kugelhaufenreaktor der AVR, report published by the firm Hochtemperaturreaktorbau (Mannheim, December, 1977), p. 3.

3. Ibid.

4. Interview with Ziermann of AVR.

5. W. Cautius, "Warum unterstützte die AVR die Hochtemperaturentwicklung?," atw (May 1966): p. 220.

6. Ibid.

7. Schulten, "Entstehungsgeschichte," p. 218.

8. Mattick and Bugl, "Die Hochtemperaturreaktorlinie," p. 456.

9. Schulten, "Entstehungsgeschichte," p. 218.

10. Müller, Schweiger, and Stürmer, "Probleme," p. 225.

11. Karsten Prüss, Kernforschungspolitik in der BRD, (Frankfurt: Suhrkamp, 1974), p. 71.

12. Wirtz, "Was brachte Genf?" atw, (November 1958): p. 418.

13. Minister Siegfried Balke, Bulletin, March 14, 1959, No. 50, p. 470 and Handelsblatt March 9, 1959, both cited in Bieber, "Kernenergienutzung in der Bundesrepublik," p. 49.

14. Chrysanth Marnet, untitled article in Zeitschrift für Kommende Wirtschaft, Number 95, April 1962.

15. Ibid.

16. Wolf Häfele, "Neuartige Wege naturwissenschaftlich-technischer Entwicklung," in Die Projektwissenschaften, Bundesministerium für Wissenschaft und Technologie, Heft 4 (1963): p. 28.

17. The saying that made the rounds then was, "Laßt uns die Kohlepreise halten, Atome mögen andere spalten," which loosely translated means "Let's hold coal prices down and let someone else split atoms." Quoted in Häfele, Ibid., p. 25.

18. Ibid., p. 28.

19. Aachener Volkszeitung, April 27, 1960.

20. Interview with R. Schulten of the KFA.

21. Shaw, Three Virtues, p. 68.

22. Ibid.

23. "Kraft durch Kugeln," Der Spiegel, Vol. 51 (December 11, 1967): p. 106.

24. Interview with R. Rumler of BBC.

25. Interview with Josef Bugl of the Bundestag, formerly with BBC.

26. Interviews with Ziermann and Marnet.

27. Interview 32 with industry representative, April 1981.

28. Cited in Shaw, Three Virtues, p. 67.

29. Ibid.

30. Interview 33 with government official, April 1981.

31. 10 Jahre Stromerzeugung, p. 2.

32. Interview 25 with utility official, April 1981.

33. Winnacker and Wirtz, Nuclear Energy, p. 241.

34. Shaw, Three Virtues, p. 55.

35. "Ein neuer Anlauf mit dem Hochtemperaturreaktor," FAZ Blick durch die Wirtschaft, June 1, 1976.

36. Mannheimer Morgen, August 17, 1959.

37. Handelsblatt, December 11, 1967.

38. Ibid.

39. The information in this paragraph is based on three interviews with AVR, KFA and NRW people.

40. Winnacker and Wirtz, Nuclear Energy, p. 91.

41. The following is based on interviews 8, 12 and 25.

42. Interview 14 with utility official, April 1980.

43. Shaw, Three Virtues, p. 65.

44. Interviews 14 and 25 with utility officials, April 1980 and April 1981: the e.V. refers to "eingetragener Verein," i.e., registered organization. Later it became the AVR G.m.b.H., "Gesellschaft mit beschränkter Haftung," i.e., it was incorporated.

45. Interview with Marnet.

46. Interview 25 with utility official, April 1981.

47. Interviews 8 and 14 with government and utility officials, January and April 1980.

48. Interview 8 with KFA official.

49. Interview 12 with a former KFA official, January 1980.

50. Ibid.

51. Interview with Hans Olivier, April 1981.

52. Cartellieri et. al., Taschenbuch für Atomfragen, 1969 (Bonn: Festland Verlag, 1969), pp. 152-3.

53. Kitschelt, "Kernenergie," p. 603.

54. Ibid., p. 605.

55. Shaw, Three Virtues, p. 272.

56. Ibid., p. 67.

57. Ibid., p. 272. Shaw says, "Traditionally, technical developments in Germany are led by industry, and nuclear energy, at least in the early years, was not considered to require any fundamental change in the established practice."

58. Ibid.

59. Otto Keck, Fast Breeder Reactor Development, p. 87.

60. Ibid., p. 92.

61. Interview with Marnet.

62. Nucleonics Week, June 4, 1964, p. 1: see also the issues of February 6 and April 30, 1964 describing the complexities of German-American negotiations.

63. Nau, National Politics, p. 196.

64. Ibid.

65. See Deutscher Forschungsdienst, Sonderbericht Kernenergie, September 27, 1960, cited in Ibid.

66. 10 Jahre Stromerzeugung.

67. Interview with Marnet.

68. Ibid. The coal companies owned mining rights to the land on which the reactor was to be built. They demanded guarantees that their coal resources would not be in any way endangered.

69. Müller et. al., "Probleme bei Planung und Bau des AVR-Versuchsatomkraftwerke," p. 224.

70. Ibid., p. 225.

71. Interview with Ziermann.

72. Müller et. al., "Probleme bei Planung und Bau," p. 225.

73. Ibid.

74. Nau, National Politics, p. 197.

75. Ibid.

76. Interview with Schulten.

77. Interview 12 with KFA official.

78. Interview with Schulten.

CHAPTER SIX

THE DEMONSTRATION STAGE OF H.T.R. DEVELOPMENT

This chapter continues the argument set out about the first small high temperature reactor, the AVR, that market reasons were not mainly responsible for technological choices concerning the pebble bed HTR. Here, the focus is on the demonstration stage of HTRs, specifically on the 300 MW thorium high temperature reactor (THTR) in Schmehausen which has been a study in frustration. German HTR policy became stalled in this demonstration stage. The construction of the prototype reactor started in 1971 and was to be completed in 1977. Now, however, the time of completion is still uncertain except that it is three years away at the earliest. The delays have been partly due to technical problems, but mainly due to continual changes in the licensing requirements and to the shift in emphasis in 1971-75 from the pebble bed to the block HTR. The main utility involved with the THTR, VEW, has grown quite discouraged and pessimistic about future HTR development.

The reasons for the snags in development in this period can be attributed to: (1) a continuation of the struggles within the individual sectors; and (2) the unwillingness of the reactor manufacturers or operators

to follow an aggressive marketing policy. In general, the development of advanced technologies goes through an initial period of broad development followed by a narrowing of alternatives; the THTR development from 1966-75 reflects how these hard decisions about narrowing choices can be avoided. Still, the frustrations of this period paved the way for a more directed and realistic policy approach beginning in 1976.

The structural arrangements which affected the AVR development continued into the THTR phase of development. The involvement of North Rhine-Westphalia remained important, but a turning point became evident in 1968 with the Third Atomic Program. Because of the worldwide breakthrough of the American LWRs, the German government put its major emphasis on advanced reactors. Despite the additional funding, though, this period still shows the Federal Republic groping for a priority. On the one hand, centralized programs, such as the British and French ones, tended to make decisions about reactors too soon. For the British and the French, making the transition from the government-directed programs to efforts led by industry and the utilities proved to be difficult.[1] The Germans and Swiss on the other hand, were more accustomed to government assistance following industrial initiative. For the Germans, it was not the transition but the choice of reactors

that provided a stumbling block: the diversity of efforts made it difficult to narrow choices.

The Germans had too many options. This was clear to several actors in nuclear policy even in the late 1960s. Still, a lack of clear purpose, a tendency to be overly ambitious regarding sophisticated technology, and pride in the pebble bed design precluded a choice being made. The government had helped to facilitate a concentration of industry in light water reactors through the formation of Kraftwerk Union. It tried to do the same for HTRs, but neither the utilities nor the manufacturers could get together successfully. American firms proved to be bolder and more aggressive. Especially from 1968-71 there were some missed opportunities regarding German HTR development which we will see. Not until 1976 was real progress made toward a consolidation of interests.

Again, the problem centered around commercialization. Rudolf Schulten has always been one of the first to stress how difficult it is to introduce a new reactor type.[2] Conflicting inclinations were unleashed among firms as commercialization approached. BBC and Krupp had different perspectives: BBC wanted to increase orders for nuclear reactors and become more competitive with KWU; Krupp was more interested in delivering parts

to the reactors. After Krupp left the partnership with BBC, BBC jumped at the chance to join with the American firm Gulf General Atomic Company because of the prospects of commercialization. In turn, though, the federal government, the NRW Land government and the KFA Jülich took steps to protect the pebble bed design, and through these steps KWU was brought into the HTR picture via the process heat application of the HTR.

The THTR case shows how essential it is to have agreement on the development strategy for a specific line of reactors such as the HTRs. Several options were feasible, but no common strategy was formulated and the THTR suffered accordingly. On an international level, the same problem plagued the Dragon project in Britain: international cooperation worked as long as everyone's ideas were pursued. As soon as Britain suggested eliminating some options, opposition arose because countries would not give up their own ideas. Similar conditions occurred within the German context, only there it was the specific companies that refused cooperation if that entailed giving up their own ideas. Through all of this, the utilities were also at a loss about which design to support. This contrasts with LWR development in which the utilities were the key decision-makers. For overall German nuclear energy policy, we

categorized the years 1963-75 as a period of consensus; for HTRs, however, the years reflect a time of infrastructural struggles and the outcomes were significant for subsequent development.

AN OVERVIEW OF THE T.H.T.R. DEVELOPMENT

The following chart summarizes the early development of the THTR:[3]

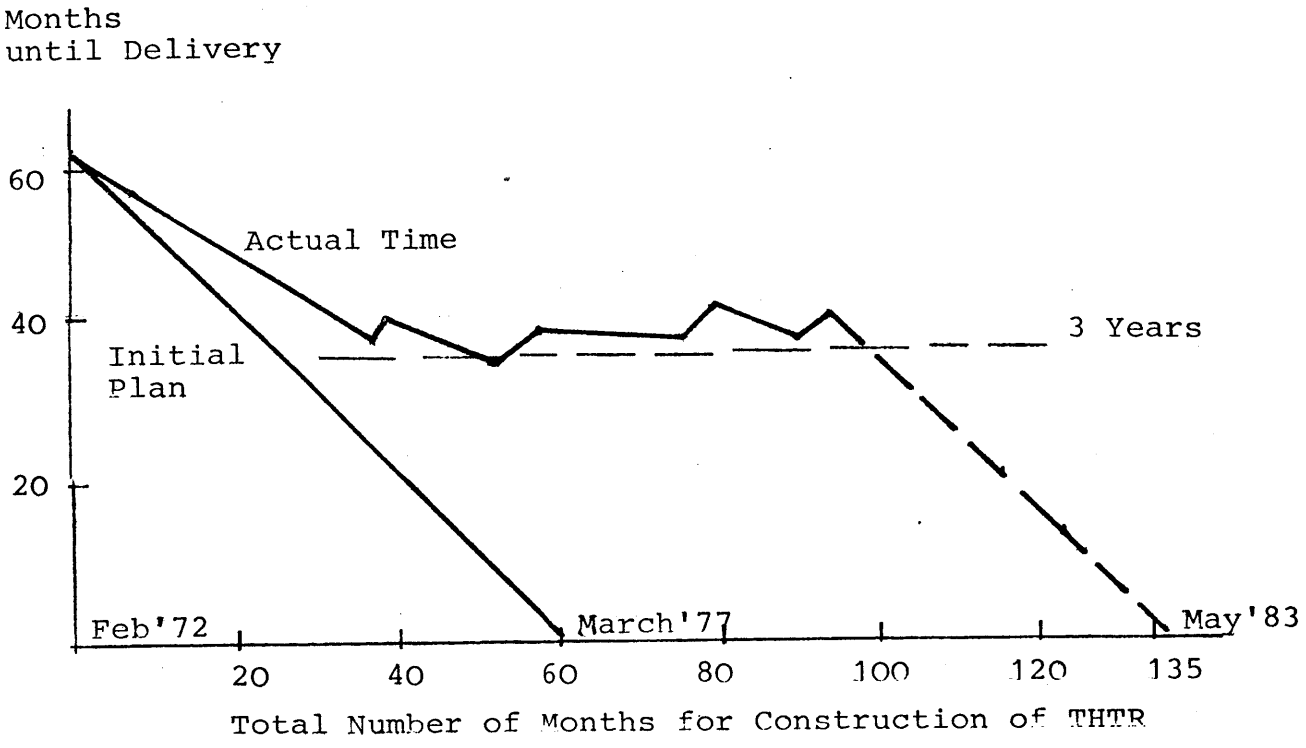
Development of the project by BBC/Krupp...1964-68
Formation of HKG utility group, Hagen...6/14/1968
Order placed for THTR offer through
the Consortium THTR-BBC-BBC/Krupp.....10/1969
Application for 1st license.....1/12/1970
Formation of HKG utility group,
Uentrop.....7/17/1970
Receipt of federal approval.....7/28/1970
Letter of intent with Consortium THTR...7/30/1970
Beginning of preliminary construction...12/1/1970
Beginning of actual construction.....2/1/1972

BBC first launched the idea of a 300 MW thorium pebble bed demonstration HTR in 1963 and started developing the project the next year. The construction of the experimental HTR, the AVR, was already underway in 1963 and BBC was looking to the future. The use of the thorium-uranium cycle also offered a means to minimize the use of enriched uranium. Euratom was interested in the potential use of thorium as a nuclear fuel; the Germans -- who were eager to recoup some of their

contributions to Euratom and expected Euratom funding for several projects in return for these contributions -- started negotiations early, involving Euratom first with fuel development and then as a contract partner in the THTR Consortium.[4] Originally the reactor was scheduled to go critical in April 1975 and be delivered to the operator in July 1976.[5]

The following chart indicates the number of months needed for construction of the reactor until actual operation could be started.[6]

Construction Time for the THTR



Since 1975 the time to completion has been basically the same -- three years.

VEW, the leading utility involved with the THTR, has grown discouraged because of the uncertainty regarding completion and costs. On the one hand, the following chart on the financing of the building project shows the low contributions of the utilities:[7]

Capital from the utility group.....3%
Long-term loans.....10%
Federal subsidies.....61%
Land (NRW) subsidies.....13%
Investment allowance.....9%
Participation of THTR Consortium.....4%

On the other hand, however, the following table shows how the costs have risen in terms of millions of D-Marks.[8]

Proposed Delivery	March 1977	Dec 1977	April 1980	Sept 1981	May 1983
Delivery Time (Months)	61	70	98	115	135
Extension of Delivery Time	--	9	28	17	20
FINANCIAL SUPPORT (Year)	1971	1973	1976	1978	1980
1. Fixed capital	50,0	50,0	70,0	75,0	75,0
2. Long term loans	126,0	175,0	215,0	232,5	232,5
3. Federal subsidies	374,0	475,0	714,5	1012,5	1435,1
4. Land subsidies	100,0	100,0	152,0	212,8	304,4
5. Additional subsidies	60,0	85,0	125,0	167,0	219,7
6. THTR consortium's share (i.e., utilities)	--	--	23,5	50,2	93,3
Total Costs	710,0	885,0	1300,0	1750,0	2360,0

This table can also be extended as of April 1981 so that delivery time would become 151 months and costs would amount to DM 3 billion.[9] The delays now add an additional DM 1 million per day to the cost of the project.[10] The causes of the delays have been not only the changing safety regulations to which the THTR has had to adapt, but also the fact that in the first half of the 1970s the pebble bed HTR was relegated to second place in the German HTR program behind the block fuel element reactor. Since 1976 there has been general agreement among all the actors involved with HTRs that the top priority in the HTR field is completion of the THTR.[11] Still, there is no certainty regarding when completion will occur.

Technological Purpose of the THTR

The THTR was conceived as the next step toward commercialization of HTRs beyond the experimental 15 MW AVR. The aim of the THTR consortium -- comprised of BBK, BBC and NUKEM with the financial participation of Euratom -- was to develop design studies for a prototype nuclear power plant.[12] These studies were completed by early 1968 for a 300 MW prototype and they envisioned an extrapolation up to 1200 MW.[13] The large reactor, assumed in 1968 as an immediate next step, was never built because of delays in the THTR and the switch of emphasis to other types of HTRs. In the construction of

the THTR-300, BBC was responsible for the overall planning, design and supply of the secondary part of the reactor (the electricity generating plant); BBK -- a partnership subsidiary formed by BBC and Krupp -- supplied the primary part (the reactor plant); and NUKEM was responsible for supplying the fuel elements.[14]

The design characteristics of the THTR are essentially similar to those of the AVR except that the reactor core and all components of the primary system are housed in a prestressed concrete pressure vessel and the core structure and control system have changed.[15] Special features of the THTR include:[16]

a) the pebble bed core with approximately 675,000 spherical fuel elements;

b) the location of the core within a graphite structure;

c) the use of helium as a coolant for the primary circuit with a temperature of 750 degrees centigrade;

d) the integration of six steam generators in a prestressed concrete pressure vessel;

e) continuous refuelling;

f) the direct insertion of 42 absorber rods into the pebble bed core (the 36 control rods move in bore holes in the graphite reflector as in the AVR).

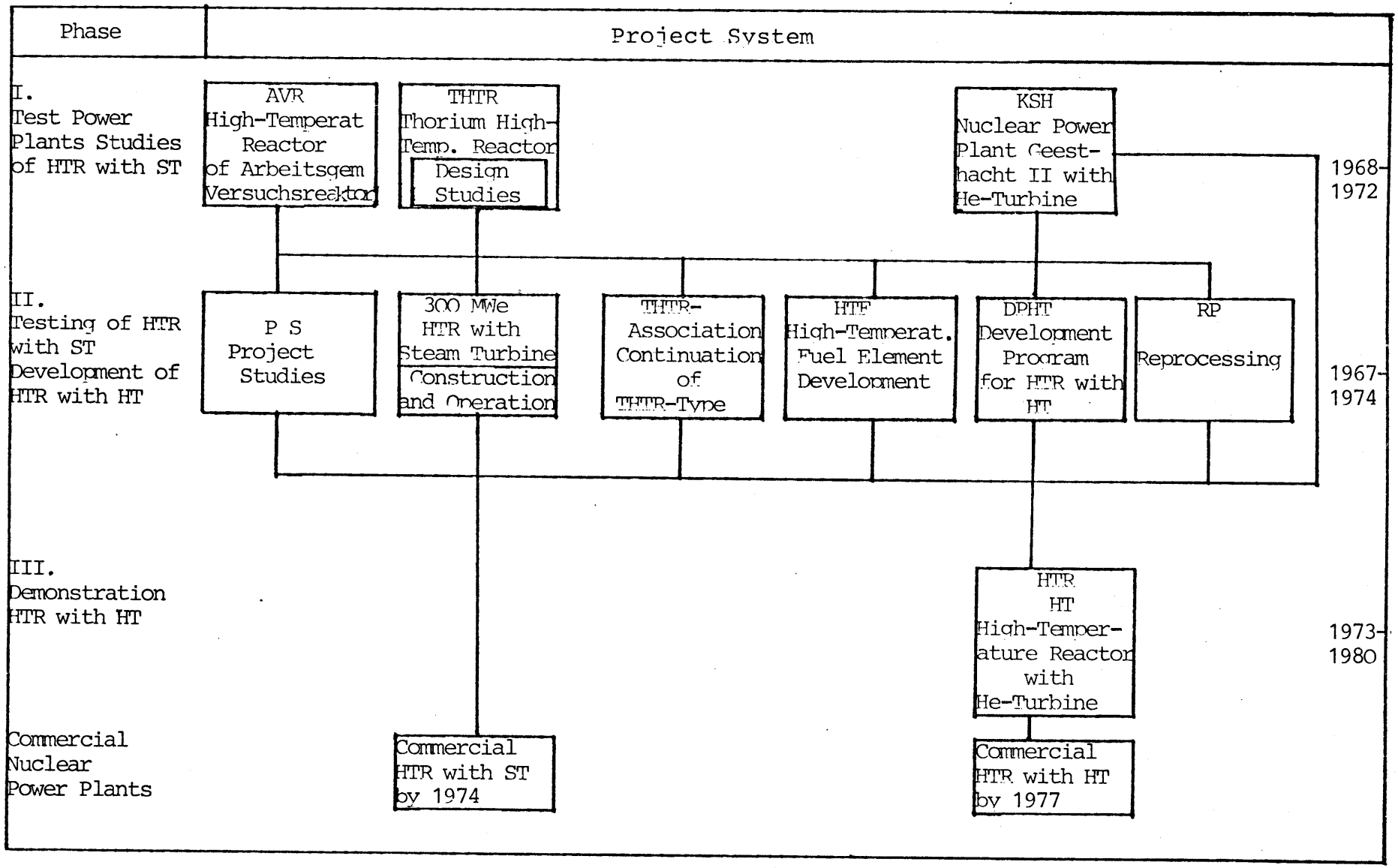
The Bonn government attached some far-reaching hopes to the THTR which also explains Bonn's willingness to finance so much of the project.[17] The new container

vessel was considered so safe that even reactor sites in heavily populated areas would be conceivable. Core melt-downs were not possible, given the design. Possible applications of process heat to the chemical industry and the future use of more efficient direct helium turbines also affected government attitudes. In sum, the pebble bed HTR had certain technological benefits to offer, and these were recognized by all the actors in German nuclear policy-making. The challenge was to convince reactor purchasers to select HTRs over the well-established LWRs.

Periods of Optimism for the HTR

In the years 1967-72, the prospects for HTRs seemed bright. In 1967-68 the Germans were optimistic that the pebble bed design would be successful. By 1971-72 its chances had diminished, but the Germans joined the rush to the American block fuel element design which appeared on the verge of commercialization. In retrospect, these years reflect a series of missed opportunities: as one official claimed, commercialization might have been possible during this period if different strategies had been followed.[18] The table on the next page indicates what expectations the Germans had for HTR development in 1968.[19] This period from 1967-71 shows how German industry was exposed in the

PROJECT HIGH TEMPERATURE REACTOR



first place to nationalist pressures to maintain the pebble bed program and in the second place to competitive pressures to cooperate internationally in marketing prismatic fuel reactors.[20] Industrial interests shifted to the international emphasis as the economic promise of the prismatic fuel reactors increased.

The optimism in German circles in 1968 about the pebble bed HTR's future stemmed from several factors. The first experimental HTR was functioning very well and design studies for the follow-up THTR prototype were completed. Utilities were impressed by the AVR performance and several of them joined together to form the Hochtemperatur-Kernkraftwerk GmbH (HKG) which had the objective of commissioning the erection of a pebble bed power plant. The decision of VEW to join this group was particularly significant because it meant that no longer were only smaller regional utilities involved with HTRs. Moreover, the government also was more amenable to financing HTR development. In the Third Atomic Program, support for reactor development jumped to double the amount in the previous program; the HTR was a major beneficiary although no specific figure was set for supporting it.[21] The Land North Rhine-Westphalia was also much more forthcoming with support.

Nonetheless, commercial orders required more than bright prospects. No such orders were forthcoming and, hence, industrial interests were attracted to the more successful American design. VEW was not large enough or experienced enough with HTRs to order a large commercial reactor by itself. RWE, five times larger than any other German utility, was fully engaged in fast breeder reactors so it had little interest in HTRs. The Germans had also always developed their pebble bed system in isolation and, thus, there were no international partners in view. Neither BBC nor VEW had large stakes in the pebble bed design. They were more interested in building an HTR than in worrying about what type of HTR was being constructed. It was at the KFA Jülich and in Bonn and North Rhine-Westphalia that more focus was put on the pebble bed system.

Although the shift to the American design was a setback for pebble bed advocates, the optimism about the HTR's future remained in 1972. The thought was that the pebble bed system would still be developed in the long-run because of the advantage it had over the block HTRs in non-electricity uses. The situation for HTRs looked favorable at the start of 1972 because:

-- construction of the THTR had just begun and the reactor was expected to be completed by early 1977;

-- the Fort St. Vrain reactor in Colorado was nearing completion and General Atomic had several orders for follow-up already in hand;

-- England and France were still interested in the possibilities of HTR development.[22]

In March 1972 VEW and HKG presented the results of a study about the development of advanced HTRs. At that time the commercial future of electricity-producing HTRs seemed assured, and the general view was that no more public money would be needed for them. Instead, many claimed that support should be shifted to the more complex direct-cycle helium-turbine HTRs. The 1972 VEW report argued against this shift. It urged that the main priority of the HTR program should be to develop the technical and economic potential of the more conventional two-cycle HTR to its fullest before stressing advanced applications.[23] Again, in 1972 as in 1968, we see that the inability to determine a common course of development hindered the reactor's chances for commercial success.

Obstacles to Commercialization and Delays in the THTR

A commercial breakthrough for HTRs during these years seemed to be a distinct possibility. Orders were placed in the U.S. and VEW indicated its willingness to place orders in the Federal Republic, but nothing materialized. Undoubtedly, the economic uncertainties

surrounding HTRs prevented both utilities and manufacturers from taking larger risks, but market factors alone were not determinative. Günter Hirschfelder of VEW attributes the lack of success in the Federal Republic, U.K. and U.S. partly to the strong competition from LWRs, partly to the question of when and if the fuel cycle could be closed, and largely to the huge investment costs and accompanying risks that reactor operators face.[24] He feels that the financial means needed for market introduction of the HTR may well outstrip the capabilities of individual national economies, let alone firms. As a result he emphasizes the need for international cooperation, especially concerning the fuel cycle.[25]

A BBC assessment in 1975 of why commercialization did not occur related the problem mainly to competition with LWRs.[26] First, the HTR was hindered because potential operators insisted that the new reactor immediately had to have more to offer than the state-of-the-art LWRs before they would place orders. The customers for HTRs were not impressed that the HTRs then available could already offer essentially the same attributes as LWRs, and they completely overlooked that future HTRs -- such as the helium-turbine direct-cycle reactors -- could offer substantially more. The BBC authors urged operators to keep long-range possibilities in mind.

Second, size of the reactors also hindered a market breakthrough. Regardless of positive results from small experimental reactors, HTRs lacked credibility because no larger reactor of a comparable size to LWRs was in operation.[27] In the U.S., commercial orders for HTRs were placed even before the prototype Fort St. Vrain reactor was operating. When that reactor encountered problems, the credibility of the entire HTR line was questioned. The strategy followed for fast breeder reactors is different than for HTRs: for the fast breeders no efforts to obtain commercial orders are being made at all until a commercial-sized prototype is in operation. By implication, the BBC authors are critical of the HTR marketing strategy dictated by Gulf General Atomic in the U.S. because, in contrast to the FBR strategy, Gulf General Atomic forced decisions too quickly.

In the case of LWRs in the Federal Republic we saw how the utilities jumped at the prospect of commercialization. With the HTRs, it was not the utilities but rather the American manufacturer which jumped at the prospect. Gulf became a partner with General Atomic Company in order to compete with the other American reactor manufacturers. In turn, it convinced American utilities to sign letters of intent for HTRs but under terms which GAC later could not fulfill. Eventually the orders were cancelled. German utilities were definitely

interested in a variation of the GAC reactor, but they were never given enough information about cost and performance to merit placing an order. VEW was ready to order a large HTR in 1974 if only BBC could make a concrete financial offer competitive with LWR prices. In light of the absence of any offer and of a June 30, 1974 deadline from the Federal Ministry for Research and Technology for rebates on new reactor orders, VEW felt obliged to opt for an LWR rather than the HTR.[28] The point here -- and it will be elaborated in this chapter and the next one -- is that the prospect of commercialization of a reactor design tends to unleash certain unpredictable forces, but it is not only the utilities but also the manufacturers which quickly shift priorities in an attempt to reap a share of the commercial benefits.

STRUCTURAL CONDITIONS UNDERLYING THE T.H.T.R DEVELOPMENT

In the early years of German nuclear policy-making the effort was to support all approaches and make the German nuclear industry internationally competitive. By the late 1960s it was more important for some specific choices about German policy to be made than for a blanket approach to be followed. Choices were made, but often in haphazard fashion and with too little thought given to the implications. As with the period covering the AVR project, the period covering the THTR -- at least

until 1976 -- is characterized by disputes within the various sectors. Those within the manufacturing sector are particularly significant. For the AVR development, an open-ended approach to developing nuclear technology seemed logical; for the THTR development it was not as necessary. Several actors recognized the need to narrow options and thereby increase the chances of technological success, but individual interests prevented agreement on how to proceed.

The Manufacturing Industry

BBC, the main manufacturing firm behind German HTR development, faced a difficult series of challenges which affected HTR strategy during this period from 1963-1975. Certainly the consensus which prevailed at the time about options in the German light water and fast breeder reactor programs was missing for the HTR. For the other reactors there were some specific factors operating to narrow choices: international technology, governmental preferences and industrial policy worked together to determine which path should be followed for the LWRs and FBRs, but not for the HTRs. The choices for the HTRs were more confusing and less clear-cut. The challenges confronted by BBC in this period included: (a) domestic competition from GHH which was seeking to develop the prismatic fuel HTR and was involved in an international consortium for HTR development,

InterNuclear; (b) the loss of its partner in BBK, Krupp, just at the time that construction of the THTR was to move forward; (c) the need to find a new partner and then to determine the new strategy with the American partner, Gulf General Atomic, for HTR development; and (d) the entrance into the pebble bed HTR field of Kraftwerk Union, the largest German reactor manufacturer, after BBC opted to stress the American GAC design. Each of these challenges will be examined in turn.

Competition between GHH and BBC: BBC's first challenge came from the firm Gutehoffnungshütte Sterkrade (GHH) which was also interested in the development of HTRs. The GHH example is instructive for showing (a) the contrast between GHH's more internationalist perspective and BBC's isolationist approach; (b) the differences of opinion even within the BBC-Krupp partnership about how to proceed with the HTR; (c) the need to balance the most sophisticated and the most realistic applications of a technology; and (d) the weight which Kraftwerk Union assumes as the dominant German reactor manufacturer.

GHH's nuclear department was established in 1962, and it was headed by a former German Babcock and Wilcox manager who had experience from an early date with gas-cooled graphite-moderated reactors. GHH, under this

leadership, viewed the U.S. as the main nuclear country but saw no chance to enter the LWR or FBR fields, so GHH turned to another U.S. possibility -- General Atomic and the prismatic fuel HTR.[29] GHH did not recognize adequately the limits of what it could achieve. The case provides a good example of the relationship between market considerations and technological choices which often pertains to German nuclear reactor policy -- namely, the market considerations are determinative for deciding when an option should be dropped.

In addition to its interests in the prismatic fuel HTR, GHH also became interested in the direct cycle HTR system through its cooperation with the German nuclear ship research organization GKSS (Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt m.b.H.), and it found in Dragon a corresponding enthusiasm.[30] In 1965 the Dragon project concentrated on gas turbine applications of the HTR, but even after that approach was dropped both Dragon and General Atomic officials encouraged GHH to continue its work.[31] Until the mid-1960s the Dragon and THTR projects had cooperated well, but as signs of commercialization appeared, "open wounds" between the two programs were created.[32] Dragon also scored a public relations advance over the pebble bed design in 1966 because at the same time that the THTR

was experiencing some design problems concerning the insertion of control rods into the reactor core, Dragon officials announced that their reactor could also operate on low enriched uranium.[33] This increased Dragon's attractiveness internationally and gave the impression that the pebble bed concept was falling behind.

Henry Nau blames BBK for this impression because the German firm essentially isolated itself by "keeping the lid on information outputs" and by awarding essentially no THTR contracts to non-German industries.[34] Dragon attracted more interest because people knew more about it. Even BBC requested an official exchange agreement with Dragon in 1966, and according to Nau, there were differing opinions within BBK about THTR prospects: Krupp displayed more faith in the pebble bed concept than BBC.[35] GHH's focus at this time was on large gas turbines suitable for full-scale power stations and on the design of a 25 MW direct cycle demonstration plant. The Land Schleswig-Hostein was a potential customer for this demonstration plant, and in the spring of 1966 an offer of a direct-cycle HTR was made at a price competitive with large LWRs.[36] With the acceptance of the offer, the Kernenergiegesellschaft Schleswig-Holstein (KSH) was formed to own and operate the reactor which was to be built at Geesthacht.

The competition between Dragon and THTR was viewed as wide open by all parties -- the British, the German and Euratom officials. Euratom convened a joint symposium on Dragon and THTR in May 1967 and concluded that "the commercialization of high temperature reactors only has a chance within the framework of an international consortium. . . ."[37] British firms were wary of such a consortium unless other international firms were involved. An Italian firm, a French firm and GHH joined the discussions in January 1968 and a formal agreement was concluded (without the French firm but with a Belgian firm) in October 1968, creating the company Inter Nuclear.[38] THTR people were sharply critical of Inter Nuclear which they saw as an attempt to isolate the THTR program and force consolidation on Dragon; German opinion was also critical of GHH joining a foreign consortium which was competing against the German pebble bed system.[39] The German Research Service's special report on nuclear energy said, "We would have welcomed it more if beforehand GHH had come to an arrangement with BBK concerning cooperation on the development and construction of a German prototype reactor."[40]

The evidence in this section suggests that GHH and Inter Nuclear were serious competitors to BBC, but that overstates the case. Inter Nuclear was never more than

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an organization on paper. It lacked the capital to be a serious reactor company. Rudolf Schulten maintains that the company was not a threat, did not offer any competition, and could never have been successful. According to him, GHH was not a reactor manufacturer; it simply wanted to sell turbines.[41] The German program did face the question directly of whether to cooperate with the Dragon project, but the Germans saw cooperation as an either/or proposition and they were not prepared to give up their own approach.[42] After 1966 process heat became a major goal of the German HTR development; British advanced gas reactors were therefore less attractive because of their low efficiency. In 1966 the decision was made by the Germans to proceed with the THTR, and KFA officials today say that Henry Nau's conclusion that progress on the THTR was effectively terminated in 1966 because of a stalemate within the European Community which affected the THTR consortium is wrong.[43] Utility and North Rhine-Westphalia officials also claim that GHH caused them no concern; in fact, they thought a certain amount of competition was healthy.[45]

The GHH policies did have an impact, however, on both the government's approach and BBC's willingness to cooperate with other firms. The federal government wanted to shed some of the financial burden which it was

increasingly shouldering for nuclear development. It wanted to consolidate the national HTR effort, and it encouraged this in the Third Atomic Program of 1968 which set out a 600 MW HTR project specifically designed to foster cooperation between BBC and GHH. The government was anxious to avoid having a monopoly exist for Kraftwerk Union in the reactor manufacturing sector so it encouraged its research ministry to bring BBC, Krupp and GHH together.[45]

BBC was not averse to considering HTR approaches other than the German pebble bed system. According to one representative from the manufacturing industry, officials at BBK decided in 1966 that they should work more closely with the Americans, and hence they conducted secret negotiations with U.S. officials in Düsseldorf in 1966-67.[46] BBK felt that the HTRs would be successful only if there were international cooperation designed to make the HTR competitive with LWRs. The negotiations broke down, however, because each side insisted on adhering to its own concepts.[47] BBC was not opposed to international arrangements. It would have welcomed cooperation with the Americans, or later with the French, but nothing worked out. BBC also blames the Bonn government partly for the failures. BBC felt that Bonn should have stressed more the equal development of HTRs with

FBRs; the minister of research, Hans Matthöffer, over-emphasized the FBRs in establishing international arrangements according to this industry representative.[48]

A lack of international cooperation was also at the heart of GHH's inability to deliver the direct-cycle HTR it had agreed to build for the KSH at Geesthacht. GHH had contracted to build the reactor at a fixed price of DM 65.8 million; but 14 months later it was already apparent that the firm had underestimated the difficulty of technical problems, and the extra costs would nearly double the price.[49] The major problem concerned the fuel element. The problem had been foreseen before GHH made the offer to KSH, but GHH assumed that its license with Gulf General Atomic would give it access to the broad technical know-how of the American firm.[50] From the very start of negotiations with GAC, however, it was evident that the American firm was only interested in the more conventional two-cycle HTRs and did not want to risk the failure of its fuel element technology on the "avant-garde German concept" for fear of setting back the overall development program.[51] GHH then wanted to utilize Dragon's fuel element, but that proved impractical enough that GHH was compelled to develop the technology itself. This seemed feasible, but would have been expensive and time-consuming.

In short, GHH obtained the contract for the 25 MW HTR and then realized that it might not be able to fulfill it. In an effort to meet its responsibilities, the firm brought in outside consultants and then shook up management.[52] A major goal of the new management was to develop broader contacts -- at that point GHH had some ties to General Atomic in the U.S., minimal ties to Dragon and essentially no ties with the KFA Jülich. It quickly became evident, though, that money and technical personnel were simply too limited at GHH so the firm began looking for a way out of its contract.[53] It welcomed the suggestion made by the federal government that BBC, BBK and GHH form a joint company to take over all HTR projects including international cooperation such as with the U.S. firm or the British consortia.

Negotiations were started, a pre-contract was signed and offices were set up in Cologne, but then the joint company fell apart.[54] Krupp decided suddenly to drop out of the organization.

Both Krupp and GHH were in the heavy component business and received many orders from Kraftwerk Union. Kraftwerk Union was displeased with the whole development in the HTR field which impinged on KWU's dominant position in German nuclear policy: the Americans were entering the German market and BBC was merging with GHH. Kraftwerk

Union put pressure on both Krupp and GHH, saying you cannot expect both to deliver components to us and be major competitors.[55]

A second reason for the failure of the merger was that it became apparent that the new company would be bearing financial responsibility for the unrealistically priced Geesthacht reactor. That project was abandoned late in 1971. Many officials in BBC are quite critical of GHH in retrospect. They doubt that GHH was ever serious about joining with BBK but rather was just buying time and waiting until liquidation of GHH's contracts occurred.[56]

GHH's competition did not alter BBC's reactor strategy significantly, but certain lessons can be learned from it. The competition underlines the issue of national versus competitive interests. Paradoxically, through GHH licenses with Gulf General Atomic, BBC came into closer contacts with the American firm which eventually became its partner. The competition also convinced the government to try harder, although unsuccessfully, to bring about a merger in the German HTR industry. The pressure and influence of the dominant German reactor manufacturer, Kraftwerk Union, is also evident in the BBC-GHH negotiations. The roles played by Kraftwerk

Union and RWE should not be underestimated concerning the extent to which they limit the flexibility of other actors. Finally, the BBC-GHH competition was significant because it served as a warning to BBC not to overstep its capabilities as GHH had done or else the credibility of the entire German HTR line would be undermined.

Krupp's Departure from the BBK Partnership: The competition with GHH may not have altered BBC's development strategy for the HTR, but the loss of Krupp as a partner certainly did. This was an important change that shifted the entire emphasis of the German program. One industrialist involved with negotiations at that time said there was regret that GHH did not join the new HTR company, but "Krupp's departure shook up matters much more."[57] Looking at the circumstances surrounding Krupp's leaving and the search for a new partner (covered in the next section) shows how politicized industrial arrangements are.

In this case the choice of arrangements essentially determined the type of HTR technology which would be pursued. With the departure of Krupp, the emphasis shifted away from the pebble bed reactor. Competitive interests favoring the prismatic fuel design asserted themselves over national interests -- or more precisely, Land interests. Relations between Krupp and BBC

also indicate how essential it is for firms to balance expectations with realistic possibilities for a particular project: Krupp expected that the pay-off for HTR development was much closer than it was, and it was not prepared to wait too long.

BBC was becoming exasperated with its lack of success in obtaining nuclear reactor orders. It was interested in competing with large firms like AEG and Siemens, but it received no orders besides the AVR between 1960 and 1970. BBC felt that it had to do something, that it could not just wait for the HTR; in fact, BBC had always considered other partners including Gulf General Atomic in the U.S. and Babcock and Wilcox in Britain and Switzerland, but no arrangements emerged. Krupp, in contrast, was not as interested in building nuclear reactors. It wanted instead to provide reactor parts for other firms, and the pebble bed reactor was essentially a "hobby" for it.[59]

This is not to say that Krupp's involvement was unimportant. The firm's broad palette of activities made it a good partner for reactor development. Krupp thought that the HTR breakthrough to marketability was 10-15 years away so it was interested in the technology, and the firm also wanted to get away from the image carried over from the war that it was only engaged in producing

military armaments.[60] We saw in the previous chapter that there was some controvery right from the start about Krupp's becoming a partner with BBC. There were also some insinuations about different styles of leadership in the two firms. The partnership lasted over 10 years, but it was not always a happy one.

The disputes between BBC and Krupp had a direct impact on the THTR progress. One newspaper account quotes BBC officials who claim that the quarrels led to one-and-a-half years of delay in the THTR construction by 1971.[61] A KFA official went further and said they held up the project four to five years.[62] The delays were created because Krupp was siding more with domestic groups which supported the pebble bed system. Henry Nau suggests that Krupp's decision reflected the firm's pessimism that the pebble bed reactor could overcome growing commercial skepticism even if the THTR prototype were constructed.[63] The breakup of the partnership, though, should not just be blamed on Krupp's pessimism.

The pessimism existed, but the reasons for Krupp's departure went far beyond the HTR. The firm was in a very tense financial crisis brought on by iron and steel ventures, specifically, involving a Spanish steelwork project from 1965-68.[64] Krupp was near bankruptcy and the German banks forced a management change in the Board

of Directors and installed the crisis manager Günther Vogelsang as commissioner. Vogelsang had enormous power to rearrange Krupp's financial commitments. At first he fought for the THTR and he nearly concluded a contract for new arrangements with BBC. The reports he received about the prospects for HTRs were positive, but in the end he decided that the distant prospects of marketability made the venture too risky.[65] Vogelsang sold a half-dozen of Krupp's firms and cancelled several contracts; the THTR was one of the victims.[66] Krupp was worried about the risks it was undertaking: it estimated them at DM 75 million and the firm was especially concerned about the unpredictable follow-up costs.[67] Vogelsang himself was a controversial person who got involved in personal struggles with other Krupp executives and the Research Minister, Hans Leussink, but the general consensus was that he did a good job saving Krupp.

Krupp also left the BBK partnership because it was not receiving the subcontracts for the THTR which it had expected. The THTR was basically financed by the federal and Länder governments. Because of these subsidies, there was a legal requirement that all subcontracts go out for competitive bids. Krupp was displeased that they kept losing out on these.[68] In any case, the backing down from the partnership was sudden

and surprising. The cornerstone of the THTR was scheduled to be laid on June 23, 1971, but on June 18 the contractors for the reactor announced that the ceremony would be cancelled; a statement was issued which said, "For internal reasons within the (THTR) consortium the contract which we are prepared to conclude cannot be signed."[69] The contract had been ready for signing for five months, and it came as a surprise when Krupp pulled out of the arrangement.[70]

The year 1971 turned out to be doubly difficult for West German HTR development. Krupp backed out of the BBK partnership and GHH abandoned the Geesthacht project. BBC faced the sizeable task of finding a new partner with whom to continue HTR development.

The New American Partner: After the breakup of BBC and Krupp, BBC and the electrical utility group which ordered the THTR, HKG, continued the partnership for the prototype reactor on a temporary basis. BBC held 80 percent of the shares and HKG 20 percent, but the understanding was that Krupp would sell its share within a year, by October 15, 1972 at the latest. Several partners were mentioned in discussions -- Kraftwerk Union, the German Babcock and Wilcox, the Land North Rhine-Westphalia, the Inter Nuclear consortium, and Gulf General Atomic Company in the U.S. -- but soon the talk was concentrated solely on GAC.

The huge amounts of capital needed to support a new reactor line made it mandatory for BBC to seek a partner (and the German utilities wanted this added support); GAC was one of the few firms whose interests and financial capabilities permitted it to consider partnership. KWU, for example, had the financial assets but its interests were directed to other reactors. The fact that Gulf itself sought out a partnership with Royal Dutch Shell to share the costs of HTR development demonstrates the degree of risk involved. The Financial Times explained Gulf's and Shell's partnership by saying, "The alarming size of the sums needed to launch a new nuclear steam supply system commercially . . . (is) guaranteed to make even governments wince."[71]

The partnership between BBC and GAC to form Hochtemperatur Reaktorbau (HRB) provides a striking example of how industrial decisions can steer technological development. The choice of GAC as a partner essentially guaranteed that German HTR emphasis would shift from the pebble bed to the block design. This recognition unleashed a controversy in West Germany among pebble bed advocates who tried to find a new application for their reactor. But it was the failure of GAC, as opposed to the efforts of the pebble bed advocates, which caused a return to the pebble bed emphasis five years later in 1976.

Gulf General Atomic was a willing partner in this enterprise. It had landed several orders with U.S. utilities in the early 1970s on the strength of its 300 MW Fort St. Vrain demonstration reactor, and it was eager to expand its success to Europe. Gaining a foothold in Europe was important to GAC because Europe was home to almost all of the world's experience with gas-cooled reactors.[72] Krupp's withdrawal from the THTR project provided GAC with its great chance.[73] GAC had made a deep impression on European utilities and atomic energy commissions at the 1971 Geneva Conference on the Peaceful Uses of Atomic Energy because it could point not only to progress on the 300 MW demonstration reactor but also to two commercial orders in August 1971.[75]

These successes, which coincided with the BBC/Krupp split, prompted Gulf to make immediate efforts to break into the European market. A licensing agreement was concluded with the French high temperature consortium and discussions were started with a British group of nuclear firms, but Gulf's offensive had the most noticeable consequences in the Federal Republic.[75] One retrospective German account five years later said, "The Germans threw themselves into General Atomic's arms," and felt they had found their "fairy prince."[76]

The explanation for the willing shift in emphasis to the American design lies partly in the successes of GAC at the time and partly in BBC's own priorities.- We saw that BBC was eager to get more reactor orders and it did not have huge vested interests in the pebble bed HTR. There were others who did, however, and they tried to block the BBC-GAC partnership. Negotiations between BBC and GAC intensified the domestic debate. GAC expected to announce its acquisition of 45 percent of HRB at the October 1972 Nuclex '72 meeting in Basle, but Gulf's aspirations were checked "by an unexpected upsurge of technological and economic nationalism in West Germany."[77]

According to David Fishlock's account:

> The cause of the storm is Professor Rudolf Schulten . . . . In an eleventh hour bid to block the deal with Gulf, Prof. Schulten persuaded the politicians of North Rhine-Westpahlia that Gulf's admission would mean the death of the first all-German power reactor, and moreover could jeopardize future energy supplies for this highly industrial region. Prof. Schulten argued that Gulf was not interested in the pebble bed reactor, . . . (but) was interested only in selling its own, more conventional reactor design. Once admitted, Gulf would unleash its massive commercial strength to ensure that the native ideas made no further progress.

We see here that national pride (or Länder pride) was present at certain levels. As one industry official put it, "the problems with the pebble bed reactor are

enormously complex because they quickly become emotional and lapse into the area of personalities."[78]

In this case, the pebble bed adherents were not strictly opposed to more emphasis on the block-fuel element HTR, but they wanted guarantees that the pebble bed design would also be pursued, especially for process-heat applications which they saw as the big advantage of the pebble bed concept. Government officials were worried that GAC would gain majority control of HRB and neglect the German pebble bed project, thus making all the government subsidies useless.[79] The government's concern is one reason why only 45 percent of the HRB capital was sold to GAC. BBC, at the same time, argued resolutely that only an association with GAC could broaden and enrich the technical basis of German programs.[80]

GAC executives were taken unaware by the whole domestic storm in the Federal Republic and professed vehemently that they had no intention of killing the pebble bed reactor.[81] They stressed that the delay had nothing to do with choosing between the two reactor systems -- a decision which they saw as at least two years away and which might even reveal a clear future for the pebble bed HTR.[82] But privately GAC did admit to some doubts such as whether the pebble bed reactor could be scaled up successfully to commercial sizes of 1000 MW.[83]

The Land North Rhine-Westphalia was, not surprisingly, especially supportive of its "favorite-son" design. The NRW cabinet actively followed the BBC-GAC negotiations. The economics minister, Horst-Ludwig Riemer, stressed that the reasons for backing the pebble bed design were not nationalistic but industrial.[84] According to the minister, it would not be good business to stop development of the pebble bed reactor. As long as the independence of the pebble bed line were assured, the minister said he would have no objections to cooperation with the American firm.[85]

Some discussion occurred within the NRW government about whether the Land should assume Krupp's share in the BBC-Krupp partnership. That would have guaranteed an emphasis on the pebble bed HTR. Minister Riemer even got to the point of bargaining with the Krupp management about a price, but BBC was not willing to go along with the deal -- and it had the right to reject arrangements.[86] Henry Nau, on the basis of interviews he conducted at the time, reports that BBC was eager to "dilute" its commitment to the pebble bed system and therefore was pleased with the GAC partnership.[87] David Fishlock of the Financial Times described the idea of NRW buying the Krupp share as "panicky talk."[88] In contrast, one of the top Land officials involved with the negotiations then, Dr. Hans Olivier, still maintains that that would have been the best course to take.[89] The notion of NRW

taking over the Krupp share was very alien to German thinking -- and according to one BBC executive, it would have been "damned difficult"[90] -- but the fact that the proposition could be seriously considered shows how great the Land interests were. Eventually, NRW decided against either sponsoring Krupp to stay in the BBC-Krupp partnership or buying out Krupp's share itself, but it made efforts to get other German firms (rather than GAC) to take over the share.

German officials were skeptical about GAC. One KFA official said he was surprised at first that BBC brought in GAC, but it was a logical choice because of GAC's commercial success and because GAC's involvement would free BBC from the high costs of reactor development.[91] Another KFA official said that the government's wariness eased as it became evident that GAC was the only logical partner. The government was in a dilemma because it was trying to strengthen the German industrial base for the gas-cooled reactor line, and it recognized that partnership with GAC would probably be the most effective means to achieve this.[93] GAC's assurances that the pebble bed reactor might still have uses for more advanced HTRs assuaged the government, although Schulten and his team still saw the new partnership as a blow.[94]

Bonn overcame its concern about GAC because it decided that the American partner was most able to make German advanced reactor systems competitive. Karl Heinz Beckurts, then director of the KFA, felt that the breakthrough of the American design was inevitable.[95] BBC was striving to win its first commercial reactor order and was confident it could do so with GAC's backing. One of its executives said that the first order of business was to "get rid of the emotion," and the Bonn government echoed that view because it wanted to see a second nuclear company emerge in West Germany to rival the powerful Siemens-AEG concern, Kraftwerk Union.[96]

In sum, the crucial decision to bring in the American firm of Gulf General Atomic was made largely by BBC. The decision was forced upon BBC because its German partner, Krupp, stepped out of the business of building nuclear reactors for financial reasons. Because of this decision, the pebble bed HTR line was de-emphasized -- despite some protests and efforts on the Land level -- and not stressed again until 1976. The attraction of GAC lay not so much in its technological skills as in its marketing skills. GAC seemed on the verge of commercial success with the HTR, so once again the prospects of commercialization were influential in directing the line of technological development.

One should note that BBC had had a long-run interest in the GAC design, but the complete shift in emphasis would not have occurred without Krupp's withdrawal. Given the opportunity, through, BBC was quite willing to go the American route. It was not receptive to suggestions that North Rhine-Westphalia -- and the major pebble bed proponents -- assume Krupp's share in the THTR partnership. BBC's interests were more in the high temperature reactor line in general, not in a particular approach. BBC did continue its involvement with the pebble bed THTR project, however, because it needed the prestige, the experience and its own reactor facility; otherwise it would have been little more than a GAC licensee.[97]

KWU's Entrance into the HTR Field: The fourth challenge to BBC in this period came from Kraftwerk Union, and it too influenced the direction of HTR development in the Federal Republic. KWU realized that it had to pursue the HTR domestically both because of some of its own interests and because it would make the firm appear more as an international reactor supplier since it would add diversity to its reactor line. The dominant position of KWU in the German nuclear market also meant that BBC, as a smaller and unproven supplier, had little chance to resist the KWU participation. KWU's interest was primarily in process heat applications of the HTR while BBC, once it

opted for the GAC block-fuel element design, was more interested in electricity production. This emphasis on electricity, however, lost importance with the failure of GAC. KWU, at the urging of Rudolf Schulten and other pebble bed HTR backers, focused its interests on the pebble bed reactor in 1972 after BBC decided against it.

KWU was attracted to the high temperature reactor by the possibilities of process heat application and by the public acceptance of the HTR. Two forces drove KWU to its interest in the HTR in 1972.[98] First, there were good business reasons to pursue the HTR. It had some parallel lines of development with the fast breeder reactors -- a major concern of KWU -- and parliamentary committees were continually calling for parallel development of the two lines. Second, the utilities wanted KWU involved with HTR development because of the firm's broad reactor construction experience. On the one hand, the utilities wanted KWU involved due to its experience; on the other hand, they wanted a stronger BBC role to preclude a KWU monopoly of the German nuclear market. The utilities could also foresee the financial problems at AEG, one of the two partners in Kraftwerk Union. These problems soon compelled AEG to sell out completely to the other partner, Siemens. The utilities felt that an alternative to KWU was valuable. This was not a paradoxical position because, as is often the case in German nuclear

development, the real priority was to strengthen the domestic industrial base.

The utilities did not feel that a choice had to be made between reactor lines. They just wanted to bolster the German nuclear industry. Thus, when problems arose concerning the HHV project (Hochtemperatur-Heliumturbinen-Versuchsanlage -- i.e. helium turbine HTR) at the KFA Jülich so that BBC's technical management was called into question, the utilities welcomed a broadening of the technical basis through the inclusion of KWU.[99] There were questions about BBC's capability to manage HTR development successfully. For KWU, which had been attracted to process heat applications and at first had even tried to use its light water reactors for process heat, the partnership with BBC offered an easy way to monitor its competitor's progress at minimum risk.[100]

BBC had to go along with licensing its know-how to KWU in part because it needed the business and in part because the utilities felt that the financial backing of BBC alone for a new reactor line was inadequate.[101] The dominant electrical utility, RWE, carried the risk for the fast breeder reactor, but the utilities involved with HTRs were not confident that BBC could play a similarly strong role for the high temperature reactor. BBC's

funding was tied up with a controversial LWR at Mühlheim-Kärlich which the utilities scornfully called Mühlheim-Kläglich (loosely translated, the pitiful reactor in Mühlheim). To complicate matters further, the government made it clear that money would only be available for one major HTR project, thus putting pressure on the KWU and BBC industrial groups to formulate a common R&D program.[102] It is interesting to note that the government was trying to force technological choices and narrow options, but it did so at an early stage of development so that neither firm would be severely penalized.

KWU never felt threatened by BBC's competition, but it kept a watchful eye on developments. We saw earlier that KWU exerted certain pressures on Krupp and GHH in the late 1960s because it did not welcome competition. Likewise, it had some concerns about the new BBC-GAC partnership and consequently was quite willing to provide a challenge to BBC in the HTR field.[103] It did this by moving into the pebble bed reactor gap left by BBC. Schulten convinced Hans Heinrich Frewer, chairman of the board at KWU, to start work on the pebble bed HTR through KWU's subsidiary firm Interatom.[104] Thus, the pebble bed advocates, who had suffered a setback when BBC formed a partnership with GAC, did not give up their case. They turned to KWU for support.

Without much commitment, KWU was able to enter the HTR field claiming that its interests in process heat did not conflict with BBC's interests in the production of electricity. Process heat applications are another effort to define a future for coal in the German economy. Coal gasification has been the major thrust of German HTR development since the failure of GAC in 1975. Coal always has been a special national problem for West Germany -- with North Rhine-Westphalia leading the cause.[105] KWU thus entered the debate on the side of the coal interests. This did not force changes in the BBC strategy, but it imposed restrictions on what steps could be taken. We see that the apparent freedom of action which BBC exerted in establishing partnership with GAC was really rather limited. The coal interests, the pebble bed advocates, and the presence of KWU in HTR policy meant that subsequent steps could not be taken so independently.

The Electrical Utilities

The previous section leaves little doubt that conditions in the manufacturing industry most directly steered the THTR development, even though utilities were important at certain levels. The impact of the utilities was not as critical as with LWRs. Instead, the utilities played the role of potential partners waiting to be convinced by the manufacturers regarding which direction to go, but the utilities were unable to coordinate efforts. Thus,

in contrast to the experimental AVR phase and post-1975 phase of HTRs, the role of the utilities in the demonstration THTR phase was less significant. The items to note in this THTR phase are (a) the lack of coordination among utilities both at home and internationally, (b) the low financial commitments which they made, and (c) the gradual dissatisfaction of VEW with HTR prospects. VEW today remains skeptical about prospects for finishing the THTR and is not eager to pursue a THTR follow-up project.

Views of the utilities' role in German HTR development vary considerably. Only a few of the utilities showed interest -- or were in a financial position to show interest -- in nuclear energy. On the one hand, Rudolf Schulten says that it was the electrical utilities which made the THTR possible.[106] On the other hand, a German politician states bluntly that the cooperation of the utilities concerning nuclear energy has always been "miserable," and they finally had to be brought together under pressure after 1976.[107] Der Spiegel accuses the 380 utilities of acting like "17th century princes" with their cartelized energy fiefdoms (i.e., each utility has a monopoly in the area it serves), and the magazine says the utilities lack not only the money but also the courage to switch to nuclear energy.[108]

These views are not contradictory because they encompass different scopes. For the HTR, though, it was critical to involve a major utility. The Stadtwerke Düsseldorf had always been a friend of the HTR and it has remained so, but the participation of VEW in the THTR project was the step needed to put the reactor on more solid footing.

The Stadtwerke Düsseldorf, in fact, is not part of the consortium building the THTR. The utility, according to one of its board members, Chrysanth Marnet, was involved in helping to convince the HKG consortium to place the order. The Stadtwerke itself, however, is part of the city of Düsseldorf and needed city council approval before becoming part of the consortium. The approval was not given for budgetary reasons, and thus the leading utility for the AVR project was not involved with the THTR follow-up project.[109]

VEW opted for the HTR because BBC convinced them to do so.[110] The utility had not been involved with the AVR, but process heat applications of the HTR were becoming apparent and that attracted VEW. It chose the HTR simply due to the technology, not due to the specific participation of firms in West Germany or elsewhere -- i.e., VEW had no specific relationship with BBC. For VEW it was important that its competitior RWE had committed

itself fully to the LWRs; in response, VEW preferred the HTR alternative, and that probably explains why the smaller utilities made a similar choice.

In other words, the size of the utilities per se does not explain why RWE pursued the LWR while the smaller utilities and VEW followed the HTR. The reason relates more to RWE's early decision for LWRs so that the other utilities sought an alternative.[111] VEW, for example, already had its own 250 MW LWR at Lingen. It considered the British advanced gas reactors but had reservations about the AGR's process heat applications. That left the HTR as a logical remaining option.

This orientation also indicates why VEW was less concerned about building the pebble bed reactor and more interested in simply moving ahead with HTRs as soon as possible. The utility immediately showed interest in the block-fuel element HTR-K when it was first proposed by BBC and GAC. The HTR-K 1160 MW reactor seemed to offer the chance to bring Gulf's commercial success to Europe, and VEW was more interested in that than in which fuel element would be used.[112] VEW's interest in the project was the real breakthrough in the German switch to the prismatic fuel design.

VEW, the CEGB (Central Electricity Generating Board in the U.K.), the SSEB (South of Scotland Electricity Board), and EdF (Electricite de France) analyzed the 1160 MW reactor and asked for changes to enable it to have application throughout Europe. The Ministry for Research and Technology (BMFT) financed the work to make the plant licensable in the Federal Republic.[113] We will focus more on the influence of the BMFT on nuclear policy in the next chapter dealing with the post-1975 situation, but it had influence before then too. One utility official points out that the utilities were compelled to participate on the THTR, but that the ostensible participation rate of 25 percent is actually much lower once federal financial guarantees are considered.[114] Moreover, in the early 1970s, the BMFT told the utilities either to support the 1160 MW reactor or else the ministry would withdraw support. The utilities had some doubts about committing themselves, but they also were not convinced that they wanted to drop the whole project.[115] The BMFT was able to use the unions -- who favored the HTR -- as a point of leverage with the utilities.[116]

The 1160 MW HTR was never ordered. The British and the French were ready for 15 percent participation each in the project, but they lost interest when German considerations swung to the one-cycle reactor. The other countries favored the two-cycle HTR, and, in fact, German

interests also returned to the simpler concept just a few years later.[117] VEW decided not to order the 1160 MW reactor because of technical difficulties relating primarily to the protection system of the PCRV (pre-stressed concrete reactor vessel). Günter Hirschfelder of VEW says that the HTR's container vessel has long been a significant discussion point concerning HTR development.[118] It does not attain economies of scale and thus makes the HTR expensive. VEW wanted to develop a substitute container using cast iron. That would have allowed individual parts to be replaced if problems arose rather than replacing the entire container, and it would have meant smaller and cheaper reactors. At the same time, though, it would have required a whole new prototype, and neither VEW nor the BMFT wanted that so the suggestion was dropped.[119]

The order for the 1160 MW HTR also failed because BBC/HRB could not make an offer in the appropriate time. They made a technical offer but no financial offer. Hirschfelder says that VEW sometimes is blamed for not ordering the reactor, but he asks how the utility could have been expected to order something when no price was offered.[120] And the reason no price was given was that BBC could not be sure of costs. The GAC failure in the U.S. also affected VEW's decision. Even more importantly, the BMFT had offered a six percent rebate on nuclear

reactors ordered before June 30, 1974; BBC could not meet the deadline so instead an LWR order was placed with KWU.[121] VEW had had a positive orientation to the HTR-K 1160 and had started licensing procedures, site selection and a safety assessment, but it could make no commitment without a price.[122]

Earlier in this chapter we saw the open-ended nature of the costs and completion possibilities for the THTR-300. At best, the costs will be four times the original estimate and completion will be eight years later than the original projection. These figures, combined with the situation described in this section, have dampened VEW's enthusiasm for pursuing the HTR. As Hirschfelder says, "The schedule for completing the THTR is completely open, and that means the costs are wide open . . . . Under these conditions no one can see fit to order an HTR."[123] An LWR today costs DM 3 billion -- or DM 6 billion when all the extras including interest are added. Hirschfelder says that a similarly-sized HTR costs the same amount, and he says that no individual firms or utilities can afford that.[124]

In brief, the utilities wait to see what the manufacturers have to offer. This does not imply a lack of coordination between the groups, but it does indicate

that utilities have not been the most significant factor in determining HTR development in the Federal Republic. One utility official described contacts with manufacturers as very good and says the manufacturers will not produce what the utilities do not want.[125] Again, though, this represents more of a veto power than a steering power. This follows the traditional German approach to non-nuclear power plants: it was left to the manufacturers to develop technologies and make offers to the utilities.

The German utilities provide electricity for a certain area and they have a monopoly for that area. They have always assumed that they were therefore less susceptible to competitive economic swings, and this may explain to an extent why they have been less willing to provide money for commercialization. The more traditional pattern -- whether domestically as we see with VEW or internationally as we saw in Chapter Four when we described how European utilities were convinced to pool experiences only after Gulf's commercial sales successes -- has been to wait for manufacturers to offer commercialization possibilities. Two qualifications are in order here, however: first, utilities are quite able to move quickly toward commercialization when opportunities arise, as with the LWRs; second, the complexity and expense of nuclear development is necessitating some rethinking of the traditional patterns. The next chapter

centers on new directions in coordination among manufacturers, utilities and the government.

The Süddeutsche Zeitung in 1974 called the THTR-300 a "gift to the participating utilities from the federal government."[126] In the first part of this chapter, we saw that the utilities only had to provide three percent of the capital for the entire THTR project.[127] These arrangements will not be repeated in the future. Research and Technology Minister Andreas von Bülow told the heads of several utilities, "There is a credibility gap between your interest in atomic energy development and your willingness to finance these developments."[128] He was critical of contributions for both SNR-300 fast breeder reactor and the THTR-300. He pointed out that only RWE had set a good example on the SNR-300 (for which it is the main shareholder) and promised to contribute DM 62 million in 1981 and 1982.[129] Even this, however, is a mere fraction of the present estimated cost of DM 5 billion. The utilities and the manufacturers will have to shoulder more of the costs because Bonn is not prepared to let its share of expenses keep rising.

The Government

The last two sections have given an indication of the development of the government's role in German nuclear policy-making. The government has not been too

involved with the THTR project itself, but we see an unmistakable trend toward more influence on overall policy direction. The government is quite actively involved in the formation of post-THTR policy. By the term government, we refer both to the cabinet level in Bonn -- mainly the BMFT -- and to the Land level.

The influence of the Bundestag on the THTR is still minimal, although the parliament is beginning to be much more concerned with nuclear energy. For the THTR, though, the Bundestag's influence is restricted to financial appropriations. Thus, some pro-HTR members of the Bundestag held up the money in the budget for the fast breeder reactor because they felt the HTR was being slighted relative to the FBR, but the BMFT argued convincingly that there was no discrimination and the funds were released.[130] Besides that, there has been little debate in the Bundestag about the THTR.[131]

Government influence on the federal side has increased not only because its budgetary share has continued growing, but also because its expertise has increased. Originally, the Ministry for Atomic Questions was little more than a tool of the German Atomic Commission, but the Commission was disbanded in 1971. By then it had grown old, it lacked the key people, and it had become a huge body with too many sub-commissions.[132] The ministry had become

more competent and self-confident, and a new advisory system was needed to reinforce this.[133] Manfred Popp, head of energy and research at the BMFT, suggests that the early 1970s may have marked the time when the ministry had the most power because the role of its advisory committees had diminished and the Bundestag was minimally involved.[134] If the power of the BMFT reached its peak in the early 1970s, then the developments since then should not be described as a reduction in power, but rather a sharing.

The increase in the BMFT's power did not come suddenly. It was more of a "quiet transition" which related somewhat to the change of government in Bonn to the coalition between the Social Democrats and Free Democrats, but the change should not be seen as a "sharp edge."[135] The Fourth Atomic Program, drafted in 1972-73, was the first one formulated by the Ministry. Formerly, the responsibility lay with the Atomic Commission. The ministry also reorganized itself in 1975-76 so that nuclear and non-nuclear programs were not divided and so that fundamental scientific research on nuclear energy was treated with other fundamental scientific issues.[136] Public hearings were held on the Fourth Atomic Program, and the BMFT is proud that in the talks about alternative energy sources they were the ones who first raised the issue of conservation.[137] The ministry has taken on a

new more active role as it has developed its own expertise, but officials point out quickly that one cannot even begin to compare BMFT's resources with the U.S. Department of Energy.[138] In examining the post-1975 period, we will get a better idea of what influence the BMFT can exercise. In the Third Atomic Program in 1968 the government attempted to bring BBC and GHH together in a common HTR project and failed. After 1975 the ministry was able to steer policy directions most successfully, but certain conditions contributed significantly to this.

The Land government in North Rhine-Westphalia has also increased its influence even though it could not keep pace with increased expenditures the same way Bonn did. The THTR was the real starting point for NRW's support of the HTR according to Dr. Hans Olivier; the Land contributed DM 80 million to the project, as opposed to DM 1.8 million for the AVR.[139] We saw how involved NRW was in trying to influence events after Krupp withdrew from the BBK partnership.

The simple fact is that coal is essential for NRW (and for the West German economy), and the HTR seemed to be a means to provide a brilliant new future for coal. One BMFT official said, "We are interested in the HTR, but the people in North Rhine-Westphalia, they are the

priests of HTR development."[140] Given the historical role of coal in Germany, that is understandable, especially in NRW which is the historical center of German industrialization which was based on coal. As one politician put it, the view on HTRs in NRW is "my technology -- right or wrong."[141] The view in NRW is that the BMFT is far less supportive of the HTR than is NRW itself, and that the Chancellor's Office, the Bundestag and the federal Interior Ministry are all more pro-HTR than is the BMFT.[142] In NRW, the view is that 80 percent of the Bundestag members favor the HTR over the fast breeder.[143]

The Land has an undeniable interest in the promotion of the HTR. Not only does it have a 17.6 percent share in the THTR project, but also it seizes the initiative in many situations such as alternative uses of coal or nuclear process heat. Part of Bonn's Fourth Atomic Program stemmed from discussions within North Rhine-Westphalia: the NRW research ministry brought together interdisciplinary groups to formulate an energy program; their ideas were passed on to the NRW Minister-President, who passed them on to Chancellor Willy Brandt, who passed them on to the then BMFT Minister Horst Ehmke; eventually the ideas were incorporated in the new program.[144] The wishes of NRW also carry weight in Bonn (1) because NRW is the biggest Land, (2) because coal is a national issue, (3) because the proportional representation system for

choosing Bundestag members guarantees a strong voice for regional interests, and (4) because Bonn and the NRW developed close links since NRW provided the model for the SPD/FDP coalition in Bonn. In sum, the Land was the major factor in bringing about the marriage of coal and nuclear energy in West Germany.

The Nuclear Research Center in Jülich

The KFA Jülich did not steer the development of the THTR, but it provided valuable back-up support for the pebble bed HTR in general. This ranged from convincing the federal government to give more support to the KFA and its HTR activities in the mid-1960s to assisting in keeping up interest in the pebble bed design even during the height of interest in the prismatic fuel HTR. Throughout these years, Rudolf Schulten has maintained his leading role in advocating the pebble bed HTR.

According to Schulten, there were some people even at the KFA in the mid-'60s who opposed the pebble bed approach.[145] He includes the scientific-technical director, Alfred Boettcher, as an opponent who preferred a different emphasis and therefore arranged a study on several different reactor types. Leo Brandt, however, stood out as a strong countering force in NRW who was "absolutely against the stopping of the pebble bed reactor," and in the long run he won.[146]

Boettcher himself relates the story somewhat differently. He felt that it was his responsibility as head of the Jülich research center to support the pebble bed approach, but he also saw a need to look into alternatives.[147] Focusing on one route would be bad and the selection of which design to pursue should not be made sooner than necessary, according to Boettcher. He therefore recommended looking into alternatives such as the impressive thermal breeder work conducted at the Oak Ridge laboratories in the U.S. and the molten salt reactor.[148] In Boettcher's own words, however, "One cool word about the HTR brought down the wrath of Leo Brandt," and, moreover, the utilities and chemical companies showed no interest in the alternatives because the immediate applications were not evident.[149]

This position of Boettcher's, though, was not against the HTR, and, in fact, he and Schulten led a successful fight to get the federal government to support the Jülich center at the same level as the Karlsruhe nuclear research center where the light water reactor and fast breeder reactor were being developed. Boettcher feels that it was a tactical error for the KFA Jülich to be so Land-oriented at the outset, and that is the one mistake he attributes to Schulten.[150] The KFZ in Karlsruhe went so far in making claims for what the FBRs could do that belief in the FBRs, according to Boettcher, became almost a "religion"

for them; he, in turn, worried that Leo Brandt was trying to make Schulten the "pope" of HTR development, and Boettcher wanted to avoid this because of the credibility problems which could be created.[151] Still, the focus at the KFZ Karlsruhe and the need for the KFA Jülich to attract more federal funding led the KFA Jülich to direct its work primarily at the pebble bed HTR. In December 1967, Hermann Laupsien reported in the Handelsblatt that large nuclear research centers seem to need a central task in order to stimulate the researchers and give them a common purpose, and Jülich had lacked such a focus.[152] Laupsien argued that the THTR should fulfill the role.

We also saw in this chapter that Schulten and his team did their best to keep up interest in the pebble bed HTR in the early 1970s by helping to convince KWU to pursue the design. A KFA Jülich official explained the BBC/GAC partnership as another attempt by the government to strengthen the industrial basis for a gas-cooled reactor.[153] This official said that Schulten and his team saw the partnership as a blow, but that research at the Jülich center was not greatly affected -- there was "no dramatic change of policy."[154] Looking at the situation from the manufacturing industry's perspective, a BBC official says there was tension between BBC and the KFA; and the KFA Jülich people around Schulten argued their case successfully not only with Kraftwerk Union,

but also within the Ministry for Research and Technology where they had better connections than BBC had.[155]

The focal point of the KFA Jülich since 1966 has been the pebble bed HTR, and naturally enough, the center has been supportive of the design. We need to recognize, though, that the KFA is directed mainly to basic research and certainly not to commercialization projects. Its influence, consequently, on the path of technological development is restricted, and we see this with the THTR. As soon as the THTR project was scheduled to be built, the work on it at the KFA ceased and shifted instead to subsequent HTR efforts. The type of influence which the KFA Jülich could exert after that was limited.

CONCLUSION

The critical aspect to see in examining the THTR project is the continuing disputes going on within the industrial, utility and government circles. In this case the competition with the nuclear reactor manufacturing industry is particularly significant. We saw that BBC had to cope with several major confrontations within the industrial sector, including having to find a new American partner -- thereby changing the course of German HTR policy -- and having to face the challenge of the largest German nuclear reactor manufacturer, Kraftwerk Union, entering the market. The utilities were not as much

steering technological choices as waiting in the wings to see what choices they would be offered. This has been the traditional role for German utilities, but calls are now being heard for them to fund much higher shares of expensive long-term projects. With the THTR, however, their contribution is still quite low and therefore so is their stake in its success. Finally, within the government the major distinction has been between the unwavering support of the Land North Rhine-Westphalia for the pebble bed HTR and the more internationally competitive orientation of the federal government, particularly within the Ministry for Research and Technology.

The real challenge for the development of high temperature reactors in the Federal Republic is to coordinate efforts among these sectors. The next chapter describes how such coordination did finally occur to an extent in the post-1975 era; this chapter gives some indication of why the various actors involved with HTRs had little choice but to cooperate by then. In the final two chapters we will have to grapple with how the actors in the future can benefit from the lessons of HTR development and agree on coordinated measures sooner. The partnership between BBC and GAC was both a setback and a catalyst for German HTR technology. This chapter has demonstrated the nature of the setback: the pebble bed system was put on hold and no new projects related to it

were undertaken. Schulten says that the 1972-75 period constitued a "real break" in German HTR research.[156] H. Harder of HRB says that traditionally in West Germany the manufacturing industry is responsible for planning follow-up projects; but in this case BBC and HRB could devote no time to pebble bed applications, besides the on-going THTR work, because of the new partnership with GAC.[157] The next chapter will elaborate on how the failure of the partnership was a catalyst to renewed efforts for the pebble bed system.

The 300 MW THTR was a prototype reactor, and its history certainly shows how susceptible prototype reactors are to changing priorities. Put another way, the momentum of a complicated, long-term project such as the THTR has an important bearing on the project's outcome. At the start of the project, HTRs were still viewed as competitors of LWRs for the production of electricity. Priorities shifted dramatically, however, and the application of process heat is now the major justification for HTR research. Coal gasification serves as a transition stage for the HTR, according to Karl Heinz Beckurts, and the important long-run application will be the splitting of water -- but that is still far off in the future.[158] In short, it is not completely clear which problems HTRs are supposed to be designed to solve, and the next chapter will show that the debate is still continuing.

The difficulty is that priorities shift and somehow the HTR gets adapted to the new situation. One has to question the wisdom of adapting projects to priorities rather than using priorities to determine which technologies are appropriate. Still, even though it might be wise in principle to choose priorities first and then technologies to match them, in practice such choices are not easy. One reason is that no one has the foresight to know what priorities will be in 20 to 30 years. Secondly, priorities alone will not identify which technological options are best. There are often too many choices -- as with the HTRs -- and the important step is for industrial actors to unite efforts to define which options are most feasible. A balance has to be drawn between the most advanced applications of a technology and its adaptability. Schulten hinted at this in 1968 when he claimed that, as a technician, his heart really belonged to the gas turbine HTRs, but he knew that there were too many technical problems to be solved first before the gas turbine HTRs could be a top priority.[159]

Running parallel to the issue of how to adapt a technology is the question of when to give up on a technological effort. With the pebble bed HTR no international interest in placing a commercial order has been shown; such orders are necessary if the reactor is to pay for itself, yet the German commitment remains. In fact,

the reason has become rather evident: it is the Land North Rhine-Westphalia, combined with some pebble bed adherents at the KFA Jülich. We are not implying that their support is unreasonable. Their perspective focuses more on the role for coal and jobs for the German industrial heartland, and what is interesting is the influential weight which they carry. The manufacturing firm BBC has also been reluctant to sacrifice all its HTR efforts although it was willing to refocus its efforts onto another design when prospects of commercialization seemed good. The federal government too would think twice before dropping the pebble bed HTR considering the large sums it has invested in the technology.

In other words, vested interests in a technological effort sprout up quickly and hinder the termination of a project. The successful examples of technological options being dropped in the Federal Republic usually involve major firms, like Siemens, which already have -- or can afford to develop -- other alternatives. Or else they involve firms like GHH which overstep their capacities and have to discontinue a technological option. In the Federal Republic, the manufacturing industry has made the key decisions for steering HTR policy. The most obvious example is BBC's formation of a partnership with GAC, thereby guaranteeing a shift away from the pebble bed design, but BBC's subordinate role in the reactor market limits their freedom of action in the HTR

field. In addition, the utilities have not yielded all power, and their influence would become readily apparent if talk of commercialization became evident again. The most interesting speculation, though, concerns what impact the presence of KWU will have on HTR development. After all, KWU fits the category of a firm able to afford other options and in fact already having them. One has to wonder what would happen to HTR development if KWU decided it was no longer worthwhile pursuing its process heat interests in the HTR.

In the development of a technology, it is essential to have a smooth transition from the R&D stage to the demonstration stage to the commercial stage of a specific project. The THTR example shows how HTR development in West Germany got stalled at the demonstration stage, partly because of licensing problems, partly because of changes in priority, partly because of personnel problems (e.g., many key people were shifted from the THTR to work on possibilities of an 1160 MW prismatic fuel HTR). Nonetheless, the ties of industry and the government to the HTR project have kept it going. Utilities have been less certain about what to do, and VEW obviously is still deliberating about what commitment to make to the HTR -- although officials from several utilities point out that political concerns, not technological or economic ones, are the root of the problem. The fact remains, though,

that decisions about what overall strategies are best are still left to the market in the Federal Republic, but the structure of the market rather than specific economic calculations tends to have the biggest influence on the course of technological choice and development.

NOTES FOR CHAPTER SIX

1. Shaw, Three Virtues, p. 399.

2. See, for example, the quotations from him in the Heidelberg Tageblatt, March 25, 1971, p. 10.

3. D. Schwartz and F. Schweiger, "Stand und Weiterentwicklung der THTR-Linie in der BRD," atw (May 1971): p. 235.

4. Shaw, Three Virtues, p. 275.

5. Schwartz and Schweiger, "Weiterentwicklung," p. 235.

6. In fact, extending the chart, the number of months to delivery can now be increased to over 40 and the earliest completion as of April 1981 will be September 1984. Follow-up conversation with the author, April 1981. Günter Hirschfelder, "Stand der Entwicklung des Hochtemperaturreaktors," VGB Kraftwerkstechnik Vol. 60 No. 6 (June 1980): p. 4.

7. Ibid., p. 6.

8. Ibid., p. 7; figures are valid as of April 1980.

9. Follow-up conversation with author, April 1981.

10. Hirschfelder, "Entwicklung," p. 5.

11. See for example PTH report, Program Status of HTR Development, p. 2.

12. BBK is the partnership between BBC and Krupp.

13. "Activities in the Field of High Temperature Reactors in the Federal Republic of Germany," IAEA Symposium on Advanced and High Temperature Gas-Cooled Reactors, Jülich, Oct. 21-25, 1968, SM-1117, Vol I, p. 173.

14. Konsortium THTR, Projektinformation 1, Dec. 1971, p. 2.

15. V.S. Boyer et. al., "High Temperature Reactors" in Nuclear Energy Maturity Vol. 2, Proceedings of the European Nuclear Conference, April 21-25, 1975 (Oxford: Pergamon Press, 1976), p. 213.

16. J. Bugl, W. Müller and K. Schlupp, "BBC Nuclear Development," Nuclear Engineering International, February 1973, p. 218.

17. Wilhelm Throm, "Kernkraftwerk Schmehausen -- ein teurer Versuch," FAZ, August 4, 1970.

18. Interview 24 with utility official, April 1981.

19. IAEA Symposium Oct. 1968, p. 182.

20. Nau, National Politics, p. 199. The prismatic fuel reactor, also called the block fuel element reactor, had a different fuel element than the pebble bed HTR.

21. See 3. Atomprogramm, Chart e.

22. "Die Entwicklung von Kernkraftwerken mit heliumgekühlten Reaktoren aus der Sicht der VEW," Report from VEW, Dec. 1979, p. 9.

23. Ibid.

24. G. Hirschfelder, "Entwicklung und Entwicklungstendenzen von Kernkraftwerken mit Hochtemperaturreaktoren," Sonderdruck aus VGB Kraftwerkstechnik Vol. 57, No. 1 (Jan. 1977): p. 11.

25. Ibid.

26. W. Mattick and J. Bugl, "Die Hochtemperaturreaktor - Baulinie: Stand und Aussichten," atw (October 1975): pp. 483-89.

27. Ibid.

28. Interviews 9 and 24, Jan. 1980 and April 1981 with KFA and utility officials.

29. Shaw, Three Virtues, p. 282.

30. Ibid.

31. Ibid.

32. Nau, National Politics, p. 200.

33. Ibid., p. 201.

34. Ibid., pp. 200-1.

35. Ibid. Remember BBK is the BBC-Krupp partnership.

36. Shaw, Three Virtues, p. 283.

37. Mario de Bacci and Pierre Marien, "The Moment of Truth for HTRs" Euratom Bulletin Vol. 8 (June 1968): p. 44.

38. Nau, National Politics, p. 203.

39. Ibid.

40. Deutscher Forschungsdienst, Sonderbericht Kernenergie, May 2, 1968 cited in Nau, Ibid., p. 204.

41. Interview with Schulten.

42. Ibid.

43. Interviews with Schulten and A. Boettcher.

44. Interviews with Hirschfelder and Olivier.

45. See Die Welt Nov. 4, 1968 and May 19, 1969 and FAZ Nov. 14, 1969.

46. Interview 32 with industry representative.

47. Ibid.

48. Ibid.

49. K. Müller "Der Hochtemperatur Reaktor" FAZ May 28, 1970.

50. Ibid.

51. Ibid.

52. Interview with Bugl who was brought in by GHH.

53. Ibid.

54. Interview 30 and Shaw, Three Virtues, p. 284.

55. Interview 30 with former industry executive.

56. Interview 32 with industry representative.

57. Interview with Rumler.

58. Interview 8 with KFA official.

59. Ibid.

60. Interview 32.

61. Bolke Behrens, "Kernkraftsprüche," Mannheimer Morgen Sept. 11, 1971.

62. Interview 12 with KFA official.

63. Nau, National Politics, p. 209.

64. Interviews with Schulten and Rumler.

65. Ibid.

66. Interview with Schulten.

67. Behrens, "Kernkraftsprüche."

68. Ibid., and Interview with Rumler.

69. Cited in Wolfgang Müller, "Wird der HTR auf Eis gelegt?" atw (July 1971): p. 5.

70. Ibid.

71. David Fishlock, "The Market Logic of Shell's Nuclear Bet," Financial Times, June 6, 1973.

72. Fishlock, "The U.S. Wants a Foothold," Financial Times, Oct. 25, 1972.

73. Gulf Oil Company acquired the General Atomic Division of General Dynamics in 1967. The new company was called Gulf General Atomic. In early 1974 the Royal Dutch Shell Group acquired a 50 percent share in the company which was renamed General Atomic Company. We have used the abbreviation GAC to refer to both companies.

74. Shaw, Three Virtues, p. 164.

75. Nau, National Politics, pp. 208-9.

76. Ernst Berens, "Der Kugel-Reaktor soll nicht sterben," Süddeutsche Zeitung, April 7, 1976.

77. Fishlock, "The U.S. Wants a Foothold."

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80. Nau, National Politics, p. 210.

81. Fishlock, "U.S. Wants a Foothold."

82. Ibid.

83. Ibid.

84. Jülicher Volkszeitung, Nov. 15, 1972.

85. Aachener Nachrichten, Nov. 15, 1972.

86. Interview 33 with NRW official.

87. Nau, National Politics, p. 209.

88. Fishlock, "U.S. Wants a Foothold."

89. Interview with Olivier.

90. Fishlock, "U.S. Wants a Foothold."

91. Interview with Schulten.

92. Interview with K.H. Beckurts.

93. Ibid.

94. Ibid.

95. Aachener Nachrichten, Nov. 15, 1972.

96. Fishlock, "U.S. Wants a Foothold."

97. Interview with Schulten.

98. Interview with Manfred Popp.

99. Interview 31 with BMFT official.

100. Interview 9 with KFA official.

101. Ibid.

102. Ibid.

103. Interview 30 with industry representative.

104. Ibid.

105. Interview with M. Popp.

106. Interview with Schulten.

107. Interview 27 with Member of the Bundestag.

108. "Kraft durch Kugeln," Der Spiegel, p. 106.

109. Interview.

110. Interview with Hirschfelder of VEW -- the information in the rest of the paragraph is mainly from the same interview and from an interview with Marnet.

111. Interview with Hirschfelder.

112. Ibid.

113. Interview with Alfred Dworak.

114. Interview 24 with utility official.

115. Interview 9 with KFA official.

116. Ibid.

117. Interview 24 with utility official.

118. Interview with Hirschfelder.

119. Ibid.

120. Ibid.

121. Interview 9 with KFA official.

122. Interview with Hirschfelder.

123. Ibid.

124. Ibid.

125. Interview 24 with utility official.

126. Süddeutsche Zeitung, July 7, 1974.

127. See the table above cited in footnote 7 and see FAZ criticism of low utility involvement, Aug. 7, 1970.

128. Quoted in Stuttgarter Nachrichten, April 10, 1981.

129. Ibid.

130. See Energy Daily, May 16, 1977.

131. The Committee for Research and Technology has conducted hearings about the HTR. See "Stenographisches Protokoll," 64. Sitzung, 8. Wahlperiode, May 14, 1980.

132. Interview 31 with BMFT official.

133. Ibid.

134. Interview with Popp.

135. Ibid.

136. Interview 31 with a BMFT official.

137. Ibid.

138. Interview with Popp.

139. Interview with Olivier; AVR figure cited in Bufe and Grumbach, Staat und Atomindustrie, p. 147.

140. Interview 31 with BMFT official.

141. Interview 27 with member of Bundestag.

142. Interview 33 with industry representative.

143. Ibid.

144. Interview with Olivier.

145. Interview with Schulten.

146. Ibid.

147. Interview with Alfred Boettcher.

148. Ibid.

149. Ibid.

150. Ibid.

151. Ibid.

152. "Die Atomforscher von Jülich," Handelsblatt, December, 1967.

153. Interview with Beckurts.

154. Ibid.

155. Interview 30 with industry official.

156. Interview with Schulten.

157. Interview with H. Harder of HRB.

158. Interview with Beckurts.

159. Quoted in Schulten, "Energie aus dem Kugelhaufen," VDI Nachrichten, July 17, 1968.

CHAPTER SEVEN

POST-1975 ATTEMPTS TO DEVELOP AN HTR STRATEGY

The THTR provided an example of how a reactor line can suffer if there is no agreement among the relevant actors about what common strategy to follow. Although the THTR is still uncompleted, the critical decisions at this point in HTR policy concern the follow-up project. Most of the time since GAC's 1975 failure has been directed to coordinating the next stage of HTR development, and there have been two key turning points. The first was a meeting at Dernbach in February 1976 for all the actors involved with HTR policy. The purpose was to decide if the HTR should be further developed, and if so, then how. One result of this meeting was a concentration of efforts on the pebble bed reactor, and a second result was that the actors agreed on the need to move ahead with a feasible, buildable project as soon as possible.

The second turning point was the October 31, 1979 decision by a group of electrical utilities along with two major coal and gas concerns to plan the next steps and place an order for a THTR follow-up reactor. The operating consortium consists of an association of

several utilities, the Hochtemperatur-Reaktorgesellschaft (HRG), and a consortium of Ruhrkohle AG and Ruhrgas AG each holding 50 percent shares.[1] This arrangement is essential for progress on the HTR because the federal research ministry has indicated clearly that financing for the next HTR project has to come primarily from non-state sources.

According to D. Kutschke, head of the section which deals with HTRs at the BMFT,[2] this push toward practical applications is the most important impulse which the federal government has given to HTR policy, and he says, "We are pushing the accent from R&D forward to the practicality of designs."[3] It is a distinct change from the government's previous support, and it remains to be seen how the business sector reacts. A preliminary project phase drew to a conclusion in June 1981. The manufacturers presented their joint offer to the utilities two months earlier, and the utilities, after analyzing the offer, agreed to move ahead with the project but financial arrangements are still to be arranged.[4]

These two turning points indicate that the main issue in HTR development no longer relates to disputes <u>within</u> the utility, manufacturer and governmental sectors, but rather to coordination <u>among</u> them. Many of the controversies which plagued the THTR project no

longer remain since the individual actors have realized that no progress will occur without agreement on the next HTR phase. The approach to HTR development has thus changed markedly since the initial AVR project. At that time, in the late 1950s, all projects were encouraged and the goal was to put the German nuclear program on sound footing. In the 1960s unsuccessful efforts were made to consolidate German HTR plans, and a major reason for the lack of success was the competition within sectors. By the second half of the 1970s, however, the picture had changed and the various sectors were working together to narrow options. This was spurred on both by GAC's failure with its HTR design and by the recognition of the sectors that they had to pool resources in order to have any chance of success with the high temperature reactor. The cooperation came about, however, because the actors realized that they had no other choice -- i.e., they were basically forced to work together. As Wolfgang Müller, the editor of Atomwirtschaft says, "It was a marriage of necessity, not of convenience."[5] Without cooperation, there was little chance for success with the HTR.

THE ROLE OF ECONOMIC CALCULATIONS AFTER 1975

This evolution of HTR development is important to consider because it suggests how complex the issues concerning cooperation on reactor policy are. Nearly

all the actors recognized in the late 1960s that the kind of coordination which finally took place in 1976 was necessary, but there was no catalyst to bring them together. Hence, if we talk about the relationship of economic calculations to technological choices, then we have to see that in a complex situation one has to identify whose economic costs are relevant and how they are figured. The interdependence among the sectors is so great that no individual actor can accurately predict overall cost calculations. There are too many uncontrollable factors and the goals of a project are not always evident. The problem with the HTR is that it has never had a technological priority or imperative, and thus it was never fully clear why the reactor was being built. The rationalizations for why the HTR should be pursued have changed often, and the debate is still unresolved at present -- as we see in the continuing debate on process heat applications versus electricity applications.

Three Reasons Why This Phase is Important

This phase of HTR development after 1975 is important for understanding how technological choices are made because it underscores first of all the difficulties which remain even after a technological consensus is reached. The German actors agreed in 1976 to proceed on the basis of the pebble bed system, but that

solved only part of the problem. They also had to agree on what objectives to pursue, and although they cooperated well to decide what the next step should be, old interests tended to die hard. The interests still continue to reappear.

Secondly, this phase indicates that market considerations have only limited relevance to determining the course of reactor development, partly because of the complexity of projecting costs over a long time frame, and partly because economics alone cannot determine how one should select among widely varying reactor applications. In the Federal Republic, for instance, the HTR actors decided in 1977 to concentrate efforts on the sophisticated one-cycle helium high temperature reactor (HHT) because they thought it would be the most economical reactor to operate. Shortly thereafter, the decision was reversed due to the complex technological problems involved. The time needed to solve the problems was too much; the concept remained interesting but a project that could be completed sooner was needed. In other words, economic needs have to be balanced with practical needs -- such as the training of personnel, keeping morale high on a project, and pursuing ideas that stand a chance of being approved by the licensing authorities. Such practical needs cannot be quantified easily.

A third reason why this phase is important is that it demonstrates how the market position of a firm has a major effect on how the firm determines its economic interests in a project. One example is RWE which has large soft coal reserves enabling it to produce energy cheaply without relying much on nuclear energy. Other utilities are less fortunate with their reserves and therefore have to opt for nuclear reactors or else use expensive hard coal. A second more striking example is Kraftwerk Union which has a very different perspective on the HTR market than its competitor, BBC. For KWU the HTR is one reactor line among several. For BBC, in contrast, it represents the main thrust of their efforts for the past 25 years. Whereas BBC might be content just if the HTR could be a mild success, KWU insists on a brighter prognosis with better guarantees. According to one industrialist, KWU moved into the HTR field in 1972 in order to exert some control over HTR development; the firm will be able to decide whether to drop the project or develop it further according to the reactor's chances.[6] Subsequent interviews with a KFA official and a politican corroborated this point of view.[7] KWU, in effect, acquired an option on the HTR's future, but the basis of KWU's market calculations is very different than BBC's basis.

This chapter shows the need for some agreement to be reached among actors in the policy process to narrow choices. It took a long time before the German utilities, government representatives and manufacturers reached this point, but the increased cooperation is evident beginning in 1976. The question is, however, whether the coordination came in time, is sufficient, and has applicability to future policy making.

One politician described the "blossoming" of so many HTR options 10 - 15 years ago as the "Let 100 flowers bloom" approach to reactor development.[8] He said that private industry now has to choose which route to follow. The technological possibilities of the HTR are recognized and acknowledged, but it is not enough to say that the HTR is the reactor of the future, as some claim. It is important to ask <u>which future</u> the HTR should aim at and why, and what are the circumstances under which commercial HTR orders will be placed? And for all the complexities involved in HTR development, the case actually remains simpler than it might be since the factors affecting the development tend to be domestically determined rather than internationally determined.

OVERVIEW OF POST-1975 HTR DEVELOPMENT

Before 1976 the HTR suffered from a multiplicity of possible options -- e.g., the one-cycle or two-cycle reactor, the pebble bed or block fuel element, integrated versus nonintegrated systems, and a focus on process heat or electricity production. At the beginning of 1976 several HTR concepts stood in direct competition with one another:

- --the HTR-1160 proposed by GAC and HRB and designed to use block fuel elements.
- --the HTR with helium turbines which had several variations relating to the style of construction and number of loops.
- --a reactor for process heat generation with pebble bed fuel elements and two reactor containers.
- --a new variation of the two-cycle HTR which used the pebble bed system and, at the request of the utilities, aimed at a more practical reactor container.[9]

In total there were over 10 options and they had to be reduced. That was the purpose of the meeting called at Dernbach for February 1976. Finding one basic concept for the two major applications of process heat and electricity generation was particularly essential, according to Dr. H. Harder of HRB.[10]

The Dernbach Meeting and its Outcome

The meeting at Dernbach was called by the BMFT and included representatives from the federal government and

North Rhine-Westphalia government, the utilities, the nuclear research centers and the manufacturing industry. The coal and gas industries were brought into the discussions later. At Dernbach the decision was made to return to the German HTR orientation and not pursue any parallel developments such as the GAC design. Karl-Heinz Beckurts says that calling the meeting was an important initiative on the part of the BMFT, but it was also a "logical step," particularly since the utilities had been "a little slow" on decisions.[11] The utilities were waiting for some signals on HTRs. One of the directors of VEW, Erwin Glahe, acknowledged in late 1975 that no clear decision could be made on the utility's position on the HTR until 1976 when the reports of several teams of experts would be available.[12] Chrysanth Marnet of the Stadtwerke Düsseldorf says that the utilities were pleased that the meeting was convened because it promised to strengthen the whole HTR line, but he also feels that the pressure of the politicians was the reason the session was called.[13]

In short, the invitation to the Dernbach meeting was welcomed and considered necessary by nearly all the actors. It did not signify a new commitment by the BMFT to the reactor -- the Ministry had long been the major source of funding -- but it did remove any

fears that the government might withdraw support. The real issue was whether the HTR should be used for process heat applications or electricity production. The recognition of the importance of process heat stemmed from the late 1960s and was behind KWU's decision to enter the HTR field in 1972 after BBC placed its emphasis on electricity generation. Rudolf Schulten recalls that he and his associates were often laughed at when they argued the case for process heat around 1968.[14] The attempt at Dernbach was to unify the technological bases of these two approaches to the HTR into one concept; this necessitated bringing KWU and BBC together. The goal was that each firm would be responsible for one major component of the HTR, usable for both applications. Dernbach was a recognition that one could no longer rely on the U.S. for the market introduction of the HTR, and consequently the Federal Republic needed to consolidate its efforts while also seeking international cooperation wherever possible.

Domestic considerations, as usual, were significant in this decision. Process heat applications were important because the Germans have abundant but expensive coal. Although the American firms General Electric and GAC have expressed an interest in process heat applications, coal is simply too low cost in the U.S. for the interest to be serious.[15] Energy-poor Japan with

its steel production needs is much more interested in process heat. For the Germans, coal is more than a material; it is an institution.[16] And the champion of coal is the Land NRW.[17]

Study groups were set up at Dernbach to decide on the next phase of HTR development. The Germans called this period a "new orientation phase," and they outlined five goals to achieve:

1. a narrowing of HTR concepts;
2. a concentration of efforts by industry, the operators and the research centers;
3. priority to an HTR utilizing process heat;
4. increased international cooperation;
5. top priority to completing the THTR.[18]

Short deadlines were intentionally set. A decision was made by June 1977 that the next HTR for electricity prodocution would be the direct-cycle HHT, and the next HTR for process heat would use the same reactor container, integrated construction system and pebble bed fuel system.[19] That meant that the desire to have as similar a basic concept as possible for HTR development was largely achieved. In 1978 an offer to build a demonstration HHT was anticipated for 1983 and an offer for a prototype process heat HTR was anticipated for 1985.[20]

Stated briefly, the differences among the HTR policy actors which had to be overcome were that the various utilities had differing priorities, KWU and BBC had to delineate responsibilities, the BMFT wanted to strengthen the domestic nuclear industry and reduce its own share of costs, and NRW wanted to guarantee a future for coal. The actors recognized, though, that compromise was mandatory if the German HTR program was to have any chance of success. According to utility and manufacturing industry representatives, national interests did play a part in the return of emphasis to the pebble bed HTR, but the DM 2 billion already invested by the government also influenced the choice.[21]

After Dernbach, a consensus emerged among the actors in German nuclear policy. The long term goal of the HTR program was the commercialization of the system for process heat and electricity production, and the short term goal was to demonstrate that the HTR technology was feasible for both applications and could be economically applied.[22] The government acknowledged that a national program was necessary which encouraged a concentration of efforts on the technical and organizational level. According to the government's 1978 report:

> A program of such an extent can only be performed within the frame of a national program, embedded as far as possible in international efforts. National program means that the

> main burden of the development in the introduction phase has to be carried by the public, i.e., by the government. Major contributions from the users can only be expected and demanded as far as a commercial utilization of the technology can be envisaged. As the public funding resources are limited today and in the future, a strong technical and organizational concentration is indispensable. A technical concentration will be possible by the development and application of the same basic design concept for the nuclear heat supply system for both lines. This system should have as many common features as possible for electricity production and for process heat application.[23]

The report recognized that the limited funding resources and development capacities should be directed at establishing confidence in the new technology, and hence it proposed the introduction strategy set forth in the table on the following page.[24] The strategy is geared to the eventual market introduction of the HTR, and the goal of the first phase is to demonstrate that the HTR technology is available and can be economically applied.

The Helium High Temperature Reactor (HHT)

The deliberations after the Dernbach meeting led to the surprising result in 1977 that the next HTR would be the direct cycle HHT. The expectation at Dernbach had been that the more conventional two-cycle concept would be chosen.[25] The HHT concept is characterized by coupling the helium-cooled HTR directly to a helium gas turbine without the use of a second cycle which would reduce efficiency.[26] The HHT was selected over the two-cycle

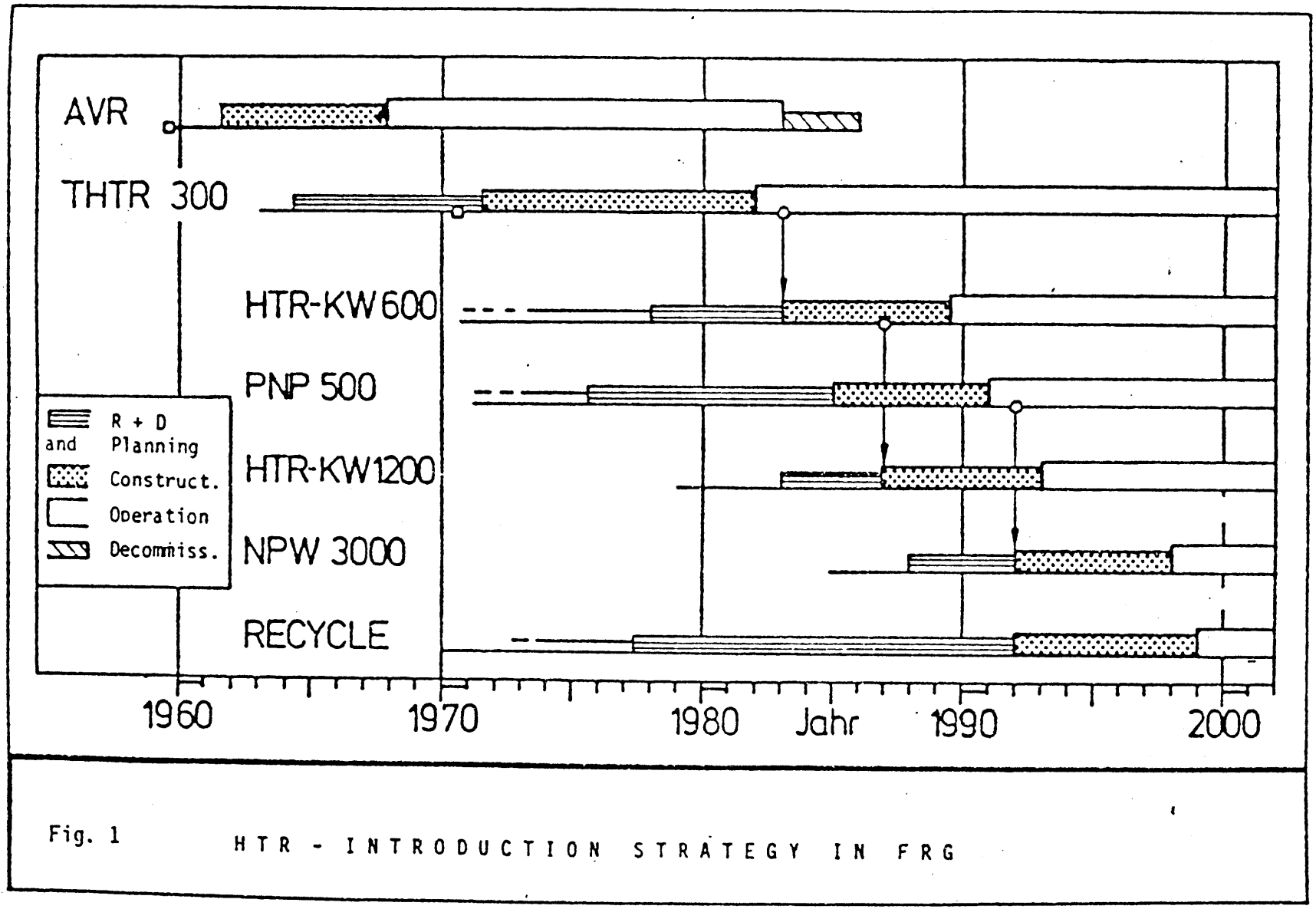


Fig. 1 HTR - INTRODUCTION STRATEGY IN FRG

Source: PTH Progress Report, p.3

concept because the market for the two-cycle process was not evident, but it was also recognized that there were some difficult technical challenges involved with the HHT which would require a longer development period. By 1979 emphasis shifted back to the two-cycle design because the HHT problems proved to be more intractable than expected.

BBC was largely responsible for the decision favoring the one-cycle system.[27] The firm held discussions with several German utilities, although the decision itself was made by BBC and then analyzed and agreed to by the utilities rather than being a joint decision.[28] One relevant factor was that Heinrich Mandel, the top executive at RWE at the time, had a long-standing interest in gas turbines.[29] More importantly, BBC had been investigating HHTs since 1972 in a joint German-Swiss program with the Swiss BBC company. BBC had some doubts about how competitive the two-cycle HTRs would be with the LWRs. BBC/HRB thought that the market chances of the HHT were greater.[30]

Moreover, the two-cycle HTR being considered, the HTR-K, had its own problems because it reflected a bad compromise between the American and German designs.[31] The two designs differed according to number and location

of turbines; the Germans sought a solution to accommodate both approaches, but the resultant reactor plant did not work well. The HTR-K promised only marginal advantages over the very successful LWRs which West Germany was building then, and hence the utilities did not feel that a new design was necessary. Interestingly, the very success of the German LWRs -- in contrast to the American LWRs -- limited the attractiveness of the HTRs.

The advantages seen for the HHT were: (1) higher efficiency than the LWRs or other HTRs; (2) dry cooling towers which are economical and establish siting independence from water sources for cooling as with the LWRs; (3) the possibility of separating a high district heating quantity (much more important for the Germans than for the Americans) without losing electric power; and (4) the potential for greater growth in know-how for process heat applications in the critical engineering areas.[32] Everyone recognized that several technical problems had to be overcome for the direct-cycle HTR, but it was not until 1979 that these problems became overwhelming enough to alter the form of the development program. BBC, RWE and Preussen Elektra were the primary supporters of the big direct-cycle plant; the opponents included the coal firms, the smaller utilities which felt that the HHT program was over-ambitious, and VEW.[33]

The revisions which have occurred recently in the HTR program go back more to the wishes of the HHT opponents.

Detailed design and optimization studies were conducted on the HHT between 1977 and 1979, and the studies revealed technical details which were going to require considerable unforeseen design and R&D work. Extrapolating the pebble bed reactor beyond 300 MW to 900 MW or more was not easy. Problem areas arose with respect to the pebble bed core, the gas turbine and safety aspects, fundamental feasibility studies, and plant cost assessments.[34] The predicted yield on plant efficiency decreased to the point that it was not significantly higher than the expected steam cycle figures (40% versus 37-39%), and the advantages of dry cooling and the utilization of the HHT as an economic district heat source also were questioned. The 1979 government status report on the HTR concluded that although the HHT project should be continued, it should not be the short-term THTR successor because "the necessary development tasks such as materials testing, gas turbine demonstration, component development and testing, graphite qualification, design optimization and licensability require a longer development time and will not allow a decision for construction before the late 1980s."[35] The HHT remains an intriguing idea, but its practical application is too far off in the future.

The interesting point about the HHT is that it reflects the need to balance off the technically most promising projects with the technically most feasible.- The HHT is an example of a sophisticated idea which simply poses too many difficulties to be the first priority of the German HTR program. Fortunately, the recognition was made in the planning phase so that it was not too expensive. Developing a new reactor is a function of trail-and-error, but the good cooperation after Dernbach meant that problems could be recognized early in the process.

Three working groups had been set up to study HTR development (one on plant design, one on physics and thermohydraulics, one on R&D necessary for the whole plant), and these groups affected the swing back to the steam-cycle HTR in 1979 due to the problems they discovered.[36] At first, discussion was difficult and the utilities were prone to "talk around" each other, but gradually everyone benefitted from the experience of the others.[37] The HHT plant design was changed drastically, and it became clear both how expensive the project was becoming and that the theoretical efficiency of the gas turbine had been overestimated. Both the experience with nuclear reactors and also with conventional power stations helped identify problems.[38]

The Swing Back to the Steam Cycle and the October 31, 1979 Decision

The actors in German HTR policy agreed in 1979 that the basis of successful industrial development and economic application of the HTR technology could only be achieved on the basis of further construction and operation experience and not only with long-term R&D programs.[39] The emphasis was more on what could be accomplished, and the reasons were quite practical: to maintain the reactor industry's engineering capacity, to encourage the component supply industries to invest further in HTR technology through construction projects, to keep the regulatory and licensing authorities engaged through more construction, and to create users' confidence as a basis for increasing financial engagement in later projects.[40] The predictions about the construction start-up and the licensing prospects for the HHT were simply too uncertain.

The BMFT has been growing impatient with the slow progress in the HTR field. The ministry has been pointing out to the utilities that they must show a greater willingness to share the HTR financial burder, and these messages have been especially strong in the early months of 1981. Der Spiegel reports that BBC and North Rhine-Westphalia still support the HTR but that the research ministry in Bonn believes that it has done enough for the

project; State Secretary Erwin Stahl is quoted as saying that the federal government still feels the HTR can play a role in future energy programs, but "whether the HTR will play a role depends in large part on the engagement of private industry."[41]

The decision on October 31, 1979 by a group of electrical utilities together with the coal and gas firms, Ruhrkohle and Ruhrgas, to form a consortium for the development of the HTR was an important step in post-1975 HTR policy. Earlier, we labelled it and Dernbach as the two turning points in this phase of development. The importance lies in the expectation that an HTR order will emerge from the group. The basis for discussion is the two-cycle HTR; the formation of the group confirmed that the BMFT, the manufacturers and the utilities all agreed that the HHT should be dropped as the THTR follow-up.

Not only was the BMFT instrumental in bringing about the formation of this group, but also it has increased the pressure for the private sector to assume development costs. The BMFT is departing from its approach from the past and now wants to change the conditions for future HTR support. The emphasis is on the practicality of designs, not on R&D. Rather than removing its

HTR support, the ministry says it will provide additional support for the THTR line, but parallel to that it demands some evidence that the reactor operators are interested in placing their own orders for HTRs.[42] The ministry wants a clear signal. The federal government will not break off HTR funding abruptly, but it wants some proof that the private sector is including the HTR in its own budgetary planning.[43] Ten years ago there was not enough technological expertise to make such demands, but now there has been enough progress on the THTR to expect the private sector to give some clear indications about how the HTR fits into long-range industrial planning.

The challenge, then, is to determine <u>which</u> HTR design to use in trying to market the reactor. R. Rumler of BBC says that the reactor manufacturers presented themselves as one group to the utilities; now the main questions for the potential reactor operators are (1) what their financial participation will be and (2) what size reactor they want.[44] The manufacturers are prepared to build reactors ranging from 200 to 900 MW, but they need to know what the market wants. The technical basis for developing the HTRs already exists; now the financing problem has to be solved. When the BMFT insists that the private sector assume more of the financial

costs, it means both the manufacturers and the utilities, but in practice the burden falls mostly to the utilities.[45] Kutschke of the BMFT says the decisions have to be left to those who will use the technology: "That is our new approach. Perhaps it is coming late, but it is not too late."[46] The deputy editor-in-chief of Atomwirtschaft, Rüdiger Hossner, argues against this, claiming that the HTR has so many potential uses that the state should continue supporting it (although not at the same 90 percent level of the THTR) in the hope that a market breakthrough might take place.[47]

STRUCTURAL CONDITIONS

The effect of political-organizational structural factors on this phase of HTR development differs considerably from earlier phases. In the earlier phases, the striking characteristic was the competition within the individual sectors. Here, the striking characteristic is the coordination among the utilities, manufacturers, research centers and government. This also differs from LWR development where the utilities, for specific reasons, assumed a special role. The purpose of this section is to examine the various sectors to see how and why coordination since 1975 has taken place, but also to see how old interests keep reappearing.

said the utilities, including RWE, wanted the manufacturers together, and that left BBC little choice because the manufacturing firms have to heed what their reactor operators want.[52] If the manufacturers wanted the utilities' business, they had to combine their total technological potential. North Rhine-Westphalia also welcomed KWU's involvement in the HTR field; the Land gave KWU a DM 1 million grant to study process heat applications for the HTR as a means to bolster the pebble bed concept.[53]

The cooperation between the two firms, however, is only adequate. Utility representatives, industrialists and politicians all made this point and said one should not forget that the two firms are direct competitors.[54] One BBC official claimed that BBC has benefitted practically not at all from KWU's involvement with HTR technology, although it is a different story concerning the business aspects of HTR development.[55] Here, KWU's presence had a positive impact on potential financial backers. KWU, nonetheless, lacked the know-how and the personnel that BBC had, and its other interests made the firm reluctant to devote resources more fully to the HTR.[56] KWU's real interest in the HTR, according to BBC officials and politicians, was to exercise some control over its development.[57] Then, based on the HTR's projects, KWU could either pursue the project more intensely or drop it.

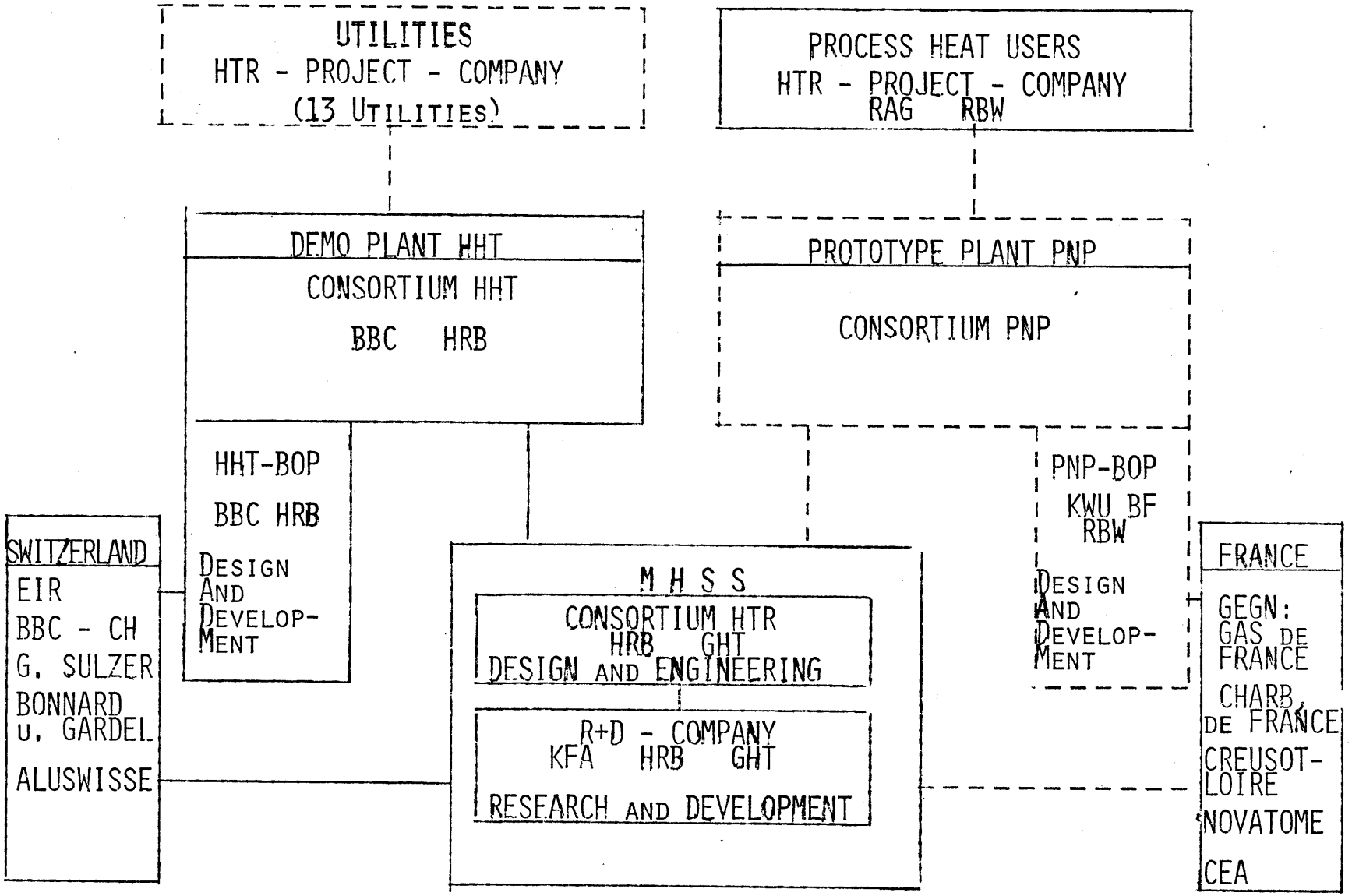
The Manufacturing Industry

Kraftwerk Union and BBC are the only two reactor manufacturing firms in the Federal Republic, and their cooperation did not become serious until this post-1975 phase. KWU entered the HTR field in 1972, but its interests in process heat were independent of BBC's interests. Only after the Dernbach meeting did the divergent interests in electricity production and process heat merge. One should note, however, that the relationship between the firms is clearly affected by KWU's dominant position. 34 orders for nuclear reactors have been placed with KWU, while BBC has had only one order.[48] One utility official said BBC has the technical background for developing the HTR, but KWU has the industrial power.[49] Another utility representative echoed this view, saying BBC has more HTR experience while KWU has more financial capacity.[50] In fact, the utilities and the government are happy that BBC offers at least token competition to KWU, thereby preventing a KWU monopoly on the domestic nuclear reactor market.

BBC did not welcome the competition, but all the other actors involved with the HTR did. One BBC official said that the BMFT and the reactor operators were responsible for bringing KWU into the HTR field.[51] They wanted to broaden the basis of the HTR. A second BBC offical

The cooperation at present looks satisfactory when one considers that the two firms agreed on a common project to offer the utilities at the end of March 1981. During early 1980 a confidential decision process took place between the chairman of BBC and KWU regarding what role KWU would play.[58] Der Spiegel, however, ran an article in January 1981 claiming that those arrangements had broken down. Each firm was to develop its own plans for a large HTR, but then BBC published its plans at the HTR seminar at the KFA Jülich in January without informing or inviting KWU.[59] KWU has doubts about BBC's plans for a large reactor, according to Der Spiegel, and it feels that its "loop-concept" which consists of several smaller HTRs placed together is safer and more feasible.[60] The Spiegel article, though, is dismissed by a BBC official as not well-based on facts, and a BMFT official says it exaggerates some concerns which KWU once had but which never became policy for the firm.[61]

It seems likely that the competition which remains is not as fierce as Spiegel implies. The chart on the following page shows how the BBC and KWU industrial groups have divided tasks for the HTR.[62] As H. Kutschke says, "It is wrong just to characterize the BBC/KWU relationship as a rivalry. They have fully different areas of interest."[63] The chart shows this clearly. The



ORGANIZATIONAL STRUCTURE OF THE HTR DEVELOPMENT

firms have differences, but mainly about projects which exist only on paper so the differences are not significant. KWU has been less active recently since the work on process heat has slowed. This bothers some of the utilities which maintain that the manufacturing firms have to pull together if the HTR is going to be developed.[64] They do not like the secondary role which KWU has been playing most recently.

It is worth recalling that KWU was attracted to the HTR because of its process heat application. In the Federal Republic, 70 percent of all energy produced is for heat application and only 30 percent is for electricity.[65] The Germans were inevitably attracted to the uses of process heat, and the HTR was the ideal reactor for the uses because of its much higher temperatures than the LWRs. In 1972 the mining companies joined in the cooperation, and the government assessed the potential in 1974-75. According to Karl-Heinz Beckurts who led the government investigation, however, the realization gradually dawned that "process heat is not the simplest thing to do."[66]

Again, as with the HHT, there are time-consuming development tasks involved -- this time concerning testing the heat-exchanging components, the elimination of tritium in the final product, and the licensability

of the combined nuclear-chemical plant.[67] The decision that the process heat project, PNP, should not be the THTR successor project came easily because all the actors agreed that PNP involved too long a waiting time for industry's purpose.[68] This meant, though, that KWU's interest would be reduced. The distinction between PNP and electricity production is also not as relevant now since plans for subsequent HTRs will not be oriented solely in one direction or the other.[69] The THTR follow-up will be primarily an electricity-producing reactor, but this is not a setback for process heat applications because an experimental chemical plant will be connected with the reactor and thus the licensability of process heat plants will still be tested.[70] The decision against making PNP the THTR successor project boiled down to the fact that a reactor project with process heat application would have cost DM 4 billion without any guarantee that it would be licensed.[71]

The Electrical Utilities

The post-1975 period was also the first time that the utilities had to work together and reach a consensus on a common strategy. The time since Dernbach has been challenging because:

(1) the utilities had to resolve major differences of opinion within their own sector about which HTR strategy should be followed;

(2) the largest utility involved with the HTR, VEW, backed off in its support and a successor had to be found;

(3) many of the utilities wanted stronger financial backing for the HTR than just through BBC so they encouraged more cooperation between KWU and BBC;

(4) the utilities faced pressure from the BMFT to finance more of the HTR costs;

(5) the BMFT's pressure and the utilities' shared technological interests compelled the utilities to work more closely with coal and gas firms, but the utilities were reluctant to do this.

In short, the role of the utilities has been changing dramatically from the old traditional role of reacting to the initiatives of manufacturing firms.

The complexity of nuclear technologies has made it mandatory for the utilities to be involved earlier and more fully in technological choices. The manufacturers need to know what the utilities want, and they need the financial backing of the utilities; the utilities also recognize the need to be involved earlier in order to understand the potential of reactor systems and to gather the technical expertise necessary to operate the reactors. None of the actors in HTR policy-making was opposed to more cooperation after 1975 but, of course, some inevitable problems with working out arrangements emerged. For the utilities, any coordination

was an improvement because, in the words of Ulrich Steger, a member of the Bundestag, "the cooperation among the utilities had always been miserable."[72] They knew that more coordination was a precondition to any further progress on the HTR.

In the last chapter, we saw that the utilities were willing to support a whole range of HTR strategies. Following GAC's failure, the utilities were not at all certain about what path to follow. The regional utilities, including the AVR group, favored the small steam-cycle reactor. VEW supported the big steam-cycle reactor. RWE and some of the North German utilities, such as Preussische Elektrizitäts A.G., wanted the big direct-cycle reactor. Some other North German utilities shared BBC's preference for the block fuel element HTR.[73] No real agreement existed until 1978 when the large direct-cycle reactor was chosen. According to one AVR official, E. Ziermann, the BMFT's pressure on the utilities to agree on a common position was effective, but it is still not clear what the final outcome will be.[74] The individual utilities do not have to abandon their former interests because the tentative nature of the HTR development plans means that the old interests may become relevant again.

The effect of this process is that the utilities do respond to pressure from the BMFT, but they are always careful not to take too big steps in a new direction. The tendency for German utilities is to hesitate on forcing technological development and instead opt for low risk alternatives.[75] The government, on the other hand, wants to encourage a more systematic, long-run oriented approach. The utilities proved willing to go along with the one-cycle HTR once a decision was made by the manufacturers for it, and then the utilities proved equally willing to switch priorities back to the two-cycle reactor. The situation is rather paradoxical because utility and manufacturer representatives alike acknowledge that the manufacturers have to listen to the wishes of the utilities, yet the utilities seem to wait for the manufacturers to suggest initiatives. The government and the manufacturers want clearer signals from the utilities -- and that will involve more of a consensus.

VEW was the leading utility in HTR policy until the decision for the one-cycle HHT was made. VEW had never liked the HHT; it felt that the project was too ambitious and it advocated -- and still advocates -- that the HTR emphasis should be on producing electricity rather than on process heat.[76] VEW had established close international contacts with the French, English and

Scots, but this international interest faded when the Germans made the direct-cycle reactor their priority. VEW remains bitter about the HHT decision.[77]

VEW yielded its leading role on HTR policy to a new utility group led by Preussische Elektrizitäts A.G. (Preag). According to Günter Hirschfelder of VEW, the utility conceded its position due to personnel reasons and the politicization of nuclear energy in the Federal Republic which stalled development plans.[78] VEW wants to concentrate its staff expertise on completing the THTR project, and it feels that the political conditions are too open-ended to proceed with another HTR project now. The politicized situation keeps the schedule for THTR completion open and uncertain, that leaves the costs uncertain, and as a result VEW has grown discouraged about future HTR prospects. There also are indications that VEW is displeased that KWU has reverted to playing a secondary role in HTR policy.[79]

Non-utility officials regret that VEW is no longer involved with the THTR follow-up project. It would have been a logical choice. At the same time, HTR advocates are at least pleased that another large utility consortium with considerable industrial strength including Preag and NWK (Nordwestdeutsche Kraftwerke A.G.) has filled the void left by VEW.[80] In political circles,

the explanation for VEW's backing out is that not only was the utility discouraged by the lack of progress on the THTR, but also it faced serious economic problems.[81] The explosion in gas prices hurt VEW which had placed too much reliance on gas. Past decisions and a lack of cheap energy sources haunted the utility: it had been involved with too many overly ambitious projects, and after the gas price increases, it had no money left for other long-range alternatives.[82]

In other words, there may be internal reasons contributing to VEW's changed role, but it is also evident that the utilities are restricted in their freedom of action about reactor policy because of both their approach to the problem and the pay-offs which are important to them. The utilities are attempting to analyze needs from a long-run perspective, but their thinking is still oriented to the short-run pay-offs and to encouraging electricity use rather than evaluating overall energy policy. Herman Hatzfeld says that the utilities are using clever pricing schemes and new devices such as heating pumps to maximize the use of electricity. Their goal is that one-third of all German households will be heated by electricity by the year 2000.[83]

The utilities may be what one utility representative labelled as "the controllers" of reactor development,[84]

but they also favor low risk-taking in determing reactor policy. On the one hand, they are able to engineer cooperation between the manufacturing firms. Another utility official says that the coordination between the manufacturers and the utilities is "very good," and the manufacturers will not produce what the utilities do not want.[85] On the other hand, the utilities tend to opt for conservative alternatives and not force technological development in order both to reduce risks and to add to the chances of achieving consensus within their own ranks.

The Federal Government

Whereas the manufacturers and utilities had to learn to coordinate policies among firms, the federal Ministry for Research and Technology was learning to assert itself more in steering German nuclear policy. This represented a continuation of the pattern of increased influence for the BMFT which was described in the previous chapter, and the last two sections of this chapter have also pointed to this new role. The federal government, through the BMFT, put pressure on the private sector after 1975 to coordinate HTR efforts, and the ministry has maintained this pressure. One reason it has been able to do this relates to its increased expertise in nuclear matters (especially compared to the early years of German nuclear policy when the ministry

played a subordinate role to the German Atomic Commission), but a more significant reason is that the other nuclear policy actors knew that coordination was essential and therefore they appreciated and accepted the BMFT's efforts.

The nature of the ministry's attempts to exert influence has also been responsible for the success of the policy. For the most part, the BMFT has only tried to affect organizational and financial issues. The ministry has avoided forcing issues on technical questions.[86] Even though it has provided about 90 percent of the support for HTRs, it still leaves technical decisions to the participating firms. Since 1976 most of the decisions on HTR strategy have occurred in the committees and working groups involving the various actors. The BMFT has always been present at such meetings, but it considers itself a guest at them.[87]

Nevertheless, the BMFT has given some important impulses to HTR development in this period. We discussed above that the ministry now insists on seeing that the private sector will incorporate HTR plans into long-range industrial planning. The message now is that a decision on a THTR follow-up project should be made soon, should be feasible, and should be financed by the priavte sector -- i.e., mainly the operators. The

federal government too has gone through a learning process, and now feels it is time to shift from general to practical applications of the HTR.[88] Despite this shift in focus, though, the BMFT says adamantly that they are not forcing a selection process between the fast breeder and high temperature reactors; each has its own significance and there is no rivalry, but more utility participation is needed for each system.[89]

Although there is satisfaction with the role played by the ministry for the most part, some criticism can be made that the ministry has become too involved in steering reactor development policy. The criticisms are that the BMFT assumed too much of an activist role. One KFA official accused the ministry of going beyond financial and organizational problems starting in 1976 with the Dernbach meeting and trying to force technical solutions.[90] In the HTR-K decision, for example, the BMFT went too far in deciding even what the reactor should look like -- i.e., it was to have a pre-cast iron vessel. Finally, after several months of working with this assumption, the actors recognized that the decision was wrong.[91] A utility official also criticized the BMFT for exerting too much pressure on the utilities and being too strict with them.[92] Another utility official, however, defends the BMFT, saying they have never demanded technical solutions but rather have supplied

support for the manufacturers and utilities and have relied on them for technological development.[93]

Some criticism has also been made that the BMFT opposed HTR development, but the ministry vehemently denies this. One politican claims that the BMFT wanted to let the HTR project die, but the North Rhine-Westphalia government and the I. G. Bergbau trade union prevented this.[94] According to him, the Bundestag, the Ministry of the Interior and the Federal Chancellory are all more positive about the HTR than is the Ministry for Research and Technology.

BMFT officials admit that NRW's support for HTRs has been greater than their own, but they dismiss the accusations that they wanted to let the HTR project die as nonsense.[96] One official stated bluntly, "At no time in the whole HTR history did the federal government lead an organized process to cancel the HTR."[97] The BMFT feels that its present efforts are constructive because they attempt to shift the burden of financial development of HTRs to private industry for the post-THTR phase without abruptly cutting off government support.[98] The BMFT wants the focus to shift from possible applications of the HTR to industrial planning for actual orders; the ministry is asking the potential operators to signal their interest in the concept even if high

government subsidies are terminated. Although present reviews and evaluations of the HTR might lead to a decision against the reactor, the BMFT claims that the process is fair and cannot be called an attempt by the ministry to kill HTR development.[99]

The Projektträger (Coordinating Agencies): One way that the BMFT has become more active in the coordination of energy policy is through the use of Projektträger (coordinating agencies for specific projects). These "coordinating agencies" were set up beginning in 1976 as a means to involve the BMFT more in development policy without expanding the permanent staff of the ministry. The BMFT wanted to limit the work of its individual sections (Fachreferate -- i.e., departments), but it permitted the sections to rely on the coordinating agencies for expertise on individual projects. The coordinating agencies are part of the BMFT and they are also integrated into one of the nuclear research centers.[100] The division between the two roles is not fully defined: the agencies are linked completely to the BMFT, but their work is all related to the research centers and written assessments have to be submitted to the research center's board of directors.[101] The task of the coordinating agency is to follow the administrative extension of the BMFT. They do not play a political role; that remains a function of the ministry.

The coordinating agency for the HTR project (Projektträger HTR) is just one of several similar agencies -- at the KFA alone there are four, including one for non-nuclear research.[103] The coordinating agency for HTRs is small -- just two professional staff members -- and it reports to the small HTR section within the BMFT which also has only two members. The HTR coordinating agency does not make HTR policy, but it has responsibilities such as following committee sessions of the Bundestag closely and issuing "status reports" on the HTR. At times, these reports have been quite critical of policy.

The strength of the coordinating agency, according to a former member, A. Dworak, is the trust it has engendered through years of working together with other HTR actors; the other actors are willing to entrust the HTR coordinating agency with confidential information because they know the information will not be misused.[104] Günter Hirschfelder of the VEW utility describes the coordinating agency's relations with the utilities as good; he says that its function is not to influence decision-making on technical questions, but rather to facilitate communication among the various actors.[105] This fits in with the role which the BMFT has seen for itself after 1975, namely, to bring the HTR policy actors

together. The coordinating agency for the HTR project has provided an additional means for the BMFT to improve the exchange of ideas on HTR development policy.

Role of the Bundestag: The discussion thus far has implied that federal government policy on HTRs can be equated with the BMFT's policy, and for all practical purposes this representation is fair. The Bundestag has not been involved with any policy guidance for HTRs, but it does provide a kind of brake on the BMFT's power. All three parties support the HTR so that if steps were taken to reduce funding for the HTR, the Bundestag would almost certainly react. Even the members of Parliament acknowledge that the only power which the Bundestag has is to approve financial arrangements for support of nuclear projects, but this power could be effective in blocking other programs if the Bundestag members were upset about HTR cutbacks. Whereas the reactor industry has shown more favor to the fast breeder reactor, the Bundestag has been more positive toward the HTR. One KFA official suggests that the reason for this is the attractive combination of coal and nuclear energy.[106] A member of the Bundestag says that the size and influence of North Rhine-Westphalia is also critical.[107] NRW covers one-third of the area of the Federal Republic. This guarantees that many members of Parliament will be positively inclined to the

HTR since it supposedly will boost NRW's industrial base. Moreover, given the influence of the Land in selecting candidates for the Bundestag, especially for those not elected directly, there is a need for candidates to pay attention to the Land's interests.[108] Most of the Bundestag's dealings with the HTR come through the Committee for Research and Technology, but one member of the Parliament criticizes the people on the committee for having only limited expertise in technological matters.[109]

North Rhine-Westphalia

In the early 1970s NRW took steps to protect the pebble bed HTR technology, and it continued this role as "high priest" of HTR development in the post-1975 period. This is understandable since coal is so essential to NRW's economy, and the Land sees the HTR as the means to ensure a future role for coal. We saw that the federal government, through the BMFT, tried to play a mediating role in HTR policy. North Rhine-Westphalia plays more of an advocacy role.

NRW and the BMFT have different priorities and therefore are not always in agreement about how to proceed with HTR development. NRW is most interested in the application of HTRs to coal, and consequently its priority is on developing process heat. BMFT officials

feel, though, that such technological solutions are too far off in the future. They say that the application of nuclear technology to coal is a "fantastic idea" and a good point for politicians to sell, but enormous technological problems have to be overcome before a solution can be found to produce nuclear heat.[110] Moreover, finding reactor sites in the heavily industrialized Ruhr district is likely to be impossible according to BMFT officials, but the reactors have to be near the coal to make them economically feasible.[111]

The BMFT is less enthusiastic about process heat applications because of the uncertainty involved with the development. The ministry's priority is more to make sure a decision is made on a practical THTR follow-up project. In fact, the BMFT would like to build a consensus with NRW about future HTR policy: the HTR-900, which places more emphasis on the production of electricity, and the process heat project should not be seen as competitors.[112] At present, the BMFT feels that process heat applications involve too long a waiting time for industry. The BMFT prefers to involve industry as soon and as fully as possible in the next stage of HTR development.

The impact of NRW is more indirect than direct. We saw its influence on Bundestag members, and the

informal contacts among NRW officials, industrial representatives and the members of Parliament are also important. There is a close relationship between the Land and its coal companies and electrical utilities too. These firms are important for the German economy and, hence, to the extent that NRW represents their interests, its priorities have to be heeded. The NRW Ministry for Economics (Ministerium für Wirtschaft, Mittelstand and Verkehr -- referred to as the Economics Ministry) is the main vehicle for voicing the HTR policy of the Land. Like the BMFT, it has played an activist role in HTR policy. It too provides financial support for reactor parts and thus can sublet certain component contracts. When the coordinating agency for the HTR project was trying to arrange a cooperative agreement with the Japanese for the development of HTR heat exchange components, it was surprised to discover that the NRW Economics Ministry had already subcontracted to a German firm without any consultation.[113]

The Nuclear Research Center in Jülich (KFA)

The importance of the KFA in this post-1975 period is primarily as a stabilizing factor which leaves key decisions to industry and the utilities. The research center intentionally did not play a key role in the decisions made after the Dernbach meeting regarding which reactor design to pursue.[114] In fact, the KFA officials

preferred the two-cycle reactor, but they deferred to the BBC/HRB decision which went against them.[115] The only criticism heard about the KFA was that it should have a more practical orientation: the KFA's plans for building a series of 500 MW reactors for the Ruhr district were criticized because they were uneconomical and siting would be nearly impossible.[116] In the future, however, the KFA will be involved more in practical aspects of development programs since it is essential to complete the early stages of a program in order to keep to a time schedule for later stages.[117]

CONCLUSION

In contrast to the AVR and THTR phases of HTR development which reflected competition among and within the government, manufacturing and utility sectors, the post-1975 phase is chracterized by coordination among the sectors. The direct cause for this was the failure in 1975 of the HTRs offered by Gulf General Atomic Company. German HTR actors realized that they could not rely on anyone else for the market introduction of HTRs, and consequently they were compelled to work together. The initiative to consolidate HTR efforts came from the Federal Ministry for Research and Technology, but the other actors all welcomed it. They had to learn, however, to work together more closely than they were accustomed to doing.

The working relationships which have evolved are often uneasy ones. Manufacturing firms and utilities are not comfortable working as partners with their competitors, and old interests are not given up readily. Nonetheless, the post-1975 phase reflects an important step to better cooperation among the HTR policy actors, and it provides some important insights into how technological choices are made in the Federal Republic.

First, traditional patterns are changing. The utilities used to wait for manufacturers to make offers before the utilities would decide whether to place orders. Now, the complexity of technological projects and their long-term nature require that utilities be involved much earlier. The utilities accept this change in principle, although in practice they still show some reluctance to break from the old approach.

Second, more emphasis is now supposed to be given to actual construction projects, rather than to long-term R&D projects. The credibility of a technology depends on tangible progress on a step-by-step basis, and therefore it is not wise to opt for the most technologically sophisticated projects. This explains why the helium direct-cycle HTR was dropped as the THTR follow-up project. The type of policy which has evolved in German nuclear policy is incremental, conservative, and

oriented to construction and operating experience rather than long-term R&D projects. In other words, the policy is geared to low-risk alternatives because it may prove impossible to build the high-risk alternatives. The federal government has proven to be more inclined to a pragmatic approach for the next stage of HTR development than has the Land North Rhine-Westphalia. NRW is more intent on developing process heat because of its applications to coal, but the federal government feels that there are too many technological uncertainties involved with the development of process heat to place too much emphasis on it at this time.

Third, the most difficult problem for German nuclear policy remains how to attract private financing for reactor projects. The BMFT is currently trying to shift the financial burden from the government to private business, meaning mainly the reactor operators. This switch of emphasis from government support for possible applications of HTRs to industrial support for ordering the reactors has occurred since 1979, and the BMFT considers it as the most important impulse it has given to HTR development. It remains to be seen how successful the BMFT will be with this impulse. The willingness of all the HTR actors which emerged after 1975 to coordinate efforts still remains. One business manager expressed

the view that there have been no winners or losers in the HTR policy of the last five years; it has simply been an attempt to find a common orientation.[118] Still, the goals after 1975 were to bring the policy actors together (1) to decide what the next stage of HTR development should be and (2) to obtain specific orders. These goals have yet to be achieved.

NOTES FOR CHAPTER SEVEN

1. E. Baust and G. Wittchow, "Der Hochtemperaturreaktor -- Ergebnisse und Perspektiven," atw (March, 1981): p. 147.

2. His German title is Ministerialrat and Referatsleiter.

3. Interview with Dieter Kutschke.

4. See, for example, the news articles on recent HTR developments in atw (October 1981): pp. 527-8.

5. Interview with Wolfgang Müller.

6. Interview 32 with industry representative.

7. Interviews 9 and 27 with a KFA official and a Member of the Bundestag.

8. Interview with Ulrich Steger, Member of the Bundestag.

9. P. Engelmann and H. Oehme, "Ziele der HTR - Entwicklung für Stromerzeugung und Prozesswärme," atw (Sept. 1977): pp. 484-90, here p. 485.

10. Interview with H. Harder, director at HRB.

11. Interview with Beckurts.

12. Quoted in Hans Overberg, "Offene Fragen um den Hochtemperaturreaktor," Rheinische Post, Oct. 17, 1975.

13. Interview with Marnet.

14. Interview with Schulten.

15. Interview with Beckurts.

16. Interview with Marnet.

17. The HTR is not seen as competitive with coal, but rather as a means to apply modern technology to coal. For example, the HTR may enable coal reserves to be stretched through the liquification of coal at high temperatures.

18. H. Oehme and J. Schlösser, "Weiterentwicklung des HTRs," atw, (Sept. 1978): pp. 408-12, here p. 408.

19. Ibid.

20. Ibid., p. 410.

21. Interviews 15 and 24 with industry and utility officials.

22. PTH, Progress Report of the HTR Development Program, August 1978, p. 1.

23. Ibid., p. 2.

24. The chart is from p. 3 of the Progress Report.

25. Interview with Kutschke.

26. Progress Report, Aug. 1978, p. 61.

27. Progress Report, 1978, p. 8, and Interviews 28 and 32 with BMFT and industry officials.

28. Oehme and Schlösser, "Weiterentwicklung des HTRs," p. 409.

29. Interview 9 with KFA representative.

30. Interview with Harder.

31. Interview with Dworak.

32. Progress Report, 1978, Program Status Report, 1979, Oehme and Schlösser, "Weiterentwicklung des HTRs," and Interview 9 with KFA official.

33. Interview with Beckurts.

34. Program Status Report, 1979, p. 4.

35. Ibid., my emphasis.

36. Interview 9 with KFA official.

37. Ibid.

38. Ibid.

39. Program Status Report, 1979, pp. 2-3, my empahsis.

40. Ibid., p. 3 and Interview with Harder.

41. "Heisse Kugeln," Der Spiegel, Vol. 35 No. 5, (Jan. 26, 1981): pp. 176-180, here 177.

42. Ibid.

43. Ibid.

44. Interview with Rumler.

45. Interview 28 with BMFT official.

46. Interview with Kutschke.

47. R. Hossner, "Wer bezahlt den nächsten HTR?" atw (Feb. 1981): p. 65.

48. "Kernkraftwerke 1980 Weltübersicht," atw (March 1980): pp. 211-18, here p. 217. This refers to BBC/HRB.

49. Interview 25 with utility official.

50. Interview 24 with utility official.

51. Interview 15 with industry representative.

52. Interview 32 with industry representative.

53. Interview with Hans Olivier.

54. Interviews 25, 32 and 27 with utility and industry representatives and a Member of the Bundestag.

55. Interview 32 with industry representative.

56. Ibid.

57. Interviews 27 and 32 with a Member of the Bundestag and an industry representative.

58. Interview 9 with KFA representative.

59. "Heisse Kugeln," Spiegel, Jan. 26, 1981, p. 178.

60. Ibid., p. 180.

61. Interviews 32 and 28 with industry and BMFT officials.

62. The chart reflects the original division of responsibilities. Although the helium HTR project (HHT) has now been abandoned, the distinction between process heat and electricity applications between KWU and BBC is clear. Design and engineering work and R&D are shared. Chart prepared by PTH, 1977.

63. Interview with Kutschke.

64. Interview 24 with utility official.

65. Peter Thomsen, "Explosion im Atom-Staat," Der Stern, Feb. 19, 1981, pp. 182-3, here p. 183.

66. Interview with Beckurts.

67. Program Status Report, 1979, p. 5.

68. Interview with Kutschke.

69. Interview with Rumler.

70. Interview with Dworak.

71. Ibid.

72. Interview with Steger.

73. Interviews with Beckurts and Egon Ziermann of AVR.

74. Interview with Ziermann.

75. Interview with Marnet.

76. Interview with Hirschfelder.

77. Ibid.

78. Ibid.

79. Interview 24 with utility official.

80. Interview 28 with BMFT official.

81. Interviews 27 and 31 with a Member of the Bundestag and a BMFT official.

82. Ibid.

83. Interview with Hermann Hatzfeldt, nuclear energy critic.

84. Interview 14 with utility official.

85. Interview 24 with utility official.

86. Interview with Kutschke.

87. Ibid.

88. Ibid.

89. Ibid.

90. Interview 9 with KFA official.

91. Ibid.

92. Interview 14 with utility official.

93. Interview 24 with utility official.

94. Interview 27 with a Member of the Bundestag.

95. Interview 33 with an NRW official.

96. Interviews 28, 29, 31 with BMFT officials.

97. Interview 28 with a BMFT official. Note that the BMFT sees itself as the representative of the federal government here.

98. Ibid.

99. Ibid.

100. Interview with Kutschke.

101. Ibid.

102. Ibid.

103. Interview 9 with a KFA official.

104. Interview with Dworak.

105. Interview with Hirschfelder.

106. Interview 10 with KFA official.

107. Interview 27 with a Member of the Bundestag.

108. Half the members of the Bundestag are elected directly; the other half are selected through party lists based on proportional representation. Each Land determines its own ordering of candidates for the party lists, and thus it is important not to fall out of favor with the party officials of one's Land.

109. Interview 30 with a Member of the Parliament.

110. Interviews 28 and 31 with BMFT officials.

111. Ibid.

112. Interview 28 with a BMFT official.

113. Interview 9 with a KFA representative.

114. Interview with Beckurts.

115. Interview 16 with industry official.

116. Interview 24 with utility official.

117. Progress Report on the HTR, 1978, p. 4.

118. Interview with J. Schlosser, HRB.

PART IV

CHAPTER EIGHT

CONCLUSION

This thesis has examined how technological choices are made in German nuclear energy policy-making. Because the development of sophisticated technologies such as nuclear reactors is a long-term process involving multiple actors, we organized our analysis around (1) the stages of development of German nuclear reactors and (2) the shifting leadership roles among the actors through these stages. We looked at how responsibilities have been shared among reactor developers, vendors and operators from the initial stage to commercialization. The analysis compares "market" and "political-organizational" approaches to explaining technological choices. The two approaches are not mutually exclusive; rather, each provides a special perspective on the way in which political and economic objectives are balanced in German nuclear policy-making.

We first considered overall German nuclear policy and then analyzed in more detail a specific second generation reactor, the high temperature reactor. The former suggested the significance of differing outlooks among the government, manufacturing and utility sectors; the HTR case showed how important disputes were within

these individual sectors. A major advantage of the in-depth case study method used here is its ability to reveal the complexities of the policy process. At the same time, any generalizations from case studies have to be drawn cautiously, for technological choices are strongly influenced by national patterns and traditions. Although caution is necessary, it is nonetheless useful to seek lessons from this case which may improve our understanding of technological choices applicable to future policy-making both in the Federal Republic and elsewhere.

This chapter links our findings about German nuclear policy to the conceptual framework presented in Chapter One. First, we look at two contrasting studies of the German nuclear energy program: one considers it a success, the other stresses its problems. With these divergent opinions as background, we then make our own assessment of the German program in the context of the market and political-organizational approaches described in this thesis. Second, we present a more general series of policy observations and conclusions about technological choices. Finally, we examine the implications for future technological choices in HTR development. We consider both international and domestic factors and close by considering the key role which the utilities will have in future HTR policy.

ASSESSMENT OF THE GERMAN APPROACH TO TECHNOLOGICAL CHOICES

Opinions as to whether the German nuclear reactor development program has been successful vary widely. Peter DeLeon compares reactor development in several nations and terms the German program a success due in large part to its decentralized policy process.[1] In contrast, in a report for the "International Consultative Group on Nuclear Energy" Måns Lönnroth and William Walker find that West Germany and other countries with strong private sectors are at a distinct disadvantage to countries where governments exert strong control over nuclear industries, espcially the electrical utilities.[2] The different conclusions result from the differing emphases in the two studies: DeLeon focuses on the successful development of multiple options in the German program; Lönnroth and Walker stress the inability of countries with decentralized approaches to coordinate policy and consolidate efforts. Together, these views highlight two important features of technological development: a wide range of options has to be created, and then the options have to be narrowed and effots concentrated in a small number of areas. The remainder of this section analyzes German nuclear energy policy-making to see what helped or hindered it and discusses how the market and political-organizational approaches apply to these two features of technological development.

DeLeon contends that the best strategy for reactor development is one that relies on the development of multiple options. This minimizes risks for high priority projects requiring major technological advances because it compensates for the high degree of technological uncertainty.[3] According to DeLeon, the way for a nation to guarantee several technical alternatives for itself is through the active involvement of a number of different participants, preferably with different perspectives or objectives; the question becomes one of numbers while the issue of affiliation -- e.g., private industries, government laboratories, public or private utilities -- becomes secondary.[4]

There is, of course, a trade-off in research strategies: focusing on just one reactor design concentrates resources, while relying on multiple designs minimizes the risks of failure. The Germans followed the low-risk, multiple options route. One way to encourage such multiple options is the inclusion of private industry as an equal partner with the government in reactor development strategy. DeLeon praises the United States and the Federal Republic for doing this in virtually every phase of reactor development; France and Britain, in contrast, treated the electrical construction industry less as a contributing partner and more as a supplier of components in a severely constrained market.[5]

Lönnroth and Walker share the view that institutional arrangements are critical for reactor development programs, but they focus on how effectively control can be exercised by the central government. They claim that the structure of the industry and its relationship to government have important implications for the industry's robustness in difficult and uncertain market conditions.[6] In light of the difficult political and economic conditions that have prevailed since the early 1970s, Lönnroth and Walker say that countries in which governments control and share risks with nuclear industries to a large extent are better off than those countries in which risks are born by private concerns and policy coordination is limited.[7] France and Britain, for instance, are countries in which government policy proposals have customarily been less exposed to wide public debate at early stages of consideration, and both have had comparatively little difficulty in promoting nuclear power.[8] Lönnroth and Walker emphasize that countries with centralized and relatively closed political systems and with substantial state control over the utility and nuclear industries have greater ease in promoting nuclear power because of their ability to avoid both political and economic difficulties.[9] Countries with more fragmented decision-making systems, in contrast, are more vulnerable to the breakdown of political consensus and to economic diffi-

culties such as those encountered by private utilities.

The arguments presented by DeLeon and by Lönnroth and Walker are not necessarily incompatible, and our findings corroborate each of them in part. The Germans were remarkably successful at fostering multiple reactor options right from the start of their nuclear program. The government preferred this route, partly to bolster as many segments of German industry as possible, and partly because no one in the public or private sector had strong inclinations toward any particular reactor design. The objective was simply to establish an internationally respected and competitive nuclear industry. Designs were not evaluated in comparison with each other: for example, no comparative assessments of the fast breeder and high temperature reactors were ever conducted. To this day, there is strong resistance to having to choose between these two major alternatives for second generation reactors.

The Germans were able to pursue several reactor lines because the government provided financial incentives to industry to support any feasible interests and because there was little hesitation about relying on imported technology. At the same time, however, the Germans had trouble narrowing options because of their decentralized approach. The types of difficulties

predicted by Lönnroth and Walker are indeed present in German policy: there are too many points at which the process of reactor development can be disrupted (this does not just refer to protest actions -- differing industrial strategies can also be disruptive), and convincing utilities or other private sector actors to provide funding is a constant struggle. Consolidation of efforts on German technological projects is done on an ad hoc basis; as a consequence, the lessons from one experience are not easily transferrable to another one. The actors involved with HTRs went through a long learning process before accepting the need to work together, but there is no guarantee that the lessons will be carried over into other contexts.

In sum, the German commitment to market processes has influenced reactor development strategies significantly. The government has tried to limit its intervention in the process of technological innovation and commercialization because it prefers to have initiatives come from industry, but it also is willing to try to direct industry along certain lines. Thus, the government was ready to encourage as many reactor lines as possible in the early years of the German program, and it later tried to encourage consolidation in particular industrial sectors: the government backed the Siemens-AEG merger to form KWU, it tried to facilitate BBC-GHH

cooperation in the HTR field, and -- as we saw in detail -- it has prodded the utilities and manufacturers involved with HTRs to coordinate development since 1976. In no instance, though, was heavy pressure exerted. The role of the government has been and still remains limited.

Assessment of the Market and Political-Organizational Approaches

Chapter One argued that the German context for nuclear energy policy seems especially favorable for the market determination of technological choices. The reasons relate to the free market attitudes and the decentralized decision-making structure after World War II and to the lack of military priorities to steer nuclear technologies. The German case gives us an opportunity, on the one hand, to test how well the private sector can guide technological choices under conditions favorable to the market determination of such choices. On the other hand, however, the HTR, as a German designed and developed reactor in which the Germans take considerable pride, offers us a case to test how effectively the state can control technological choices when its interest in doing so is seemingly high. Evaluating these two perspectives allows us to see how economic and political objectives interact in German technological choices.

Relying on market considerations to guide technological choices seemed to work for German light water and fast breeder reactors, but more problems are evident for high temperature reactors. A critical point in early German nuclear policy was the utilities' decision in the late 1950s to opt for the internationally available LWR technology, despite the government's wishes to stress German-developed designs which avoided dependence on enriched uranium. The utilities were not eager to stress basic R&D work or experimental designs for other nuclear reactors since LWRs seemed already to have achieved a breakthrough to commercialization. In the case of fast breeder reactors, too, the utilities were the key factor because RWE, the largest German utility, espoused the FBR cause and relieved the government of at least some of the funding responsibilities. The utilities, though, were wary of the cost estimates and development projections compiled by the pro-FBR Nuclear Research Center in Karlsruhe, and thus the money poured into FBRs by the utilities was less than the amount hoped for by the FBR adherents in Karlsruhe and the government.

The HTR case provides a different story: the utilities have not provided similar guidance and, overall, the case shows how the existence of too many options can hinder technological development. The utilities have

demonstrated an interest in the HTRs, but they have not provided leadership in determining the direction of development. Market considerations could operate effectively in the LWR case because commercialization was near. In the FBR case, the major German utility, RWE, may have been attracted by the commercial prospects of the reactor, but the commitment did not deepen as the long-term nature of FBR development became clear. With HTRs the utilities have always been uncertain about which option to follow, given the wide-range of possibilities, and this has led the utilities to be reserved in their support.

Market considerations may be able to guide technological choices once commercialization is near, but the challenge is to guide it before that stage is reached. With the German HTRs, the manufacturing firms had to carry more responsibility because the demonstration stage lasted much longer than expected or than had been the case for LWRs. Their capacity for leadership was limited, however, because of BBC's small share of the German reactor market compared to KWU, and because the utilities were unable to tell the manufacturers what they wanted. Achieving cooperation within the reactor manufacturing sector and between the manufacturing and utility sectors proved difficult until the American attempt to commercialize HTRs failed, leaving the German

policy actors to "sink or swim" together on the HTR project. The evidence which we cited on the power of the utilities in determining technological choices thus has to be modified in light of the HTR example: when commercialization is remote and the number of options is large, the utilities play a less significant role.

To what extent does the HTR case confirm that the government can steer technological choices when its interests in doing so are high? Here, the HTR case turns out to be less useful than we initially expected: despite the German origins of the pebble bed HTR, national interest and pride did not compel continued support for it. The government certainly tolerated the curtailment of another solely German technology, the heavy water reactor. It supported the HTRs through the research and development and then demonstration stages not only because of their unique attributes (e.g., the pebble bed system), but because the government sensed that the design might eventually be a commercial success. With the Third Atomic Program in 1968, for instance, the German government acknowledged U.S. superiority in the LWR field and turned its emphasis to the second generation high temperature and fast breeder reactors. The continuing problem in HTR development has been to determine whether the reactor has realistic chances for commercial success. At present,

the Federal Ministry for Research and Technology has made it clear that it feels it is time to reduce its massive aid for HTRs; in the Ministry's opinion, the decision about whether to continue HTR development now depends on the willingness of the utilities and manufacturers to invest their own money in the technology.

We expected to find that national interests would explain the German adherence to the HTR project notwithstanding the lack of international interest and the curtailing of other national efforts. In fact, the government showed little favoritism to the HTR before 1968 -- many HTR adherents, especially at the Nuclear Research Center in Jülich, complained that it was unfairly subordinated to the FBR. The key factor behind the continuing support for the HTR was the Land North Rhine-Westphalia and its interest in coal. By allowing a more efficient use of coal, the HTR offered a link between traditional and advanced technological uses of coal which is critical to the NRW and German economy. Business executives and federal government officials alike accused the Land's HTR support of being overly emotional at times. Even Reimut Jochimsen, the highly respected NRW Economics Minister, was willing to say in late 1980:

> I don't overlook the runaway costs for the HTR, and I don't overlook the hesitation abroad about this reactor line. It almost

> appears as if the North Rhine-Westphalia government is being irrational about the HTR questions because of our ties to the Jülich research center and out of posthumous respect for Leo Brandt. But we will fight to exhaust every possibility to help the HTR line achieve an economic breakthrough. . . . And anyone who wants to tangle with us will need long-range arguments.[10]

The NRW government has done everything in its power to support the HTR, especially the pebble bed HTR design. This included encouraging KWU to consider pebble bed HTR applications for process heat in the early 1970s when BBC had switched interests to the block fuel element HTRs. NRW's contribution can be evaluated positively or negatively depending on one's perspective. Technological development depends partly on commitment and partly on a willingness to drop impractical ideas. NRW has been a major factor in guaranteeing a commitment to the HTR, but it has also been a major factor in blocking any moves to cut off HTR support. In either case, we see that NRW -- and not the national government as we first presumed -- has stood in the path of leaving HTR development to the course of market decisions.

Our examination of nuclear energy policy-making in the Federal Republic indicates that free market attitudes have had an important influence on technological development, but the influence is most significant at the commercialization stage. In the preceding R&D and

demonstration stages, the institutions involved and their historical relationships are essential, as are the changing objectives of the policy actors over time.

POLICY OBSERVATIONS AND CONCLUSIONS

Our study of German nuclear energy leads us to suggest several observations about the policy-making process. These observations are certainly applicable to German nuclear policy-making; they may well be relevant to German policy-making in other advanced technological areas; and they provide some lessons to consider in trying to understand policy-making in other national contexts.

Stages of Development

(1) Market considerations have a maximum impact on technological choices in the later commercialization stages of technological development. Thus, market factors alone cannot be relied on to determine technological choices at the earlier R&D and demonstration stages.

(2) The transitions of leadership and policy objectives from one stage of development to another are critical. The government is better able to provide leadership when objectives concern national prestige, military programs, etc.; the private sector is better suited to provide leadership when cost and efficiency are the stakes.

(3) The best policies to promote commercialization are still not clear. Commercialization seems to require aggressive marketing and some luck; policy actors cannot simply wait for it to occur. In the Federal Republic, both the relationship between government and industry and the method of funding R&D promote commercialization, but there is no systematic evaluation of progress made in commercializing R&D results.

Cooperation and the International Context

(4) Cooperation within and among the business-state sectors is a necessary but not sufficient condition for successful technological development. A market is also needed for the successful development; and since the German market is too limited to support alone the commercialization of advanced technologies such as nuclear reactors, international cooperation is imperative. Although the Germans were minimally involved in joint projects with other countries, such projects are useful because they keep the international interest level high for a given technology. At the same time, however, national competition tends to remain even in cooperative ventures, and this too affects the path of development.

(5) International competition for a particular reactor design limits the control of the business and

state sectors over technological development. This is espcially true for West Germany where the policy actors are free to opt for internationally available technology, as the utilities did with light water reactors. The HTR case is unique for exemplifying purely domestic limitations, at least after 1975, because of the lack of international competition. It is instructive to see the complicated aspects of technological development when only domestic problems are relevant; when international considerations are added, the issues become still more complex.

(6) For LWRs, the German nuclear program was most successful at modifying the applications of technologies developed elsewhere. Many felt that the German LWRs, such as those installed at Biblis, were superior to American LWRs. Since the German economy alone cannot sustain a market for nuclear reactors, perhaps for the HTRs too more emphasis should have been placed on improving the applications of technologies already in use elsewhere because that increases the chances of commercial sales.

The Policy Actors

(7) The involvement of the Federal Government in German nuclear policy-making has increased markedly since 1955, as has the expertise of government officials.

The steering of policy is basically left to the Ministry for Research and Technology, although other ministries play important roles concerning budgetary and regulatory issues. The government leaves initiatives and commercialization to the private sector, and although it tries to provide some leadership in consolidating German nuclear efforts, it neither pushes the private sector too hard nor blocks its efforts.

(8) North Rhine-Westphalia persists in advocating the HTR despite several changes in justification for building the reactor. NRW is now firmly committed to the link between coal and nuclear energy. The Land, the largest in the Federal Republic, is a powerful force in German nuclear policy-making because it is the source of most German coal, has important financial capabilities, and can exert significant influence in the Bundestag. The Bundestag has not played any leading role in German nuclear policy, but it does authorize funding and thus could be a blocking force if, for example, some members of the ruling coalition objected to government policy and prevented passage of federal funding through Parliament.

(9) Both reactor manufacturing firms, BBC and KWU, are now involved with HTR development. The extent of KWU's commitment is crucial for the credibility of the

HTR because of the firm's dominant market position. The government welcomed KWU's involvement and the utilities essentially insisted on it. The signs now, however, are that KWU has lost some interest in the HTR; this should be watched closely. In general, the policy leadership of the manufacturers is strongest in the demonstration stage of development. We saw this in the HTR case, especially since the utilities were not providing policy initiatives, but even there the manufacturers depended heavily on government stimuli and utility inputs.

(10) The utilities are the key decision-makers in German nuclear energy policy because they place the orders for reactors. Their role is most significant when the costs of development are easily estimated: if it is too early in the development of a given technology or if there are too many options available, it is difficult for the utilities to choose which route to follow.

The Decentralized German Approach to Technological Choices

(11) The approach to technological development in the Federal Republic is on a decentralized, case-by-case basis. There is no systematic assessment of likely program impacts or monitoring of program effectiveness. In addition, the government does not have, or intend to

develop, targets for expected contributions from new energy technologies. This absence of targets led the OECD/IEA review team to question whether adequate judgments can be made about the desired pace of technological development.[11] The review team warned that the German program increases the risk that the right new technology may not be available at the time and in the quantity needed.[12]

(12) The German commitment to free market principles restricts the possibility of government intervention for technological innovation or commercialization. This increases the Germans' ability to encourage multiple options, but makes it more difficult to narrow options subsequently.

The Nature of Technological Development

(13) Government support affects the nature of technological development. German support tends to be through medium-term R&D funding. This encourages both industrial innovations (by allowing broad flexibility in project proposals) and commercialization (by requiring substantial R&D investments from the private sector). The limitation, though, is that the government cannot easily provide an interventionist push as some governments with a more centralized decision process are able to do.

(14) Supply and demand does not provide a good means to determine long-range development for energy policy because it is too uncertain. As the International Consultative Group on Nuclear Energy reports, long-term energy supplies have to be designed not merely to match a specified supply to a defined demand, since we can be sure of neither, but also to create a capacity for managing uncertainty.[13] A sufficient range of energy options has to be developed in time for a rational choice to be made as patterns of future demand become clearer.

(15) The course of technological development should be geared to practical projects rather than to advanced designs, especially once a technology moves beyond the R&D stage. Actual construction projects keep industry and regulatory officials actively involved in development; projects that necessitate considerable R&D work fail to keep skilled personnel occupied. The THTR-300 and its follow-up projects demonstrated this problem, and there is concern that the process heat applications of HTRs will also encounter delays because two complex technologies have to be developed simultaneously.

(16) The development of a particular technology cannot be pushed too fast. There is a danger that the government might force development in a certain direction because of certain priorities, such as national

pride. There is also a danger that utilities might agree to finance a project due more to high subsidies than to a serious evaluation of the project's feasibility.

IMPLICATIONS FOR FUTURE TECHNOLOGICAL CHOICES IN H.T.R. DEVELOPMENT

The high temperature reactor case has been instructive for seeing how technological choices are made, but final assessment about the success of the HTR will have to await commercialization of the reactor. That will occur in the 1990s at the earliest. The HTR demonstrates the difficulties involved in developing a reactor line alone, even for a country such as the Federal Republic. When work on the German HTR was started in the 1950s, no one anticipated that commercailization was so remote. There is some question whether German governmental and industrial support would have been as firm had the time frame been clear,[14] but longer development periods than originally expected are typical for other nuclear reactor projects, too.[15] In this final section, we will consider the problems of future HTR development at an international level, at the domestic level, and at the level of the German utilities which now have to assume a leadership role if the reactor is to be a success.[16]

We saw earlier that the development of the HTR has been characterized by widely divergent views about the reactor's chances. These differences are still evident in the past year: the Bonn government has had some pessimistic words for the HTR, but the possibilities of private sector cooperation and contracts for a subsequent HTR project appear at least feasible. Chancellor Helmut Schmidt indicated in his 1980 Regierungserklärung (his government program announced in Parliament after his re-election) that a choice between supporting the fast breeder or high temperature reactor might finally have to be made, largely because of German economic problems.[17] The SPD Minister for Research and Technology, Andreas von Bülow, had similar bad news for HTR adherents in his first press conference after the October election. He stated that private industry would have to share more of the costs of advanced reactor funding -- perhaps up to 30 percent as opposed to the previous 10 percent -- because other research areas would suffer if the scope of funding for FBRs and HTRs continued at the present high level.[18] Von Bülow directed his comments mainly at the utilities and threatened that a "research tax" (Forschungssteuer) might be added to electricity use if the costs of advanced reactor development were not shared.

At the same time, in February 1981 the chances for a

new HTR order suddenly revived. A controversy in north Germany about the future of a light water reactor at Brokdorf resulted in a call for more attention to HTR technology by politicians opposing the LWR. Hamburg SPD politicians did not want simply to kill plans for an LWR, and they were persuaded that the HTR provided an alternative.[19] Moreover, the cooperation in the private sector about a THTR follow-up project has progressed significantly. Plans for a 900 MW HTR are now being made following a study submitted in March 1981 by the manufacturers and then evaluated by the utilities and coal and gas firms which are the potential operators. The costs are estimated at DM 635 billion for construction, but an active debate is taking place about how industry, Bonn and North Rhine-Westphalia will share these costs.[20]

The HTR example shows that even a technology which has many apparent advantages (e.g., safety, siting, economy in the use of nuclear fuel, and, most important, applications other than just the production of electricity) and which is now characterized by cooperative efforts among utility, manufacturing and government actors may still not be realizable. Technological development depends not only on such potential advantages and on harmonious working relationships, but also on practical political and economic conditions. As economic

conditions worsen and budget-cutting becomes necessary in the Federal Republic, the government's willingness to ask hard questions and make comparisons of reactor designs increases.

Domestically, the HTR case reveals the almost inevitable need for the business-state sectors to work together. The conflicts within the individual sectors that were visible in the period 1963 - 1975 (see Chapter Six) were detrimental to the success of the HTR. Only when such conflicts were overcome after the 1975 GAC failure was progress possible. Future problems such as the storage of HTR nuclear waste only re-emphasize the need for cooperation: the utilities will have to work closely with the KFA Jülich, the North Rhine-Westphalia government and the federal government.[21] The HTR case shows us that our understanding of technological choices is obscured if we try to see such choices as a function either of economic objectives (as supporters of the market approach claim) or of political objectives (as supporters of the political-organizational approach maintain). Instead, the interactions of the two sets of objectives deserve attention, for the role of each set varies according to the stage of development of the technology.

Even if the domestic problems affecting technological

development are overcome, the international context also has to be considered because it has an important bearing on a project's chances of success. The HTR has been a special case because the reactor seldom faced direct competition from other international projects, with the exception of the U.S. block design in the 1971-75 period. Other than that, the German HTR project either was isolated from other developments (e.g., the British Dragon reactor) or was the only serious project being pursued (e.g., post-1975). One of the questions we have asked in this thesis is can the government shape technological development when its interests in doing so are high? We have examined this question, however, in terms of domestic barriers. For the HTR, this seemed appropriate since no specific international barriers to development were evident. The light water reactor example shows, though, how international factors can undermine domestic priorities. Moreover, the lack of international competition also points to a very specific problem for German HTR developers: the lack of an international market for the product.

There is international interest in the HTR, but the same kinds of problems which prevented a consensus on strategy domestically in West Germany now handicap international cooperation. There is no agreement about what kind of HTR to build. The Japanese and Soviets want

to stress process heat applications while the U.S. prefers generating electricity.[22] Internationally, then, we see that even the Federal Republic with its strong economy, export-orientation and technical expertise has not been able to develop a new reactor line alone.

If the German HTR stands any chance of success, the burden of responsibility falls to the German utilities. The reactor is approaching the end of the demonstration stage, a stage which has lasted far longer than expected and which has caused considerable bitterness on the part of some policy actors such as VEW. Although the THTR demonstration reactor still has to be finished, most HTR planning efforts are now geared to the commercial follow-up project. With the shift to a commercial reactor, the responsibility for leadership in pushing the project also shifts to the utilities. The federal government has been trying to facilitate this transition since 1979.

The simple fact to recognize is that German policy actors, on both the state and business side, have always recognized the market as the final determinant of whether a technology is successful. If more interest does not emerge for financing the next HTR from private funds, it may be time to admit that the technology should not

be developed further. This is the position of the federal government. It is not the position of North Rhine-Westphalia which favors high government subsidies, but NRW knows that money from Bonn is essential to continue the project. It is doubtful that any dramatic decision will be made against the HTR, but if the private sector is unwilling to support the project in a country which is openly committed to the market economy, the private sector firms can hardly be surprised if the government loses interest in the reactor. As the 1980 Report of the International Consultative Group on Nuclear Energy makes clear, planning for energy futures requires the freedom not to pursue, as well as to pursue, any of the options available.[23] The Germans need to keep a critical eye on the feasibility of the HTR; the commitment to the reactor line does not have to be, and should not be, indefinite.

NOTES FOR CHAPTER EIGHT

1. Peter DeLeon, Development and Diffusion of the Nuclear Reactor: A Comparative Analysis (Cambridge: Ballinger, 1979); DeLeon, "Comparative Technology and Public Policy: The Development of the Nuclear Power Reactor in Six Nations," Policy Sciences Vol. II (1980): pp. 285-307.

2. Måns Lönnroth and William Walker, The Viability of the Civil Nuclear Industry, A Report prepared for the International Consultative Group on Nuclear Energy (New York: The Rockefeller Foundation and London: The Royal Institute of International Affairs, 1979), p. 17.

3. DeLeon, "A Cross-National Comparison of Nuclear Reactor Development Strategies," paper presented at the International Congress on Technology Assessment, Ann Arbor, Michigan, Oct. 24-28, 1976. Published as Rand Institute Paper P-5739 Santa Monica, Ca.: Rand Institute, 1976), p. 51.

4. Ibid., p. 46.

5. Ibid., p. 48.

6. Lönnroth and Walker, Civil Nuclear Industry, p. 4.

7. Ibid., p. 17.

8. Ibid., p. 43.

9. Ibid., p. 47.

10. Reimut Jochimsen, "Zur Energiepolitik der Landesregierung von Nordrhein-Westfalen," (Bonn: Friedrich Ebert Stiftung, November 5, 1980), p. 18.

11. OECD and IEA, National Energy Program Review of Germany, 1980, p. 8.

12. Ibid., p. 38.

13. Report of the International Consultative Group on Nuclear Energy (New York and London: The Rockefeller Foundation and The Royal Institute of International Affairs, 1980), p. 3.

14. Interview with Rumler.

15. See Thomas Connolly, Ulf Hansen, Wolfgang Jaek and Karl-Heinz Beckurts, World Nuclear Energy Paths (New York and London: The Rockefeller Foundation and the Royal Institute of International Affairs, 1979) prepared for the International Consultative Group on Nuclear Energy. It predicts that commercialization of fast breeder reactors will be difficult. K.H. Beckurts said in an interview that it may be as long as 60 years for the reactor to be successful commercially.

16. This point was made by Ulf Lantzke, Director of the IEA, in a presentation on "Structural Policy and Nuclear Energy" at the Landeszentral Bank of Berlin and an interview afterwards on November 3, 1981.

17. Helmut Schmidt, "Regierungserklärung, Deutscher Bundestag, Verhandlungen des Bundestages, Band 117, Stenographische Berichte, 9. Wahlperiode, 5. Sitzung, Nov. 24, 1980, pp. 25-41, here pp. 29-31.

18. Cited in atw (Jan. 1981): p. 7; see Manfred Popp, atw (Oct. 1977): p. 531 for comparative figure.

19. Interview with Hermann Hatzfeldt. The role of H. Krämer, now a member of the board of the utility Nordwestdeutsche Kraftwerke and formerly a leading figure in HTR development at the KFA Jülich, was instrumental.

20. See atw, October 1981, p. 527-28.

21. See, for example, Günter Hirschfelder's testimony before the Committee for Research and Technology of the Bundestag, "Stenographisches Protokoll," 64. Sitzung, 8. Wahlperiode, May 14, 1980, page 60.

22. See testimony of P. Engelmann, member of the board at KFA Jülich, Ibid., p. 18-9.

23. "Report of the Consultative Group," p. 3.

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List of Interviews*

Karl-Heinz Beckurts--former chairman of the board at the KFA Jülich, now a member of the Board of Directors of Siemens (May 1979, January 1980)

Alfred Boettcher--former chairman of the board at the KFA Jülich before Beckurts, now director of international programs at KFA (January 1980)

Thornton Bradshaw--former president of Atlantic Richfield Oil Company, now with RCA (January 1981)

Josef Bugl--member of the Bundestag, formerly associated with BBC and GHH (April 1981)

Alfred Dworak--now with the utility, Nordwestdeutsche Kraftwerk, formerly with the PTH at the KFA Jülich, and before that with the Dragon project (January and April 1980)

P. Engelmann-member of the board of the KFA Jülich (January 1980)

Bruno Fritsch--Center for Economic Research, Zürich (September 1981)

H. Harder--member of the Board, HRB (April 1980)

H. Hatzfeldt--energy critic (May 1981)

Günter Hillenbrand--KWU (May 1979)

Karl Kaiser--Director of the Research Institute of the German Society for Foreign Affairs (May 1979)

Dieter Kutschke--head of the section in BMFT dealing with advanced reactors, including the HTR (April 1981)

Ulf Lantzke--Director of the IEA (November 1981)

G. Marchetti-IIASA Energy Project (December 1980)

Chrysanth Marnet--Stadtwerke Düsseldorf and AVR (April 1981)

W. Müller--Editor-in-Chief of Atomwirtschaft Atomtechnik (atw) (April 1981)

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*dates of interviews are in parentheses

Hans Olivier--Head of Energy Technology Section in the North Rhine-Westphalia Ministry of Economics, Small Business and Transport (April 1981)

Christian Patermann--BMFT (May 1979)

Manfred Popp-BMFT, head of overall section for nuclear energy (April 1981)

R. Rumler--BBC Representative in Bonn (April 1981)

Jürgen Schaewen--BMFT, section on advanced reactors (April 1981)

J. Schlosser--HRB (April 1980)

Rudolf Schulten--director of the Institute for Reactor Development at KFA; formerly worked with BBC and developed concept of a pebble bed HTR; has guided development of HTR in Federal Republic since resumption of nuclear research has been permitted; also professor at the Technical University in Aachen (January 1980)

Ulrich Steger--member of the Bundestag, SPD (April 1981)

P. Weinholz--KFA Jülich, head of Public Affairs (January 1980)

Carl Friedrich von Weizsäcker--former head of the Max Planck Institute in Starnberg, atomic physicist (January 1978)

Egon Ziermann--AVR (April 1980)

BIOGRAPHICAL NOTE

1965-1969 Harvard College, B.A. cum laude in Government, June 1969

1969-1970 Free University of Berlin, Fulbright Scholar

1971-1972 Harvard University Graduate School of Education, M.Ed. in Education and Social Policy, June 1972

1972-1973 Assistant Professor of English, Aichi Prefectural University, Nagoya, Japan

1973-1975 Assistant to the Assistant Chancellor, University of Massachusetts, Boston

Summer '75 Intern in the German Parliament, Bonn

1975-1982 Doctoral Candidate in Political Science, MIT Ph.D., February 1982

1976-1978 Instructor in Politics, Wellesley College

1978- Assistant Director and Research Director of the Aspen Institute Berlin

Publications and Major Research Papers

The Politics of Technological Choices: Business-State Relations and Nuclear Energy Policy-Making in West Germany. Ph.D. Thesis for MIT Department of Political Science, accepted December 1981.

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