SAFETY ANALYSIS REPORT AND TECHNICAL SPECIFICATIONS OF THE MITR FISSION CONVERTER FACILITY FOR NEUTRON CAPTURE THERAPY

by

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ABSTRACT

Boron Neutron Capture Therapy (BNCT) is a binary form of cancer therapy that has the potential to selectively kill cancer cells while sparing normal tissues. This can be accomplished by selectively localizing B^{10} in the tumor cells and delivering thermal neutrons to the target. A B^{10} nucleus absorbing a thermal neutron will decay into an alpha particle and Li^7 nucleus with an accompanying energy release of 2.79 MeV.

An epithermal neutron beam based on a fission converter plate driven by the neutrons from the Massachusetts Institute of Technology Research Reactor-II (MITR-II) has been designed at MIT. A study has been conducted to provide the necessary information required for the licensing of the MITR Fission Converter Facility by the U.S. Nuclear Regulatory Commission (NRC) and to demonstrate the safe operation of the fission converter. The result of the study indicates that the fission converter can be safely operated. No credible accident can be identified that would result in damage to the fuel elements.

Technical specifications for the fission converter are also included in this thesis. These specifications constitute limitations for operation of the fission converter. These limits are based on the information provided in the Safety Analysis Report of the MITR Fission Converter Facility.

An analysis has been conducted to determine the cost of the fission converter. The result of the analysis indicates an estimated cost of $2 million for the fission converter facility.

Thesis Supervisor: Prof. Otto K. Harling
Title: Professor of Nuclear Engineering

Thesis Supervisor: John A. Bernard, Ph.D.
Title: Director of Nuclear Reactor Laboratory

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Although I have only been at MIT for a short amount of time, I had the fortunate opportunity to work with many remarkable people. I would like to first thank my thesis advisors, Professor Otto Harling and Dr. Bernard for their support and guidance. I would like to thank all the Boron Neutron Capture Therapy group Dr. Zamenhof, Dr. Busse, Dr. Solares, and the graduate students, Balendra Sutharshan, Shuichi Sakamoto, Stead Kiger, Kent Riley, and Cynthia Chuang for an excellent research experience.

I would also like to thank the Reactor Operations Group and RPO for their input into the project; Tom Newton, Eddy Lau, Ed Block, Paul Menadier, L.W. Hu, and Fred McWilliams. And lastly I would like to thank Dr. Kohse, Kathleen, and Carolyn for their help.

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Introduction

The Fission Converter Based Epithermal Neutron Beam is being designed at MIT for use in Boron Neutron Capture Therapy and Epithermal Neutron Research. The objective of this thesis is to provide a Safety Analysis Report (SAR) necessary for licensing of the MITR Fission Converter Facility by the U.S. Nuclear Regulatory Commission (NRC) and to demonstrate the safe operation of the fission converter. The thesis also includes the Technical Specifications and the Cost Analysis of the Fission Converter.

The information needed to complete this thesis were provided by MIT Nuclear Engineering Graduate students and MIT Nuclear Reactor Laboratory staff. Balendra Sutharshan, a Ph.D. candidate in Nuclear Engineering provided the design for the thermal hydraulic, shutter, and medical therapy room. The neutronic design was contributed by Stead Kiger, a Ph.D. candidate in Nuclear Engineering and Shuichi Sakamoto, Engineering Degree candidate in Nuclear Engineering. Instrumentation and control design has been provided by Dr. Takahashi, a visiting Professor from Tokyo University. Many members of the MIT Nuclear Reactor Laboratory staff were consulted for their specific expertise. They include Prof. Harling, Dr. Bernard, Tom Newton, Dr. L.W. Hu, Paul Menadier, Ed Block, and Dr. Gordon Kohse. Fred McWilliams from the Radiation Protection Office has also contributed information regarding radiation safety. And finally, Joe Burns, former MIT graduate student in Nuclear Engineering has provided some of the data for the cost analysis.

The thesis required gathering information from the members mentioned above and incorporating the necessary data into the SAR, Technical Specification, and the Cost Analysis. To facilitate this process, I have established a Fission Converter Weekly Meeting. As the coordinator, I identified the unresolved areas of the design and provided initial solutions to the problems. They included instrumentation and control, cover-gas system, pre-operational tests procedures, fuel handling procedures, all accident analyses except for thermal hydraulic items. For the Cost Analysis, I have outlined all the components needed for the fission converter, fabricated the timeline and procedures for construction, calculated the required man-power, and summed up the total cost of the Fission Converter. In the meetings, these topics were discussed and resolved. The information gathered from these meetings were incorporated into this thesis.

The thesis is subdivided into three sections. Section 1 is the Safety Analysis Report. Section 2 is the Technical Specifications. Section 3 is the Cost Analysis Report for the Fission Converter.

SECTION 1

SAFETY ANALYSIS REPORT
OF THE
MITR FISSION CONVERTER FACILITY
FOR
NEUTRON CAPTURE THERAPY
AND
EPITHERMAL NEUTRON RESEARCH

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1 Introduction

Boron Neutron Capture Therapy (BNCT) is a binary form of cancer therapy that has the potential to selectively kill cancer cells while sparing normal tissues. This can be accomplished by selectively localizing B^{10} in the tumor cells and delivering thermal neutrons to the target.[1] Compounds such as p-boronphenylalanine (BPA) can be used to localize B^{10} in the tumor by taking advantage of the higher metabolic rate of the tumor cells. A B^{10} nucleus absorbing a thermal neutron decays into an alpha particle and Li^7 nucleus with an accompanying energy release of 2.79 MeV.

Recently, BNCT trials have been conducted at Massachusetts Institute of Technology (MIT) using the M67 beam that has an epithermal neutron flux of 2.1E+8 n/cm^{2}s. The M67 beam was first used for BNCT Phase I clinical trials of subcutaneous melanoma of the extremities on September 6, 1994.[2] This was the first epithermal neutron irradiation used for BNCT. Brain cancer trials were initiated in 1996. Both of the phase I trials are continuing.

The M67 beam takes approximately 2.5 hours to deliver a dose of 1000 RBE cGy to healthy tissue and correspondingly more to tumor. Because of the long irradiation time, a new beam capable of treating a patient in a few minutes is necessary for advanced clinical trials and for routine therapy.[1] If BNCT proves to be successful, a need for the beam will be evident.

The new beam design is based on a fission converter plate driven by the neutrons from the Massachusetts Institute of Technology Research Reactor-II (MITR-II). Neutrons from the reactor are converted to a fission spectrum by the fission converter plate. A filter is then used to tailor the fission spectrum to eliminate unwanted fast neutrons and photons without significantly decreasing the epithermal neutrons (1eV to 10 keV).[1] The cooling of the fuel will be provided by natural convection of H_2O or D_2O enclosed in a double-walled tank.

The purpose of the design is to deliver approximately 2 to 10E+9 n/cm^{2}s with specific fast neutron and specific incident photon doses lower than 2E-11 cGy cm^2/epi n to minimize non-selective dose components. The epithermal neutron flux at this amount would result in an irradiation time of 1 to 10 minutes.[1]

The purpose of this report is to provide the necessary information required for the licensing of the MITR Fission Converter Facility by the U.S. Nuclear Regulatory Commission (NRC) and to demonstrate the safe operation of the fission converter. Technical specifications that constitute limitations for operation are submitted to identify those features of the facility, whether functional or operational. These technical specifications are based on the information provided in this Safety Analysis Report of the MITR Fission Converter Facility.

1 References

1. W.S. Kiger III, *Neutronic Design of a Fission Converter-Based Epithermal Beam for Neutron Capture Therapy*, Nuclear Engineer Thesis, MIT, 1996.

2. D.E. Wazer, R.G. Zamenhof, O.K. Harling, and H. Madoc-Jones, "Boron Neutron Capture Therapy." in *Radiation Oncology: Technology and Biology*, edited by P.M. Mauch and J.S. Loeffler, W.B. Saunders Company, Philadelphia, 1994.

2 Fission Converter Neutronic Design

In this section, the design of the fission converter is summarized. As a part of the fission converter study, a wide range of possible designs were considered. The results obtained by using the calculation methods described in the following sections have been used throughout this report. Accident analysis of the facility is covered in Sections 6 and 7.

2.1 General Description of the Fission Converter

The isometric view of the MIT Fission Converter Beam and the medical therapy room are illustrated in Figure 2.1. The fission converter tank will be located between the reactor's graphite reflector and the thermal column. The fission converter plate will be centered on the 35.6 cm (14 inch window) in the graphite reflector. A cadmium curtain (Section 4.1.1) located between the fission converter plate and the MITR-II core is used to control the neutron flux from the MITR-II and, therefore, controls the fission converter power. To further reduce radiation dose in the medical therapy room, additional shutters are located in the collimator region (Section 4.1.2).

The neutrons from the reactor are converted to a fission spectrum by the fission converter plate. A filter is then used to tailor the fission spectrum to eliminate unwanted fast neutrons and photons without significantly decreasing epithermal neutrons (1eV to 10 keV). A collimator then directs the epithermal neutron beam onto the patient.[1]

The cooling of the fuel will be provided by natural convection of H_2O or D_2O enclosed in a double-walled tank.[2] The double wall design will prevent coolant leakage in the event of inner wall failure. The primary coolant will be cooled by a heat exchanger connected to the MITR-II cooling tower through the reactor's secondary cooling system. The thermal hydraulic design is further discussed in Section 3.

A new medical therapy room will be located in the MITR-II's hohlraum location. A heavily shielded door and a labyrinth will give access to the medical therapy room. The medical therapy room will be adequately shielded to maintain a low radiation dose outside the facility.

Written instructions and detailed procedures will be prepared for the disassembly of the original components and assembly of the new components. These instructions and procedures will be reviewed and approved in the manner prescribed for MIT Reactor documents of this type.

2.2 Fuel Design

The fission converter is an array of MITR-II fuel elements in the fuel housing assembly located in the fission converter tank. The fission converter plate can contain up to eleven MITR-II fuel elements. These elements have experienced a wide range of successful burnups.

The fission converter is designed to use MITR-II fuel elements. Each fuel element is composed of fifteen fuel plates. The fission converter will use eleven MITR-II fuel elements spaced 0.159 cm apart. Because the fission converter uses the same fuel element as MITR-II, the fuel specifications given in the MITR-II SAR Section 3.3.5.2 and MITR-II Technical Specification Section 5.2 shall apply for the fission converter.

2.3 Criticality and Power Distributions

2.3.1 Criticality Calculation for the Fission Converter

The criticality of both the fission converter and the coupled core-converter system were studied.[1,3] The Monte Carlo N-Particle (MCNP) code has been used for the neutronic studies of the fission converter. The MNCP model of the MIT Research Reactor has been extensively validated in the core region and in the thermal column region where the fission converter will be located.[1,4]

To calculate the k_{eff} of the fission converter, criticality calculations of the fission converter beam and core albedo model were performed using the kcode option of MCNP.[1] The effective multiplication factors (k_{eff}) calculated are listed in Table 2.1. The k_{eff} calculated for the D_2O cooled system are 0.268 for burned MITR-II fuel and 0.344 for fresh MITR-II fuel. For the H_2O cooled system, k_{eff} calculated values are 0.514 and 0.618 for burned and fresh MITR-II fuel, respectively. Because the k_{eff} closest to unity is 0.618, a criticality accident is not credible.

Table 2.1 Criticality of the fission converter. The statistical uncertainty listed with each value represents one standard deviation. Values from Reference 1.

Coolant	Fuel	Converter Alone
	g ^{235}U	k_{eff}
D_2O	312 (Spent MITR-II fuel)	0.268±0.001
D_2O	510 (Fresh MITR-II fuel)	0.344±0.001
H_2O	312 (Spent MITR-II fuel)	0.514±0.001
H_2O	510 (Fresh MITR-II fuel)	0.618±0.001

2.3.2 Reactivity Worth of the Fission Converter

The k_{eff} values of the coupled core-converter system were calculated similarly using the kcode option of MCNP.[3] The criticality calculations to estimate the reactivity insertion caused by the fission converter were done to study the interaction between the reactor and the fission converter. These results are shown in Table 2.2. These calculations show that operation of the fission converter by opening the cadmium curtain will cause a change in reactivity of 0.00035±0.00060 Δk/k for the D_2O system using spent fuel and 0.00125±0.00071 Δk/k for H_2O system using fresh fuel.

The reactivity worth of the fission converter was also calculated using the diffusion theory code CITATION. This was done by modifying the CITATION input file for the MITR-II model to include a simplistic model of the fission converter facility in the thermal column region with and without fuel. The results of these runs show the reactivity worth to be 0.0000257 $\Delta k/k$.[5] The actual reactivity worth of the fission converter will be determined during pre-operational testing (Section 12.3.1), but the above referenced calculations indicated that it is quite small.

MITR-II Technical Specifications provide several approaches for limiting the reactivity associated with an experimental facility. MITR-II Technical Specification 6.1 imposes limits depending on whether the experiment is classified as moveable, non-secured, or secured. MITR-II Technical Specification 6.4 imposes a limit on the allowed period for experiments related to reactor control research. The latter approach provides more flexibility because it permits any combination of reactivity given that a certain minimum period is not exceeded. Accordingly, this approach is used for the fission converter. The fission converter will be exempt from MITR-II Technical Specification 6.1, instead, the reactor period limit of 50 seconds shall apply. Reactor controls can be used to compensate for the change in reactor power due to the presence of the fission converter as long as the reactor period is longer than 50 seconds when the cadmium curtain is being opened.

Table 2.2 Reactivity change due to opening of the cadmium curtain.

The statistical uncertainty listed with each value represents one standard deviation.

Values from Reference 3.

Coolant	Fuel	Cadmium Curtain Closed	Cadmium Curtain Opened	Reactivity Insertion
	g ^{235}U	k_{eff}	k_{eff}	Δk/k
D_2O	312 (Spent MITR-II Fuel)	1.00455±0.00048	1.00490±0.00036	0.00035±0.00060
H_2O	510 (Fresh MITR-II Fuel)	1.00417±0.00051	1.00543±0.00050	0.00125±0.00071

2.3.3 Fission Converter Power

The Monte Carlo N-Particle (MCNP) code has been used to calculate the fission converter power. The calculated values are summarized in Table 2.3. As the calculations show, the maximum power generated by the fission converter is 251 kW with MIT reactor power at 10 MW.[1] At this power level, each fuel element generates an average of 22.8 kW compared to an average power of 208 kW per fuel element in the MITR-II core.

Table 2.3 Fission converter power calculated in the criticality run. The statistical uncertainty listed with each value represents one standard deviation. Values from Reference 1.

		Coupled Core Converter Criticality Calculation	
Coolant	Fuel	Fission Converter Power at 5 MW reactor power	Fission Converter Power at 10 MW reactor power
	g ^{235}U	kW	kW
D_2O	312 (Spent MITR-II Fuel)	81.5 0.3%	163.0 0.3%
D_2O	510 (Fresh MITR-II Fuel)	105.4 0.2%	210.8 0.2%
H_2O	312 (Spent MITR-II Fuel)	83.4 0.2%	166.8 0.2%
H_2O	510 (Fresh MITR-II Fuel)	125.5 0.2%	251.0 0.2%

2.4 Filter

The thermal neutrons from the reactor is converted to a fission spectrum by the converter. A filter is then used to tailor the fission spectrum to eliminate unwanted fast neutrons and photons without a significantly decrease in epithermal neutrons (1eV to 10 keV). Filtration can be accomplished with the use of resonance scattering materials with large scattering neutron cross sections in the fast energy range, 1/v behavior in the thermal region, and a relatively low, flat cross section at epithermal energies.[1] To reduce contamination from thermal neutrons, thermal neutron absorbers such as Cd, ^{10}B, or ^{6}Li can be used. High Z material such as bismuth or lead is used to reduce the contamination from photons.

Material selection for the filter will be made to insure that phase change can be prevented under normal and accident conditions. In addition, the selection will minimize decomposition and accumulation of long term activities.[1] Adequate shielding shall be provided to limit the radiation dose outside the target area.

2.5 Collimator

The resulting beam from the filter is collimated by a rectangular collimator that is lined with a 15 cm thick layer of lead. In addition to positioning the epithermal neutron beam onto the patient, the collimator serves as the location for additional shutters for the beam (Section 4.1.2).

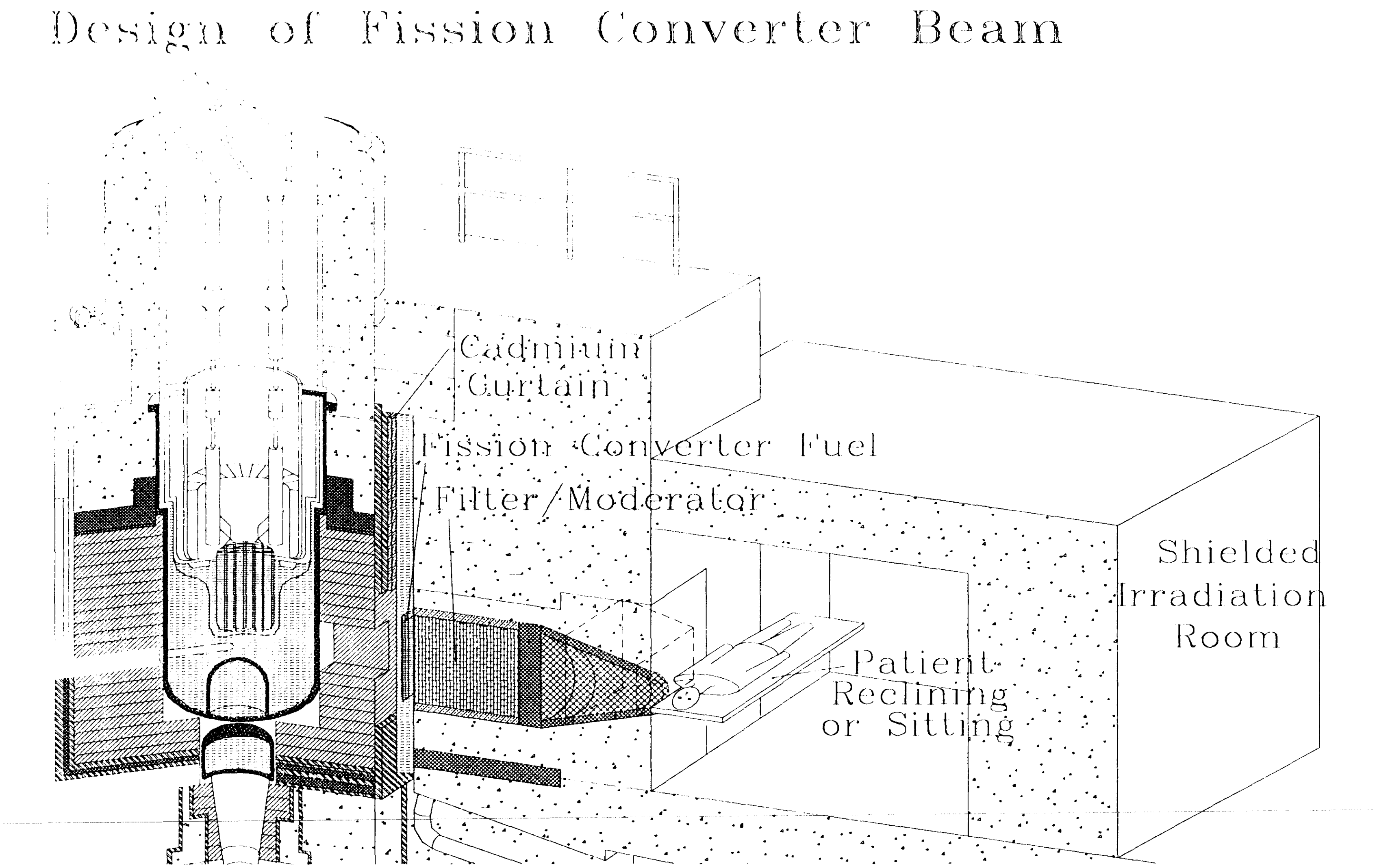


Figure 2.1 Isometric View of MIT Fission Converter Beam and Medical Therapy Room
Figure is from Reference 1.

2 References

1. W.S. Kiger III, *Neutronic Design of a Fission Converter-Based Epithermal Beam for Neutron Capture Therapy*, Nuclear Engineer Thesis, MIT, 1996.

2. B. Sutharshan, *Engineering Design of Fission Converter Based on Epithermal Beam for Neutron Capture Therapy at the MITR,* PhD Thesis, MIT, 1997.

3. S. Sakamoto, *Optimization of the Neutronic Design of the Fission Converter Based Epithermal Beam for Neutron Capture Therapy*, Nuclear Engineering Thesis, MIT, 1997.

4. E.L. Redmond II, J.C. Yanch, and O.K. Harling, "Monte Carlo Simulation of the Massachusetts Institute of Technology Research Reactor," *Nuclear Technology,* Vol. 106, April 1994.

5. T. Newton, *Calculation of the Reactivity Worth of the Fission Converter using CITATION*, MIT internal document, 1996.

3 Thermal Hydraulic Design

In this section, the thermal hydraulic design of the fission converter (Reference 1) is summarized. The fission converter has been designed to accommodate either an H_2O or a D_2O primary coolant system. The design limits of the thermal hydraulic system have been chosen to provide a reasonable safety margin beyond the desired operating range. The design limits also include consideration of the consequences of credible deviations from the operating range. Specifically, the limiting condition for operation is set to prevent incipient boiling of the primary coolant. Such a conservative design assures a wide margin to the real safety limit set to prevent critical heat flux. Accident analysis of the facility is covered in Sections 6 and 7.

3.1 General Description of the Thermal Hydraulic System

3.1.1 Design Bases

1. The system is designed to transfer 300 kW of heat from the primary to the secondary coolant system.
2. The coolant pool above the fuel elements provides shielding for the fission converter top and a reservoir of coolant for emergency conditions.
3. The system is designed to act as a barrier to the escape of fission product activity to either the reactor building or the secondary coolant system.

3.1.2 System Description

The MITR Fission Converter is designed to be cooled by natural convection using either the H_2O or D_2O primary coolant. Natural convection was chosen over forced convection after comparison of the two systems.[1] The primary coolant is enclosed in a double-walled tank (Section 3.5.1) and is cooled by a heat exchanger connected to the MITR-II cooling tower through the MITR-II's secondary coolant system (Section 3.6). The schematic of the fission converter heat removal system is shown in Figure 3.1.

The primary coolant system consists of two pumps, one or more heat exchangers, an ion column, a make-up coolant system, a chemistry control system, cover-gas system, and associated valves and piping. The pumps can be operated singly or in parallel. Part of the primary coolant flow is diverted to the ion column and the chemistry control system to purify the coolant and control water chemistry. The make-up coolant system provides a surge volume to compensate for coolant volume changes associated with heating and cooling. A pump will be used to maintain a flow through the clean-up loop and the heat exchanger after fission converter shutdown to remove the decay heat.

At the top of the fission converter tank, an air tight cover-gas system is provided to prevent radiolytic decomposition species from escaping (Section 3.5.3). During normal operation, pressure in the converter tank is maintained at atmospheric by the cover-gas system. Protection against overpressure of the coolant system is afforded by a 5 psig relief valve on the helium gasholder.

The primary coolant components including pumps, heat exchanger, clean up system, and make-up coolant system are located on top of a skid. The skid is designed to be water tight with surrounding curbs to contain the spill water in the event of any leakage from the coolant equipment. The skid will be located on the reactor top floor. The primary coolant system is discussed in Section 3.5.

The secondary coolant is light water. The secondary coolant is sent to the existing MITR-II cooling tower where it is cooled by water evaporation and air circulation. The secondary coolant system is discussed in Section 3.6.

The computational method and the thermal hydraulic design limits are discussed in Section 3.2 and Section 3.3 respectively.

3.2 Computational Method for Thermal Hydraulic Design

The primary computational tool for the thermal hydraulic studies was TEMPEST (Transient Energy Momentum and Pressure Equation Solution in Three dimensions). TEMPEST code has been developed by D.S. Trent and L.L. Eyler at the Pacific Northwest Laboratories in Battelle, Washington. TEMPEST can analyze a broad range of coupled fluid dynamics and heat transfer systems in complex three dimensional geometry that can be modeled using either Cartesian or cylindrical coordinate systems. Once the fission converter power profile, the geometry, the primary coolant inlet temperature, and the friction factors for the different regions are provided, TEMPEST will generate the velocity, temperature, and pressure fields.

3.2.1 TEMPEST Modeling of the Fission Converter

The fission converter was modeled in the Cartesian coordinate system. The fission converter was divided into finite cells arranged in rows, columns, and tiers in three dimensions as shown in Figure 3.2. Each cell represents a volume of either coolant, fission converter tank, or a fuel element.

Gravity is in the negative Z direction. There are 11 cells in X direction, 45 cells in Y direction and 96 cells in Z direction. Cell thickness vary from 0.8 inches (2.03 cm) to 6 inches (15.24 cm). An extra plane of cells surrounding the converter tank represents the boundary conditions (boundary condition cells are not shown in Figure 3.2).

To save computation time, each MITR-II fuel element (which is composed of fifteen fuel plates spaced 1.981 mm apart) was modeled by two TEMPEST cells in the Y coordinate as shown in Figure 3.3. The solid cell represents the fifteen fuel plates of a fuel element, and the other represents the fifteen coolant flow channels of a fuel element. By representing each fuel element by two TEMPEST cells, the cross sectional area dimensions are correctly represented.

However, the hydraulic diameter between the actual fuel element and the TEMPEST model is different. Adjustments for this difference is outlined below:

1. In TEMPEST, the change in pressure of the primary coolant as it passes across the fuel element is calculated by the following equation:

$$\Delta P = \left(\frac{f}{D_{\text{model}}}\right)\frac{L\rho V^N}{2} \qquad \text{(Equation 3.1)}$$

where ΔP is the pressure difference across the fuel element,

f is the friction coefficient,

D_{model} is the hydraulic diameter of the TEMPEST model,

L is the height of the fuel element,

ρ is the density of primary coolant,

V is the velocity of the primary coolant, and

N is a constant.

2. The actual fuel element consists of fifteen fuel plates and fifteen coolant channels. The change in pressure of the primary coolant as it passes across the fuel plate is given by D'Arcy's equation:

$$\Delta P = f\rho\frac{L}{2D_{actual}}V^2 \qquad \text{(Equation 3.2)}$$

where ΔP is the pressure change across the fuel plate,

$f = \frac{91.5}{\text{Re}} = \frac{91.5\mu}{\rho V D_{actual}}$ for finned plates in laminar flow,

ρ is density of primary coolant,

L is the height of the fuel plate,

D_{actual} is the hydraulic diameter of the actual system, and

V is the average velocity of the primary coolant.

(see Figure 3.4 for the cross sectional view of a flow channel)

3. By substituting the expression for f into Equation 3.2, the following equation is derived:

$$\Delta P = \left(\frac{91.5\mu}{\rho D_{actual}^{2}} \right) \frac{\rho L V}{2} \qquad \text{(Equation 3.3)}$$

4. Equation 3.3 is in the form of Equation 3.1 where

$$\frac{f}{D_{\mathrm{model}}} = \frac{91.5\mu}{\rho D_{actual}^{2}}$$

$$N = 1$$

Equation 3.3 for the TEMPEST code accounts for the difference in the friction coefficient and the hydraulic diameter between the TEMPEST model and the actual fuel element.

5. The validity of the model is discussed in Section 3.2.3.

The height of the fuel elements are modeled by eleven cells in the Z coordinate. The entrance and exit effects are modeled by an entrance and exit cells. In the X coordinate, the fuel elements are represented by 2 cells.

Solid cells in the TEMPEST model represent cells where no calculations are performed. The eleven fuel elements are represented by solid cells. The heat transfer from the fuel elements to the primary coolant have been modeled using the following steps:

1. The heat generated by each element was calculated by MCNP (Monte Carlo N-Particle).[2] In Table 3.1, the power generation of the eleven fuel elements for different primary coolant and MITR-II Research Reactor powers are listed. The

MITR-II is a 5 MW research reactor. However, a study is in progress to increase its power to 10 MW. A maximum fission converter power of 251 kW is generated using fresh fuel at a reactor power of 10 MW with H_2O as the primary coolant. As a conservative measure, a fission converter power of 300 kW was used for the thermal hydraulic design. In Table 3.2, MCNP calculations of individual fuel element powers normalized to a total fission converter power of 300 kW are listed.

Table 3.1 The fission converter power using fresh fuel elements.[2]

Primary Coolant	**MITR-II Power 5 MW**	**MITR-II Power 10 MW**
H_2O	125.5 kW	251 kW
D_2O	105.4 kW	210.8 kW

Table 3.2 The power generation rates for the eleven fuel elements from MCNP calculations[1]

Fuel Element Number	Normalized Power (kW)
1	19.8
2	21.9
3	26.6
4	31.0
5	33.9
6	35.0
7	34.2
8	30.8
9	25.8
10	21.1
11	19.3
Total	299.4

2. At steady-state, the heat generated by the fuel elements are transferred to the primary coolant. In the TEMPEST model, the heat generated by each fuel element is transferred directly into the adjacent primary coolant. By using this method, computation time is reduced and accuracy is strengthened as the need for heat transfer coefficient is avoided.

For the secondary coolant system, heat sink cells are used in the TEMPEST model. The heat transferred from the primary to the secondary coolant system is represented by heat sink cells located at the primary coolant inlets. The hot primary coolant from the fuel elements rises to the upper plenum of the fission converter tank. The primary coolant is then directed to the down comer region by the natural convection circulation as shown in Figure 3.5. The primary coolant that enters the heat sink cells is cooled to 40°C before leaving the cells. The heat sink cells represent the fluid leaving the converter tank to be cooled by the secondary coolant system and returned to the converter tank. The amount of primary coolant that leaves the fission converter tank to be cooled by the secondary coolant system can be varied by altering the size of the heat sink cells. The cooled primary fluid from the inlet (heat sink cells) and the recirculating fluid then mix in the down comer region. The coolant than moves downward in the down comer and is directed upward through the fuel elements. To decrease the amount of heat transfer from the hotter fluid rising from the fuel elements and the cooler fluid in the down comer, the inner walls of the down comer are composed of two plates of aluminum with a small gap.

3.2.2 Calculated Results of the Thermal Hydraulic System

The results of the calculations are shown in Table 3.3. The primary coolant inlet temperature is 40°C, and the average outlet bulk temperature is 72°C. The maximum primary coolant temperature above the hottest fuel element is 80°C.

The clad surface temperatures and the fuel center line temperatures were calculated using the following steps:

1. The flow between the fuel plates is laminar.[1] Therefore, the Nusselt number, Nu, is given as:

$$Nu = \frac{hD}{k} = 8.235 \qquad \text{(Equation 3.4)}$$

h is the heat transfer coefficient, k is the thermal conductivity, and D is the hydraulic diameter. The hottest channel heat flux (q''_{max}) is 19.5 kW/m^2. The maximum clad surface ($T_{max,clad}$) temperature can be expressed as:

$$T_{\max,clad} = T_{\max,coolant} + \frac{q''_{\max}}{h} \qquad \text{(Equation 3.5)}$$

$T_{max,coolant}$ is the coolant exit temperature from the hottest channel. From Equations 3.4 and 3.5, the maximum clad temperature is calculated to be 88^0 C.

2. For the fuel center line temperature:

$$T_{fuel\ centerline} = \frac{q \times 1000}{k_{fuel} / thickness} + T_{surface} \qquad \text{(Equation 3.6)}$$

k_{fuel} = 20.957 W/m°C

thickness = 1.016E-3 m

From Equation 3.6, the fuel center line temperature from the hottest fuel plate was calculated to be 87.6°C.

Table 3.3 Calculated Results of the Thermal Hydraulic System[1]

Primary Coolant Inlet Temperature	40°C
Average Primary Coolant Temperature at Fuel Element Entrance	59°C
Maximum Primary Coolant Temperature above the Hottest Fuel Element	80°C
Primary Coolant Outlet Bulk Temperature	72°C
Maximum Clad Surface Temperature	87.55°C
Maximum Fuel Center-Line Temperature	87.6°C
Mass flow rate in the primary loop	2.24 kg/s
Mass flow rate through the eleven fuel elements	3.4 kg/s

The results of these calculations demonstrate the conservative nature of the design. The primary coolant temperature above the hottest fuel element is 80°C. The clad surface temperature and the fuel center line temperature from the hottest fuel plate are 87.55°C and 87.6°C respectively which are far below the melting temperature of 649°C.[4] In Figure 3.6, the primary coolant temperature profile at the inlet and outlet of the eleven fuel elements are shown. In Figures 3.7, the power profile and coolant velocity profile are shown. Complete calculation of the thermal hydraulic design of the fission converter is discussed in Reference 1. Accident analysis of the fission converter is discussed in Sections 6 and 7.

3.2.3 Validity of the Calculated Results

An alternative method was used to validate the TEMPEST results. In the alternative method, an assumtion for the mass flow rate through the eleven MITR-II fuel elements was made. The skin friction and pressure loss (Δp_f) along the flow path were calculated for the assumed flow rate. Under natural circulation, the flow is driven entirely by the buoyancy generated by the pressure head (Δp_b). Thus, the steady state momentum equation can be reduced to: $\Delta p_f = \Delta p_b$. The above procedure was performed until the mass flow rate for the total pressure loss and for the buoyancy pressure head were equal. The results of the total flow rate, the temperature difference across the fuel element, and the pressure loss in the fuel and the down comer were listed in Table 3.4. As shown in Table 3.4, the results from the TEMPEST calculation and the alternative method correlated reasonably well.

Table 3.4 Comparison of the Alternative Method and TEMPEST calculation for steady state.[1]

	Alternative Method	**TEMPEST**
Temperature difference across a fuel element	26°	25°
Total flow rate through eleven MITR-II fuel elements	2.8 kg/s	3.4 kg/s
Pressure loss across the fuel elements	542 Pa	530 Pa
Pressure loss in the down comer	60 Pa	58 Pa

3.3 Thermal Hydraulic Design Limits

The fission converter has been designed to be safe under all reasonable conditions. In this section, the design limits are outlined. These limits have been chosen to provide a reasonable safe margin beyond the desired operating range. The design limits also include considerations for deviations from the normal operating range. Specifically, with regards to the thermal hydraulic limits, the operating limits are set to prevent incipient boiling on the fuel plates and the safety limit is set to prevent critical heat flux.

The normal operating characteristics were described in Section 3.2. The operational limits and the safety limit are discussed in the following subsections.

3.3.1 Operational Limits

The fission converter operating power limit has been chosen to be 300 kW. This operating limit provides a margin to set the safety system trip points, with reasonable uncertainties, for a maximum power of 250 kW during normal operation.

The temperature of the hottest spot on the hottest fuel plate shall not reach the condition of incipient boiling. The operating condition of the fission converter is established at values sufficient to prevent the temperature in the coolant, the clad, and fuel from reaching this limit.

The operating limit is set by the primary coolant temperature above the hottest fuel element. This temperature is 88°C. It is measured by a temperature probe located above the hottest fuel elements as discussed in Section 8.1.2. Onset of nucleate boiling occurs at a clad temperature of 106°C corresponding to the coolant temperature above the hottest fuel element of 96°C. Therefore, a margin between the operating limit and the onset of nucleate boiling is provided. Incipient boiling always precedes the initiation of critical heat flux; thus, the prevention of incipient boiling will assure that the Safety Limit (Section 3.3.3) will not be exceeded.

3.3.2 Limiting Safety System Setting

Limiting safety system setting is the parameter beyond which an action by the fission converter safety system is necessary. The limiting value is considered on the bases of whether a particular set of conditions could lead to fuel damage. It is defined in terms of primary coolant temperature above the hottest fuel element. It is set to prevent the onset of nucleate boiling. Incipient boiling precedes the initiation of critical heat flux as discussed in Section 6.1 of this report. Therefore, prevention of incipient boiling will assure that the Safety Limit (Section 3.3.3) is not exceeded. This is a conservative limit because critical heat flux does not occur until 47 minutes after the onset of nucleate boiling (Section 6.1).

If the coolant temperature suddenly increases, the cadmium curtain is capable of reducing the thermal neutron flux from the MITR-II core to lower the fission converter power by a factor of 100 so that the safety limit for the fission converter is not reached. Accident analysis is discussed in Sections 6 and 7. The limiting safety system setting is the: coolant temperature above the hottest fuel element set at 94°C. Because boiling occurs at 96°C, there is a margin between the safety system trip point and the onset of nucleate boiling.

3.3.3 Safety Limit

The goal of a safety limit is to assure that the structural integrity of the fuel elements are maintained. This will prevent fission products from being released. The MITR-II fuel element clad is made of Aluminum-6061, which melts at the temperature of 649 ^{0}C. The Aluminum melting point is much lower than the fuel (UALx) melting point of 1200 ^{0}C. Therefore, by preventing melting of the aluminum clad, MITR-II fuel element disruption will not occur. Although aluminum does not melt until approximately 649°C, it begins to soften significantly at about 490°C; thus, this temperature is a suitable criterion for guaranteeing the structural integrity of the fuel elements.[4]

The safety limit of the fission converter is set to prevent critical heat flux (CHF). At CHF, the maximum clad temperature is 106°C (Section 6.1). Simple calculation shows that the difference of about 384°C between the aluminum softening point of 490°C and the clad temperature at CHF (106°C) could not be reached if CHF is prevented. In Section 6.1 of this report, the condition for critical heat flux has been derived for total loss of primary coolant flow and continuous operation of the fission converter power at 300 kW. During the first phase of the transient, the coolant in the converter tank continues to recirculate by natural convection. The coolant temperature will begin to rise with passage of time due to continual operation of the fission converter at 300 kW. When the surface clad temperature reaches 106°C, onset of nucleate boiling will occur on the fuel plates. Bulk recirculation of the coolant continues until the liquid level in the fission converter drops below the top edge of the down comer walls 51 minutes into the transient. Critical heat flux is possible once the fluid level drops below the top edge of the down comer walls. Therefore, the safety limit for the fluid level is set at the height of the down comer wall (2.54 meters above the top edge of the fuel elements) to prevent the possibility of reaching critical heat flux.

3.4 Decay Heat Calculations

The decay power of the fission converter was calculated using DKPOWR. DKPOWR is a code for calculating decay power, energy, activity, and $\beta + \gamma$ spectra in LWR fuel using fission pulse functions. The code was prepared by Los Alamos National Laboratory, Applied Nuclear Science Group, Theoretical division, University of California, Los Alamos, New Mexico. The basic DKPOWR code was prepared originally to incorporate the 1979 ANSI/ANS 5.1 decay power standard using U.S. Department of Energy funding.

The fission converter power changes with the position of the cadmium curtain. In Figure 3.8, the decay power of the fission converter as a function of time is shown. At time zero in Figure 3.8, the cadmium curtain is fully closed and the fission converter power drops from 300 kW to 18.4 kW. The power decays from 18.4 kW to a steady state level of 2.1 kW. The fission converter power does not decay below 2.1 kW because the cadmium curtain can only absorb 99% of the neutron flux from the reactor. The neutrons that are transmitted through the cadmium curtain will produce a constant power of 2.1 kW in the fission converter. The thermal hydraulic system is designed to adequately remove the decay power after shutdown.

3.5 Primary Coolant System

Starting from the converter tank, the coolant entrance velocity into the outlet pipe is the same as the coolant velocity in the upper plenum region. As a result, the suction power created by the pump in the primary outlet pipe will not disturb the natural convection in the fission converter. The coolant velocity in the upper plenum ranges from 0.1 to 0.13 m/s in the vertical direction. Because the primary loop volumetric flow rate is 2.3E-03 m^3/s, setting the inside diameter to 0.17 m would result in coolant velocity of 0.1 m/s in the outlet pipe. The outlet pipe leads into the tube side of the heat exchanger. This is a single pass, counterflow unit. The outlet lines of the heat exchanger form a single 1.5 inch (3.81 cm) I.D. line that splits into two pipes to enter the suction sides of the two parallel single stage pumps. The outlet lines from each pump join to form a single 1.5 inch (3.81 cm) I.D. line. The coolant than enters each side of the fission converter tank as shown in Figure 3.1. The inlet flow enters the fission converter tank in the down comer region where the coolant flows downward. The fluid is then directed upwards through the fuel elements and finally is drawn through the outlet line.

3.5.1 Fission Converter Tank

The primary coolant is enclosed in a double-walled tank. Figure 3.9 illustrates the fission converter tank design. The inner tank is 1 inch (2.54 cm) in thickness except for the front plate (nearest to the reactor core) which is ¾ inch (1.905 cm). The outer tank is ¼ inch (0.635 cm) in thickness. There is a ¼ inch (0.635 cm) gap between the inner and outer layers.

Calculations were performed using ADINA, a finite element computer program used for displacement and stress analysis.[3] The design of the inner layer of the fission converter tank shall comply with Section IV of the ASME Boiler & Pressure Vessel Code. The inner tank will be pressure tested at a minimum of 100% over maximum normal operating pressure.

3.5.2 Fission Converter Fuel Housing Grid Design

All structures are designed conservatively with respect to stresses such that they are well below fatigue cycling limits. Deflection under load is also designed to be small relative to all required clearances. The fuel housing grid is designed within the ASME code stresses, and deflections will be limited to 0.015 inches (0.0381 cm) at the working load of 1100 lb. (4889 N) uniformly distributed. Cycling and fatigue limits will not be exceeded because of the low operating stresses and long cycling periods.

Fuel restraint is based on a closed-packed of the fuel elements in a sturdy casing with fixed upper and lower grid plates with side walls as shown in Figure 3.9. The fuel elements are held down by gravity and the maximum hydraulic lift created by the coolant is negligible.[1] The results of the calculations of the hydraulic lift are listed in Table 3.5.

Table 3.5 Fuel Restraint Calculation Results

Fuel Element Downward Force	29.89 N
Maximum Hydraulic Lift Generated	2.13 N

3.5.3 Cover-Gas System

At the top of the fission converter tank, an air tight cover-gas system is provided to prevent radiolytic decomposition species from escaping. All free surfaces of heavy water system are blanketed with helium which is supplied from a common gasholder. The helium blanket performs three functions:

1. Prevent air with entrained moisture from entering the system and coming in contact with the D_2O, and degrading it;
2. Inhibit the corrosive effect resulting from nitrous oxide formation from air in the presence of high radiation fields;
3. Provide an inert nonradioactive atmosphere.

Helium from a high pressure manifold is supplied through two reducing stations to a constant pressure gasholder. From there, helium is supplied to all free surfaces in the primary coolant system. There are alarms for high and low gasholder levels. If the pressure builds up despite the large volume available, steam will be vented into the MITR-II stack through the 5 psig rupture disc on the gasholder.

As indicated in MITR Technical Specification 3.3, flammable concentration of D_2 is achieved at 6.87 volume percent at a temperature of 200°C. The maximum temperature in the helium system will be less than 200°C under all foreseeable circumstances. Disassociation of the heavy water in the fission converter should be considerably less than in the MIT Research Reactor where the D_2O is subject to a higher fast neutron flux. As discussed in MITR Technical Specification 3.3, experiments were conducted at 2 MW reactor power with the recombiner shut off for varying times up to 2-1/2 hours to measure D_2 concentrations. The largest concentration of D_2 during these experiments was found to be 1.448%. Extrapolation of this data from 2 MW to 250 kW fission converter power indicates that the rate of D_2O dissociation is insignificant.

Continuous operation of the fission converter without a recombiner is considered acceptable because of the reasons given above. The quarterly frequency for performing D_2 analysis are also based on the rationale presented above.

3.5.4 Clean-Up System

A portion of the primary coolant from the heat exchanger flows through an ion column inlet filter, a mixed bed ion exchanger, and an ion exchanger outlet filter. The purified coolant then flows to the suction side of the pumps to join the rest of the primary coolant to be pumped back into the converter tank. The clean-up loop is located downstream from the heat exchanger to maintain a low coolant temperature sufficient enough to protect the temperature sensitive resin.

Two conductivity cells (one at the inlet and one at the outlet of the clean-up loop) are used to monitor the conductance of the primary coolant flowing through the clean-up loop.

There is also an on-line temperature monitor system for the inlet and the outlet line of the clean-up loop.

3.5.5 Make-Up Coolant System

The purpose of the make-up coolant system is to provide a surge volume to compensate for coolant volume changes associated with heating and cooling. If D_2O primary coolant is used, the make-up system will also serve as a storage tank for the D_2O primary coolant in the event that the fission converter tank needs to be emptied. The storage tank fluid level is checked once a week.

The coolant level in the fission converter tank is monitored by a redundant system (Section 8.1.3). If the fluid level in the converter tank is below a preset level, a make-up water will be provided by opening the manual valve that connects the make-up water tank to the primary coolant system.

3.5.6 Coolant and Cover-Gas Sampling

In order to monitor the physical characteristics of the primary coolant, sampling loops have been installed on the primary coolant flow system and the helium cover-gas system.

The purpose of the primary coolant sampling system is to permit access for sampling at any time from the primary loop during operation. A primary water analysis is taken monthly for gross beta activity. For the D_2O system, tritium content is determined quarterly and is routinely sampled for isotropic purity.

A pH meter can be installed as part of the sampling station for the primary coolant.

A helium sample analysis is taken quarterly for the following purposes:

1. To obtain an argon spectrum to check for air contamination,

2. To determine D_2 or H_2 concentration by means of a combustible gas indicator, and
3. To measure tritium concentrations (for D_2O system).

3.6 Secondary Coolant System

The secondary H_2O coolant system contains the pump, piping, and valves. The secondary H_2O coolant from the MITR-II Research Reactor is also used for the fission converter. Cool secondary H_2O is drawn from the basins of the MITR-II cooling towers outside the reactor containment. It combines into a single pipe which penetrates the reactor's containment shell leading into the equipment room. The flow is then separated to provide secondary coolant to the MITR-II and the fission converter. The pump provides flow to the shell sides of the fission converter heat exchanger. The exit flow from the fission converter heat exchanger combines with the exit flow from the MITR-II Research Reactor heat exchangers to form a single exit pipe. This exit pipe penetrates out of the containment shell and returns to the cooling towers. Return flow to the cooling towers can be directed either to the cooling tower basin or to the spray top of the cooling towers either directly or through booster pumps. Forced air convection up through the cooling towers removes the heat from the secondary H_2O by evaporation to the atmosphere.

Because the fission converter uses the existing MITR-II secondary coolant, monitoring and maintenance specifications from the MITR-II SAR are applicable to the fission converter. For specification of the MITR-II secondary coolant system, refer to the MITR-II SAR Section 9.1.

A study has been conducted to calculate the impact of the fission converter on the MITR-II secondary system.[1] The reactor was designed for 6 MW with normal operation at 5 MW. The addition of 300 kW to the reactor's secondary system was calculated to be negligible.

3.7 Material Selection

Material selection shall be based on:

1. structural requirements,
2. nuclear properties,
3. availability, and
4. cost.

All materials, including those of the converter tank, in contact with primary coolant, shall be aluminum alloys, stainless steel, or other materials that are chemically compatible with H_2O and D_2O coolant, except for small non-corrosive components such as gaskets, filters, and valve diaphragms. The converter tank shall be designed in accordance with the ASME Boiler & Pressure Vessel Code Section IV. Bulk shielding for the medical therapy room will be made of conventional materials. The cadmium curtain is composed of 0.0508 cm cadmium sandwiched between 0.635 cm aluminum on each side (Section 4.1.1). The water shutter may contain 1% ^{10}B by weight (Section 4.1.2.1). Lead and plastic are used for the mechanical shutter (Section 4.1.2.2).

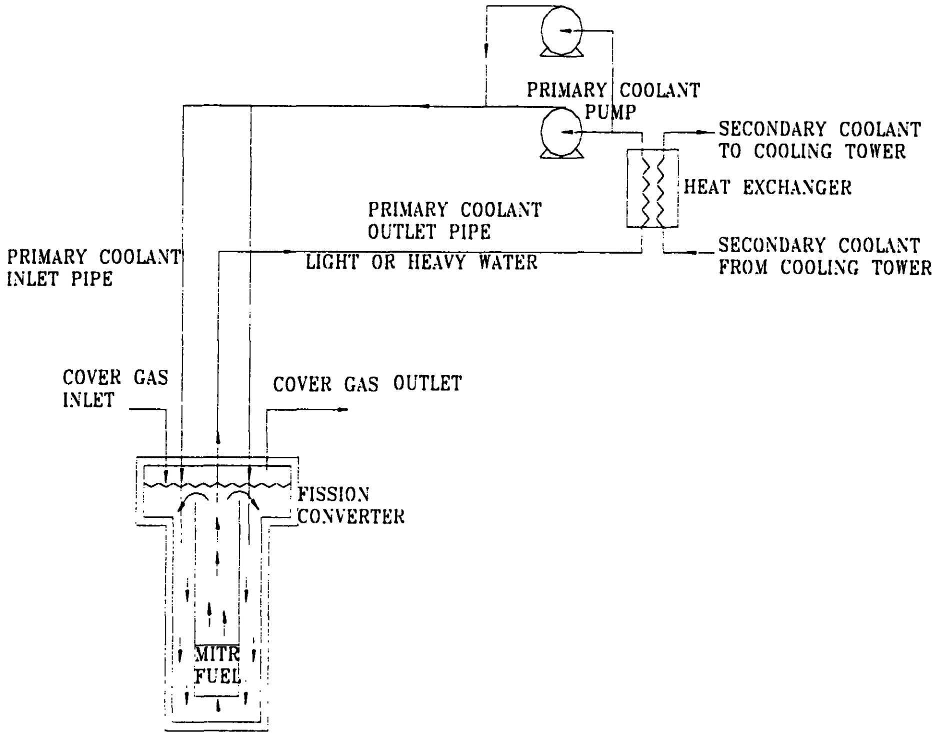


Figure 3.1 Schematic diagram of the fission converter heat removal system.
Figure from Reference 1.

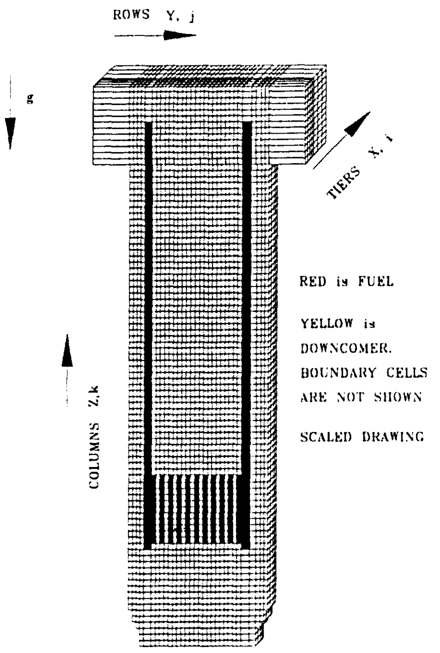


Figure 3.2 Fission Converter Finite Difference Cell Structure
Figure from Reference 1.

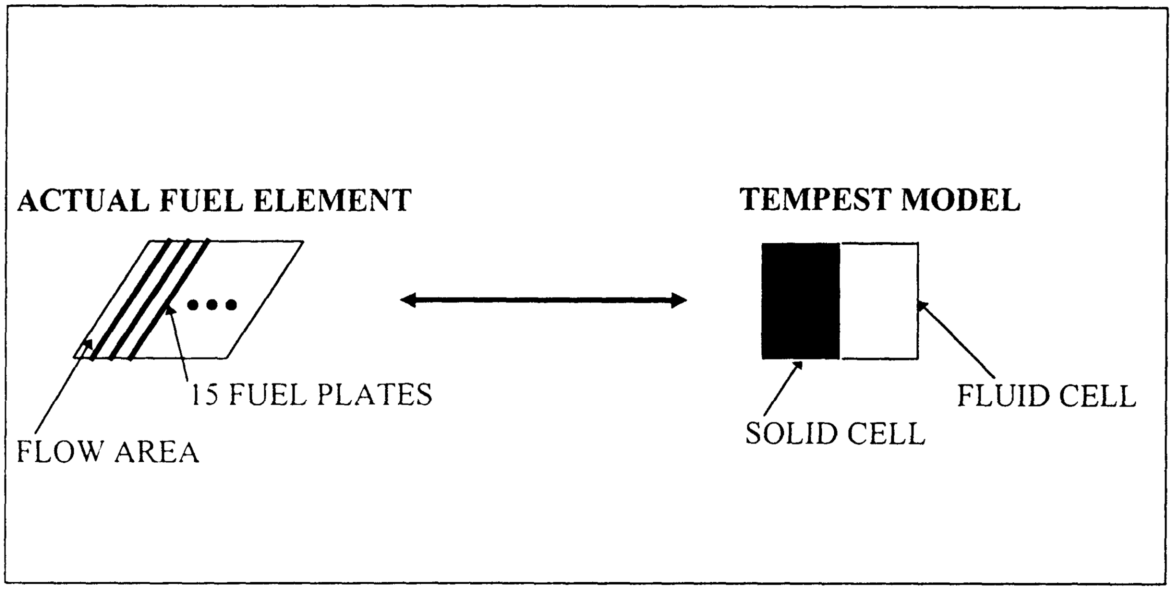


FIGURE 3.3 FUEL MODEL FOR TEMPEST

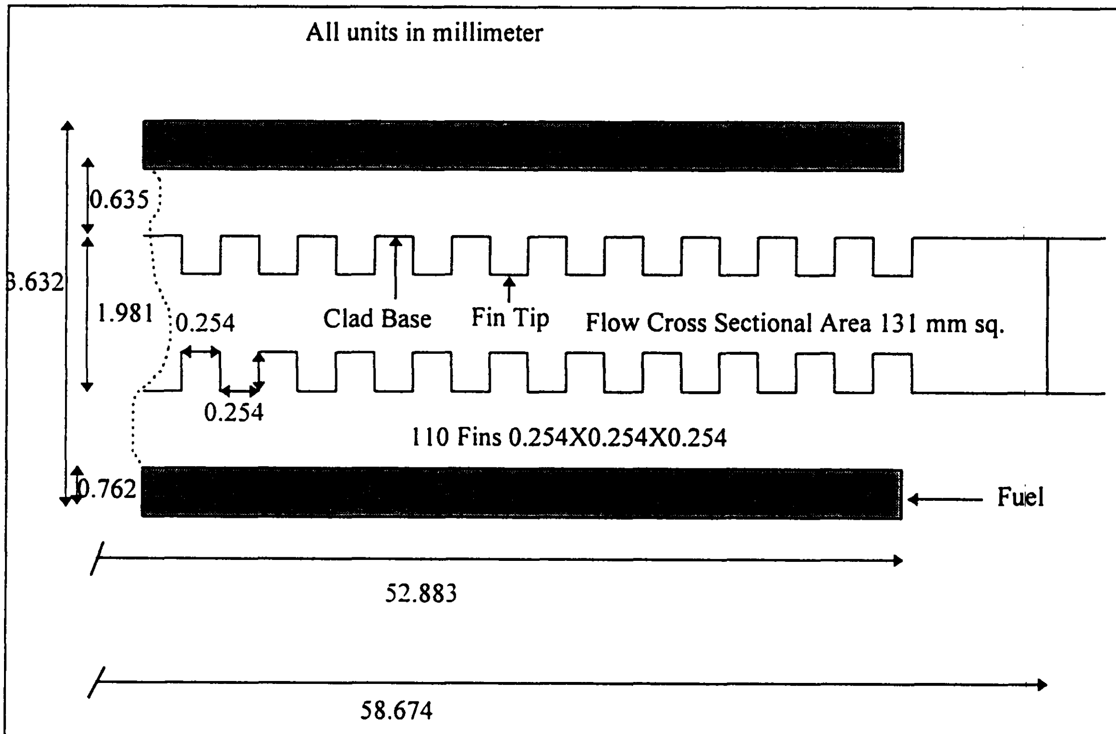


FIGURE 3.4: Cross Sectional View of a Flow Channel and Finned Fuel Plates[1]

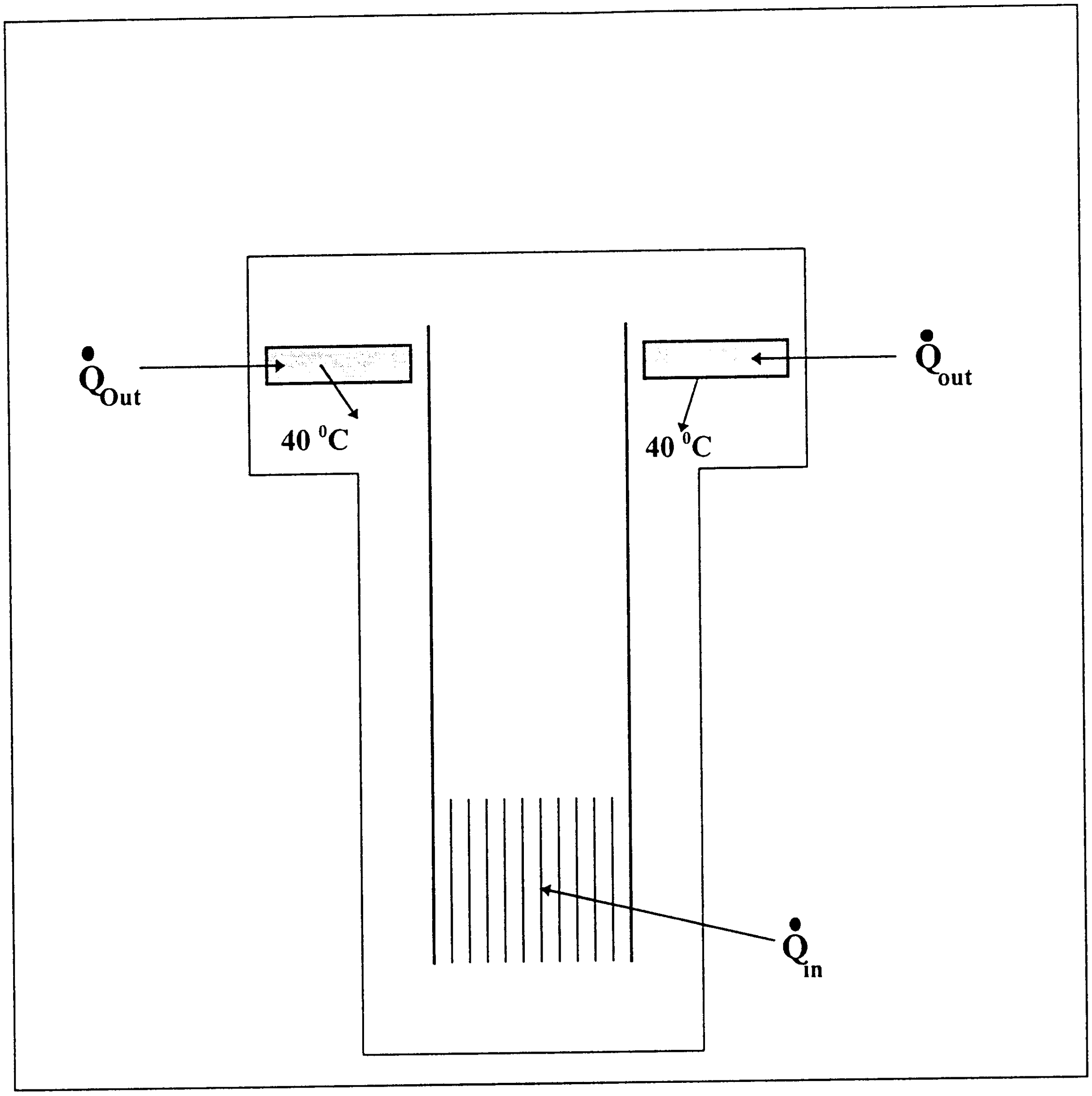


Figure 3.5 Heat Sink Model[1]

FIGURE 3.6: Core Inlet and Oulet Temperatures

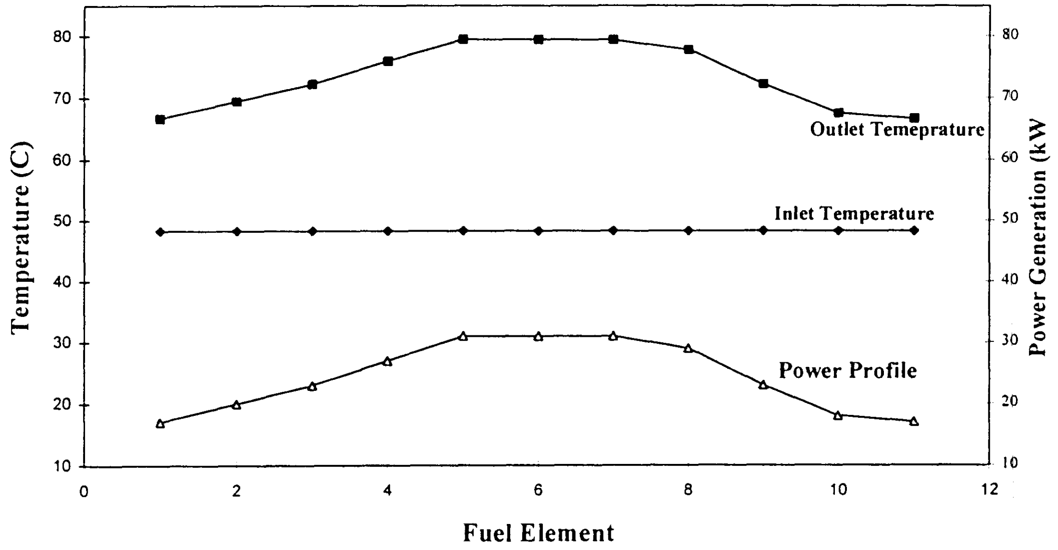


FIGURE 3.7: Velocity and Power Profiles

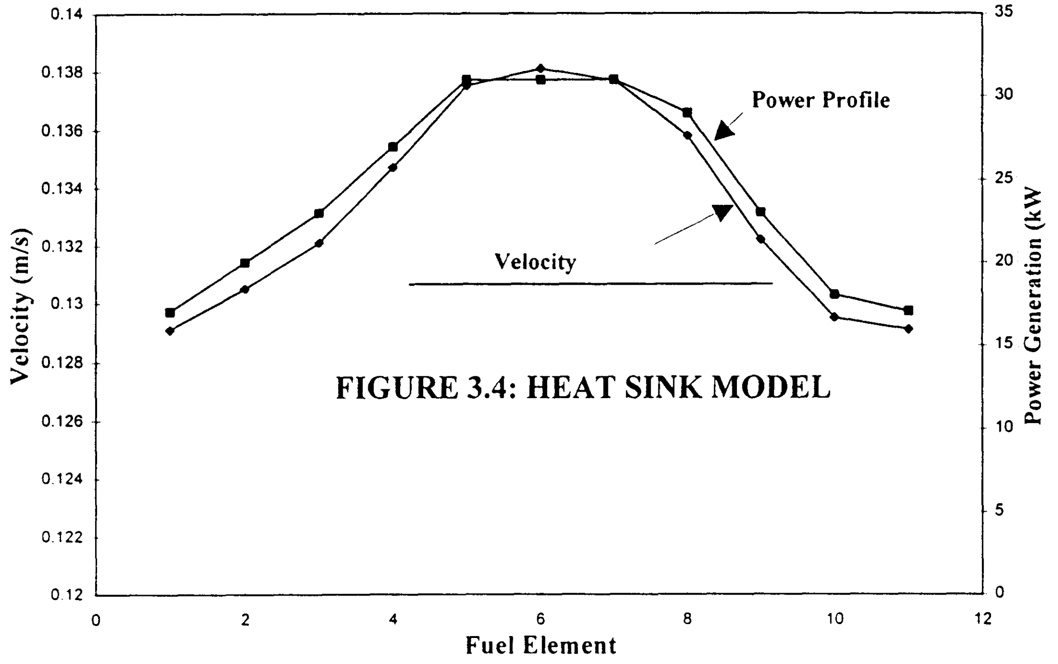


Figure 3.8 Decay Power From 0 to 27 hrs

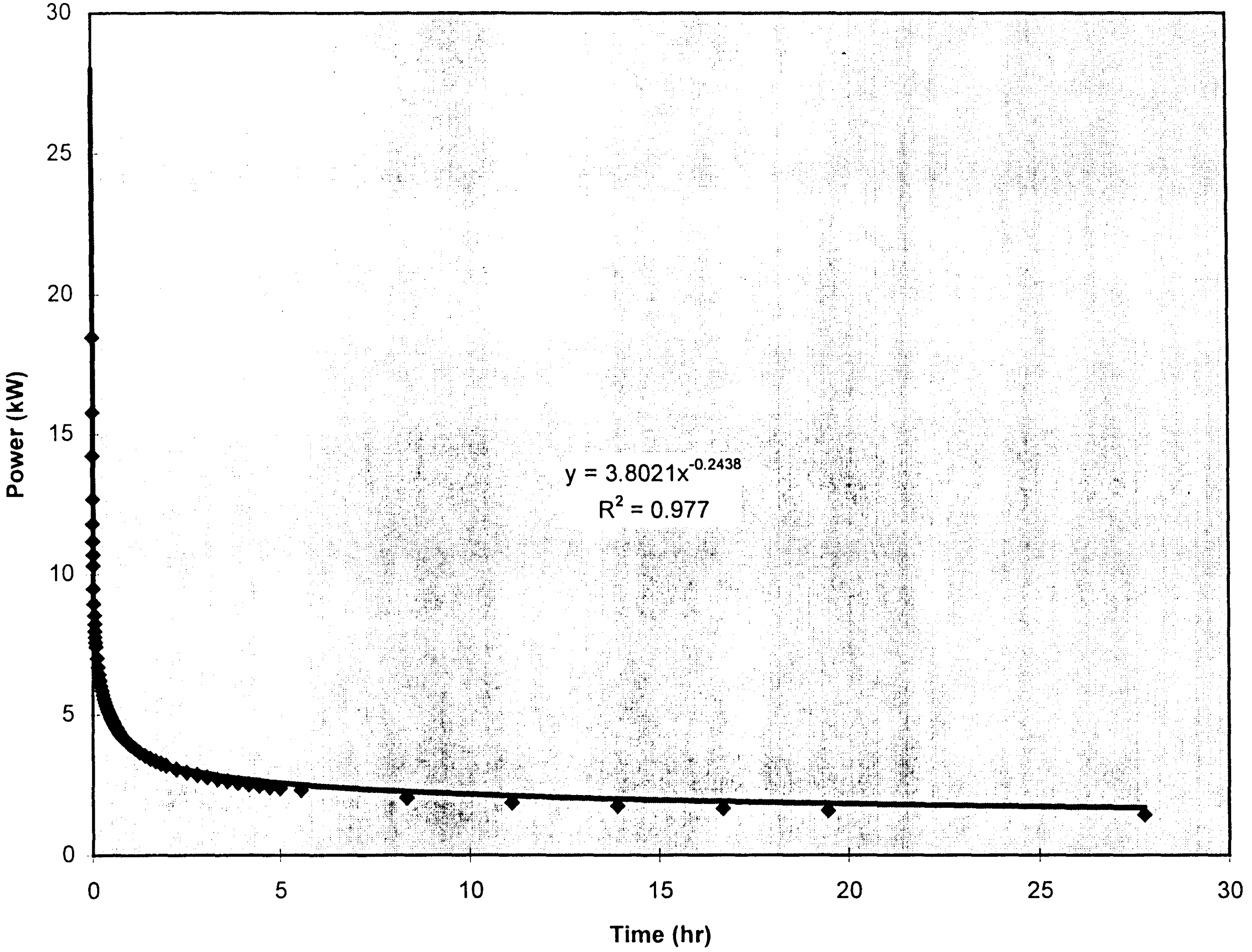
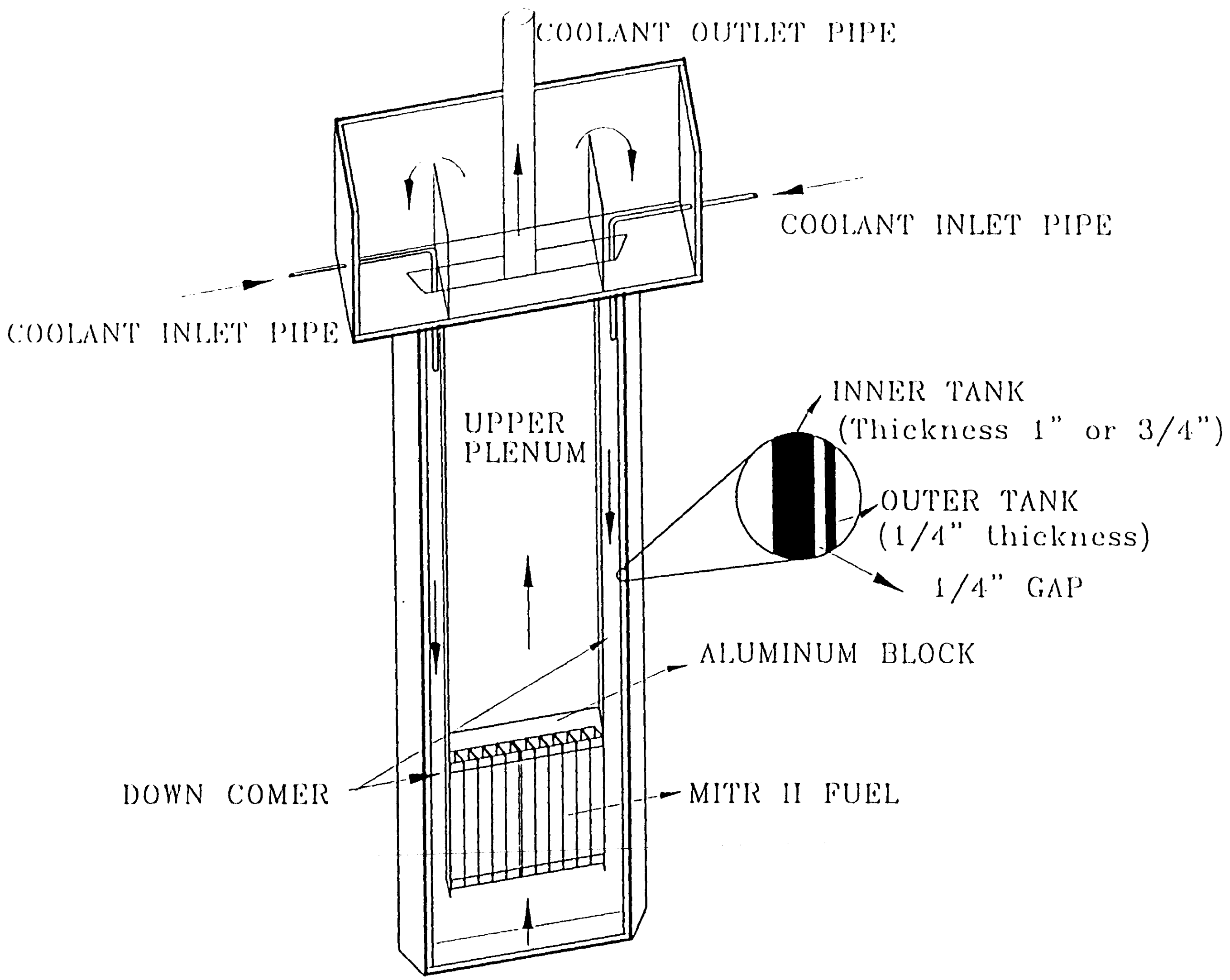


FIGURE 3.9: ISOMETRIC VIEW OF FISSION CONVERTER TANK



3 References

1. B. Sutharshan, *Engineering Design of Fission Converter Based on Epithermal Beam for Neutron Capture Therapy at the MITR,* PhD Thesis, MIT, 1997.

2. W.S. Kiger III, *Neutronic Design of a Fission Converter-Based Epithermal Beam for Neutron Capture Therapy*, Nuclear Engineer Thesis, MIT, 1996.

3. ADINA R & D, Inc., Watertown, MA, USA.

4. MITR-II SAR Section 3.3.4.

4 Fission Converter Shutter and Medical Therapy Room Design

4.1 General Description of the Shutter Design

The shutters for the fission converter provide several functions. The cadmium curtain located between the reactor core and the fission converter plate controls the neutron flux to the converter and, therefore, controls the power. Additional shutters in the collimator reduce the radiation dose to the medical personnel working in the medical therapy room. The shutters are also used to provide the correct irradiation dose to the patient. The shutters for the fission converter consist of a cadmium curtain (Section 4.1.1), a water shutter in the collimator (Section 4.1.2.1), and a mechanical shutter at the end of the collimator (Section 4.1.2.2). The MCNP (Monte Carlo N-Particle) code was used for the shutter design. See Reference 1 for a complete report.

4.1.1 Cadmium Curtain

The cadmium curtain located between the reactor core and the fission converter reduces thermal neutrons incident on the fission converter to less than 1%.[2] Figures 4.1 and 4.2 show the fission converter power, epithermal neutron flux at the patient position, and fast neutron dose at the patient position as a function of cadmium curtain height above the fuel centerline. The cadmium curtain is composed of a 0.0508 cm layer of cadmium sandwiched between two 0.635 cm layers of aluminum.

Two stainless steel cables, attached at the top corners of the cadmium curtain, are used to raise and lower the curtain by an electric motor. The control system is designed to give adequate cadmium curtain movement in both speed and distance. This design provides a smooth and stable control of the fission converter power. The control system contains the following features:

redundant drive in-limit, redundant drive out-limits, constant or variable speed drive, automatic control of the cadmium curtain, and automatic rundown provisions. The drive in-limit and drive out-limit circuits are used to stop the motor and prevent the cadmium curtain from being driven beyond its physical limitations.

Limit switches are used to inform the operator of the curtain's position, indicating it to be fully closed or fully opened. In the event of cadmium curtain failure to fully close, the reactor operator can lower reactor power or scram the reactor to shutdown the fission converter.

The maximum speed for opening the cadmium curtain will be limited by the reactor period. Reactor controls can be used to compensate for the change in reactor power due to the presence of the fission converter given the reactor period is longer than 50 seconds (Section 2.3.2).

The time for the cadmium curtain to be fully closed from a fully opened position will be measured as part of the pre-operational testing (Section 12), and at least annually thereafter to ensure proper functioning. Normal closing time shall be less than 30 seconds.

4.1.2 Collimator Shutter Design

Shutters in the collimator are needed to ensure the safety of personnel working in the medical therapy room. A two-part shutter design will be used: a water shutter (Section 4.1.2.1) and a fast acting mechanical shutter (Section 4.1.2.2) at the end of the collimator.

4.1.2.1 Water Shutter

The water shutter located in the collimator provides good neutron and gamma attenuation and does not, or only marginally, reduces the collimator efficiency when the shutter is in the open position. Figure 4.3 illustrates the water shutter design. To increase neutron attenuation, 1% of the fluid may consist of ^{10}B.

At the start of the irradiation, the water shutter is full and the upper storage tank (located on top of the thermal column or the medical therapy room) holds enough water to refill the water shutter. To open the water shutter, water is emptied by de-energizing a solenoid valve, which allows the water to drain by gravity into the lower storage water tank (located in the MITR basement equipment room). To close the water shutter, a solenoid valve between the upper storage tank and the water shutter is de-energized. Water from the upper storage tank drains by gravity into the water shutter. In the event of an electrical failure, the upper solenoid valve automatically de-energizes and fills the water shutter. Manual control of the solenoid valves will also be provided. A pump is used to refill the upper storage tank with water from the lower storage tank. However, in the event of pump failure, the reservoir water in the upper storage tank can refill the water shutter. Figure 4.3 illustrates the hydraulic system of the water shutter. Conductivity probes will be used to inform the operator (at the medical control panel) of the water shutter position, fully closed or fully open. When the water shutter is emptied, the tank may be filled with helium to reduce the production of Ar^{41}. The time frame necessary for the water shutter tank to fully close and fully open will be initially checked as part of the pre-operational testing and tested at least annually thereafter to ensure proper functioning. Normal opening and closing time shall be less than 120 seconds.

4.1.2.2 Mechanical Shutter

A fast acting mechanical shutter composed of lead and hydrogenous material such as polyethylene is located at the end of the collimator to provide shielding from gamma radiation and fast neutrons. The mechanical shutter is operated by a pneumatic or hydraulic cylinder. The shutter closes automatically when pressure is loss and in the event of electrical failure. Manual control will also be provided. Limit switches are used to inform the operator (at the medical control panel) of the mechanical shutter position, fully closed or fully opened.

The time frame required for the mechanical shutter to fully close and fully open will be initially checked as part of the pre-operational testing, and tested at least annually thereafter to ensure proper functioning. Normal opening and closing time shall be less than 4 seconds.

4.2 Shutter Controls

Controls for the fission converter shutters are located inside the medical therapy room, outside at the medical control panel, and in the reactor control room. The controls at the medical control panel consist of open and close buttons with appropriate position indicators for each shutter. All of these control buttons are activated by means of a key switch. When the key is removed, these controls cannot be used. In addition to the above items, there is a reactor scram button located at the medical control panel. The controls inside the medical therapy room consist of "close" buttons for the cadmium, water, and mechanical shutters. The shutters cannot be opened from inside the medical therapy room. The reactor control room is supplied with "fully closed" indicator lights for the cadmium, water, and mechanical shutters. The cadmium curtain can also be closed from the reactor control room.

The irradiation time for patient treatment with the fission converter beam is less than 5 minutes. Because of the short treatment time, the fission converter shutters will be controlled by an automatic timing system coupled with a provision for manual control of the shutters at anytime. The water and the mechanical shutters can also be closed manually from a location adjacent to the medical control panel. Because of the manual closing capability, the system is considered adequate and, therefore, is not part of the emergency power system.

4.3 Medical Therapy Room Design

The new medical therapy room for the fission converter based epithermal neutron beam will be located in the MITR-II's hohlraum area (Figure 2.1). Medical therapy room shielding is discussed in Section 9.3. Curved pipe ducts to prevent radiation streaming will be provided for the necessary connections and cable runs from the medical therapy room to the control centers.

4.4 Medical Therapy Room Door

Access to the therapy room is provided by a motor driven sliding door. During irradiation, the shielded door at the entrance to the therapy room is closed. This door is motor driven and is normally controlled by push buttons stationed inside and outside the door, and at the medical control panel. In an emergency, the drive mechanism can be disconnected from either side of the door, the door can then be operated by hand. Lamps on the medical control panel and in the reactor control room signal the position of the shielded door. An interlock shall prevent opening of the shutters that control beam delivery unless the medical therapy room's shielded door is closed. Furthermore, the shutters shall also close automatically when the door opens. If required by a particular experiment, this interlock may be bypassed for runs at low fission converter power or when adequate shielding can be provided to allow personnel to work in the area without radiation hazard. In all cases, sufficient warning is afforded by the radiation warning lamp outside the door.

The medical control panel receives indications of high radiation levels and the positioning of the door. The same signals are received and indicated in the reactor control room. Thus, anyone entering into this area would be observed by two separate control centers. Communications exist between both of these centers and the medical therapy room. The shielded door can be locked when the facility is not in use.

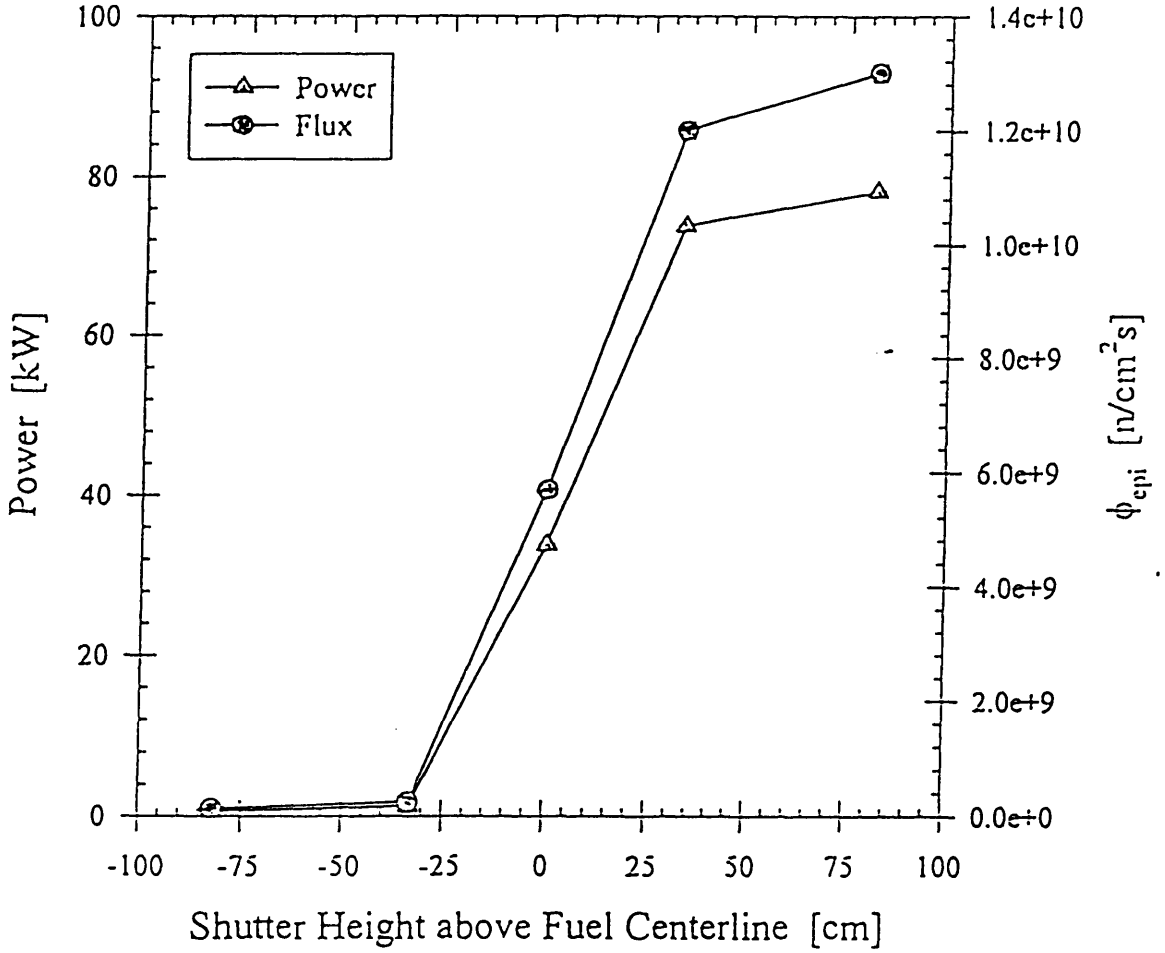


Figure 4.1 Fission converter power and epithermal neutron flux at the patient position as a function of cadmium curtain height. From Reference 2.

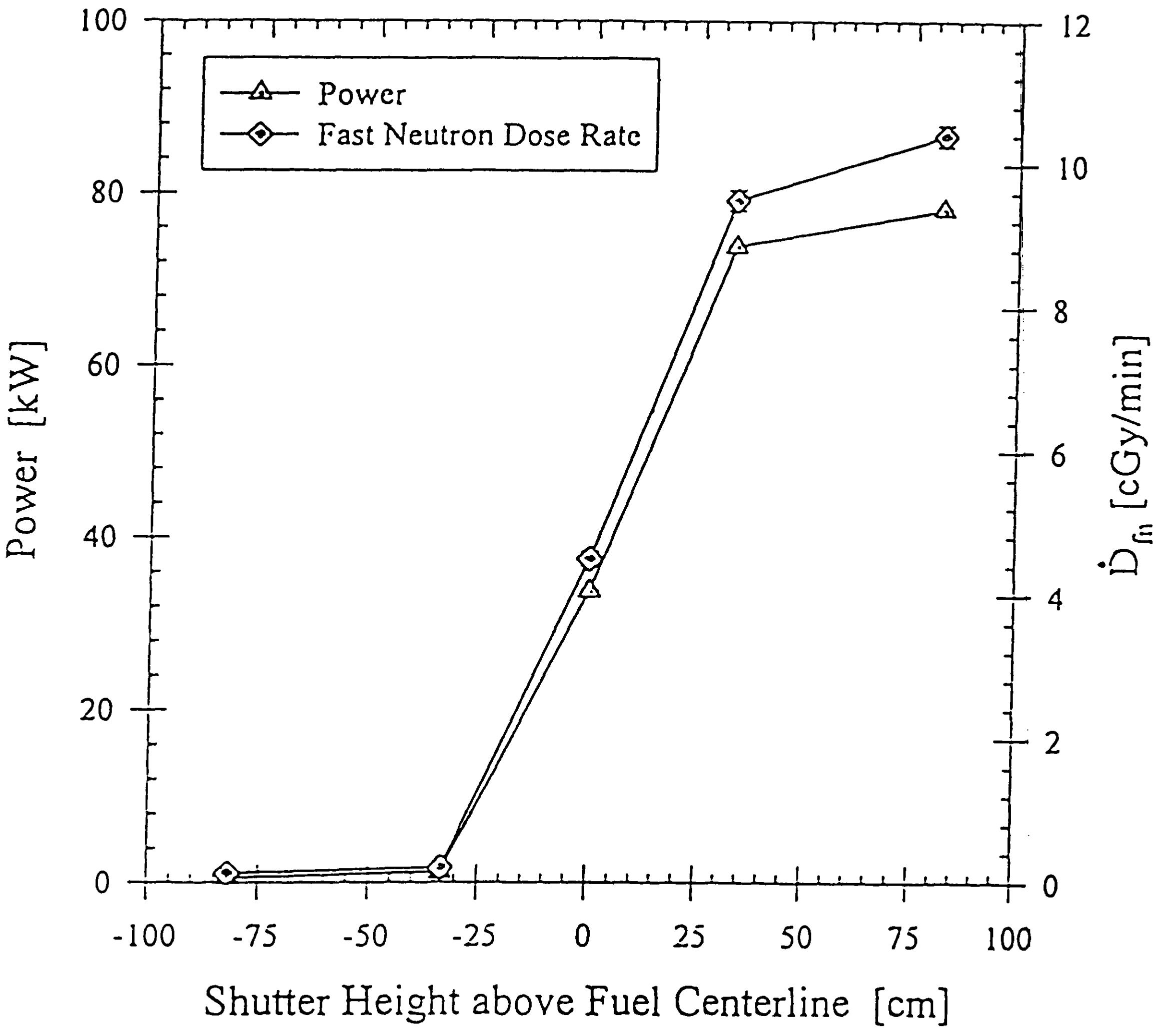


Figure 4.2 Fission converter power and fast neutron dose at the patient position as a function of cadmium curtain height. From Reference 2.

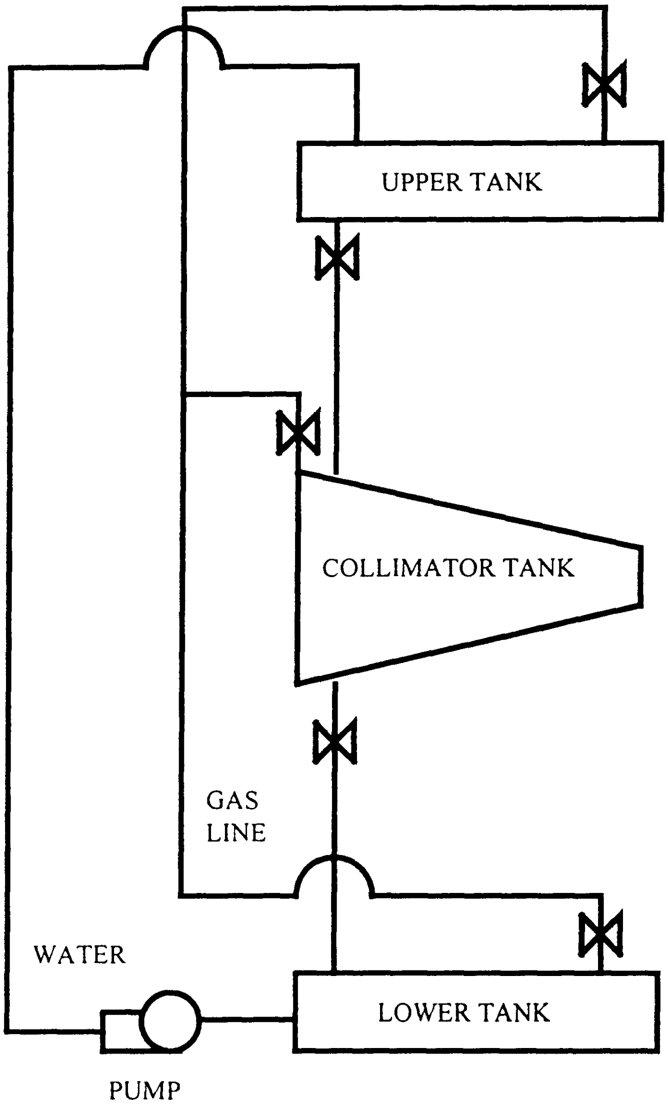


Figure 4.3 Water Shutter System

4 References

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2. W.S. Kiger III, *Neutronic Design of a Fission Converter-Based Epithermal Beam for Neutron Capture Therapy*, Nuclear Engineer Thesis, MIT, 1996.

5 Fission Converter Component Handling

Handling of the fuel elements or irradiated fission converter components requires careful administrative control as well as special purpose equipment to provide safe manipulation of these components. The procedures and handling equipment are designed to limit exposure of personnel to radiation and to prevent excessive heating of the fuel plates. Handling procedures of these components are described in the following sections. Should a need arise for handling of any other fission converter components, (such as structural components of the fission converter) special procedures, including a step by step check sheet will be established. The check sheet will be approved by the Director of Reactor Operations or his designate, and by the Reactor Radiation Protection Officer prior to the actual handling process.

5.1 Fuel Element Handling

During normal refueling, depleted or partially depleted fuel elements may be removed from the fission converter and stored in one of the MITR-II fuel storage areas (MITR-II SAR Section 9.4.1.1). Partly depleted fuel elements may be moved from one fuel position to another or removed from the converter fuel housing. New or spent fuel elements may be inserted into the converter. The main problems associated with handling spent fuel handling are shielding fission gamma rays and preventing excessive heating of the fuel plates. A shielded transfer cask provides the necessary shielding for movements and temporary storage.

A study was conducted to calculate the fuel plate temperature during fuel handling procedure.[1] The following assumptions were made: 1) heat transfer by radiation alone 2) fuel element is removed from the converter tank immediately after steady state operation at 300 kW. The maximum clad temperature was calculated to be 348°C which is well below aluminum-6061 softening temperature of 460°C. Therefore, radiation heat transfer alone is sufficient to prevent fuel damage.

Any transfer of irradiated fuel out of the converter tank will be made by lifting the fuel element through the upper grid plate of the fuel housing into the specially adapted fuel transfer cask (Section 5.2). The fuel transfer cask will be positioned on the access hole of the converter lid. Prior to positioning the transfer cask over the access hole, an adequate shielding will be provided between the transfer cask and the water in the converter tank. After the fuel element is fully lifted into the transfer cask, the shutter in the cask bottom is closed. The cask is then transferred by crane to the spent fuel storage pool in the basement where it is positioned over the discharge funnel. The bottom shutter is then opened and the fuel element is lowered into the pool and placed in one of the cadmium lined boxes in the storage pool.

5.1.1 Tritium Production Rate

For the primary D_2O system, a study has been conducted to calculate the radiation dose to personnel during refueling procedures.[1] Data from MITR-II heavy water reflector tank was used to estimate the tritium production rate. Adjustments have been made to correct for the differences in the neutron flux and the operating schedule between the MITR-II and the fission converter. MCNP calculation was also performed and compared to the corrected data from the MITR-II heavy water reflector tank.[2] The results in Table 5.1 indicate a strong agreement between the MITR-II data and the MCNP calculation.

Table 5.1 Tritium Production Rate for the D_2O Coolant (Assuming fission converter operation at

81.5 kW for 608 hrs/yr)[1,2]

	Production Rate
From empirical MITR-II Heavy Water Reflector Tank Data	1.8E-04 Ci/kg yr
From MCNP Calculation	1.47E-04 Ci/kg yr

To calculate the heavy water evaporation rate, the following assumptions were used:

1. fission converter operate at 81.5 kW for 608 hrs/yr
2. average temperature of the primary coolant is 57°C
3. reactor containment dry bulb temperature is 27°C
4. relative humidity is 50%
5. fission converter lid opens for 2.5 hours

The dose to personnel during refueling was also calculated. The calculation was based on a the following assumptions:

1. equilibrium activity (after 150 years of operation) of tritium is 3.1 mCi/kg
2. saturation of air
3. breathing rate of 20 liter/min

The result of the calculation for 2.5 hours of exposure was 639 mRem to the personnel. The results of the activity released during a 2.5 hour refueling procedure as a function of years between refueling are listed in Table 5.2.

Table 5.2 Activity Released during a 2.5 hour refueling procedure as a function of years between refueling.[1]

Years in Operation Between Refueling	Activity Released (Ci)
1	0.004
2	0.007
3	0.011
4	0.014
5	0.018
6	0.022
7	0.025
8	0.029
9	0.033
10	0.036
11	0.040
12	0.043
13	0.047
14	0.051

5.2 Fuel Element Transfer Cask

The cask for transferring spent fuel is a steel weldment, filled with lead for shielding and equipped with a bottom shutter. The cavity has a diameter of 6.5" and a length of 40" above the shutter, so that its capacity is a single fuel element. It is normally used only in the containment building. The same fuel element transfer cask used for the MITR-II (MITR-II SAR Section 9.4.1.1.6) will be used for the fission converter.

5.3 Fuel Element Storage

Because the fuel element for the fission converter is the same as the MITR-II, the same storage areas will be used as described in MITR-II SAR Section 9.4.1.1.

5.4 Fuel Element Transfer

Refueling operations for the fission converter are scheduled by the operations superintendent, based on the following fuel burnup, experiment requirements, and scheduled power operation. Records of fuel element transfer will be entered in the reactor log book. The refueling preparation and fuel element transfer procedures for the MIT Research Reactor will be utilized. These steps are outlined in Section 9.4.1.3 of the MITR-II SAR.

5.5 Cadmium Curtain Handling

Two types of cadmium curtain handling operation are anticipated:

1. Maintenance and repair of the vertical drive mechanism,
2. Maintenance of the cadmium curtain due for structural failures.

Each of these operations will be briefly described below.

5.5.1 Maintenance of the Cadmium Curtain Vertical Drive Mechanism

To gain access to the drive mechanism, the shielding blocks above the drive mechanism will be removed with the crane. Radiation levels will be checked. However no high radiation levels are anticipated during this operation. A detailed checksheet prescribing the procedures in chronological order and the necessary tools will be available.

5.5.2 Maintenance of the Cadmium Curtain

The first part of this procedure is identical with the procedure for maintenance of the vertical drive mechanism. After gaining access to the vertical drive mechanism, it is decoupled from the frame holding the cadmium curtain. Depending on the radiation level, the cadmium curtain can be lifted and transferred unshielded to the spent fuel storage pool. The residual activity will be allowed to decay in the storage pool. Reinstalling the cadmium curtain is essentially the same process in reverse order. Again, a detailed checksheet will be available for this procedure. A member of the radiation protection office will be present to monitor radiation levels throughout the operation.

5 Reference

1. B. Sutharshan, *Engineering Design of Fission Converter Based on Epithermal Beam for Neutron Capture Therapy at the MITR,* PhD Thesis, MIT, 1997.

2. S. Sakamoto, *Optimization of the Neutronic Design of the Fission Converter Based Epithermal Beam for Neutron Capture Therapy*, Nuclear Engineering Thesis, MIT, 1997.

6 Safety Analysis - Facility

The design of the fission converter has been made with emphasis on safety and effectiveness of operation. In this section, various accident conditions are considered and the inherent safety of the design is analyzed. These results are used to establish certain operation limits such as the response times of the safety system. The results of these analysis indicate the conservative nature of the design. The safety analyses is base on calculations from Reference 1.

6.1 Transient Analysis

The objective of the transient analysis is to ensure that there exists an adequate safety margin in the design and operation of the fission converter. Consideration has been given to all possible types of accident scenarios including loss of the primary and secondary coolant flow and fission converter tank failure.

6.1.1 Loss of Primary Coolant Flow

The primary coolant system of the fission converter consists of two pumps operating in parallel. Loss of pump power due to an electrical system failure is a credible occurrence. Therefore, a study was conducted to calculate the fuel plate temperature for simultaneous double pump failure. A conservative calculation has been made by assuming: 1) instantaneous loss of flow rate 2) no heat loss out of the converter tank.

Figure 6.1 illustrates the five phases of the transient. In phase 1 (Figure 6.1a), the coolant in the converter tank continues to recirculate by natural convection. The coolant temperature will begin to increase with time due to continual operation of the fission converter at 300 kW. When the surface clad temperature reaches boiling, onset of nucleate boiling will occur on the fuel plates. This is illustrated in Figure 6.1b as phase 2. Bulk recirculation of the coolant continues until the liquid level drops below the top edge of the down comer walls (Phase 3). Figure 6.1c illustrates phase 3 (no bulk recirculation flow). In phase 4, the liquid level drops below the top edge of the fuel elements. The fission heat is extracted by the vapor produced by the liquid below (Figure 6.1d). In phase 5, the liquid level drops below the bottom edge of the fuel elements and vapor is no longer generated (Figure 6.1e). Therefore, the heat from the fuel is transferred by air circulation and by the radiation heat transferred to the surrounding structures.

The computational method used for thermal hydraulic design, TEMPEST (Section 3.2), was also used for phase 1 calculation. As in the steady state, the power is inputted directly into the primary coolant. This is a conservative approach compared to the actual transient where the energy produced by the fuel is used to raise the internal energy (temperature) of the primary coolant. It is also used to raise the internal energy of the fuel. In this approach, the energy used to raise the fuel's internal energy is neglected. After obtaining the temperature and mass flow rate through the fuel elements using TEMPEST, the fuel clad temperature was calculated by hand. The heat transfer coefficient between the coolant and the finned surface of the fuel plates is calculated using the following Dittus-Boelter equation:

$$h = \left(\frac{k_l}{D_h}\right) \times 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \qquad \text{(Equation 6.1)}$$

where h = heat transfer coefficient

k_l = liquid thermal conductivity

D_h = hydraulic diameter.

Re = Reynolds number

Pr = Prandtl number

In phase 2, onset of nucleate boiling (ONB) occurs. The surface clad temperature at the ONB is calculated using the Davis and Anderson correlation, with constant (c=12.5) found by experiments on finned fuel plates.[1]

$$T_{W,ONB} - T_{sat} = \left[\frac{12.5 q'' \sigma T^{*}_{sat}}{h_{fg} k_{l} (\rho_{l} - \rho_{v})} \right]^{1/2} \qquad \text{(Equation 6.2)}$$

where $T_{W,ONB}$ = Wall temperature required for nucleation (^{0}C)

T_{sat} = Saturation Temperature

T^{*}_{sat} = Coolant saturation absolute temperature (K)

q'' = Heat Flux

σ = Stefan-Boltzmann Constant

h_{fg} = Enthalpy of vaporization

k_{l} = Liquid thermal conductivity

ρ_{l} = Density of liquid

ρ_{v} = Density of Vapor

Then the coolant bulk temperature can be calculated using the following equation:

$$T_{w,ONB} - T_{b,ONB} = \frac{q''}{h} \qquad \text{(Equation 6.3)}$$

where $T_{w,ONB}$ = Wall temperature at ONB

$T_{b,ONB}$ = Coolant bulk temperature at ONB

q'' = Heat Flux

h = Heat transfer coefficient

The TEMPEST code can only perform single phase calculations, therefore, calculations were terminated after the coolant in the fission converter reached the $T_{b,ONB}$ temperature. In phase

2, the coolant is assumed to be at the saturation temperature of 106 ^{0}C. The clad surface temperature ($T_{w,NB}$) during the nucleate boiling is calculated using the following equations:

$$T_{W,NB} - T_{sat} = \frac{q''}{h} \qquad \text{(Equation 6.4)}$$

where h is an overall heat transfer coefficient which is calculated by using Chen's correlation:

$$h = h_{NB} + h_c \qquad \text{(Equation 6.5)}$$

where h_{NB} = Nucleate boiling heat transfer coefficient

h_c = Convective heat transfer coefficient.

For the following Ditter-Boelter correlation, only convection to the liquid has been considered. An empirical factor was used for the vapor contribution.

$$h_c = 0.023\left[\frac{G(1-x)D_h}{\mu_l}\right]^{0.8} \mathrm{Pr}_l^{0.4} \frac{k_{ls}}{D_h} F \qquad \text{(Equation 6.6)}$$

where the factor F is given by,

$$F\!=\!1 \qquad \text{For } \frac{1}{X_{tt}} < 0.1 \qquad \text{(Equation 6.7)}$$

$$F = 2.35(0.213 + \frac{1}{X_{tt}})^{0.736} \qquad \text{For } \frac{1}{X_{tt}} > 0.1 \qquad \text{(Equation 6.8)}$$

with,

$$\frac{1}{X_{tt}} = \left(\frac{x}{1-x}\right)^{0.9}\left(\frac{\rho_l}{\rho_v}\right)^{0.5}\left(\frac{\mu_v}{\mu_l}\right)^{0.1} \qquad \text{(Equation 6.9)}$$

where G = Mass flux

x = Vapor quality

D_h = Equivalent heated diameter

μ_l = Saturated liquid viscosity

μ_v = Saturated vapor viscosity

k_{ls} = Saturated liquid conductivity.

The nucleate boiling heat transfer coefficient, h_{NB}, has the same form as the Forster-Zuber correlation, but contains a factor S to suppress it during low-quality flow.

$$h_{NB} = S(0.00122)\left[\frac{K_{ls}^{0.79} c_{pl,s}^{0.45} \rho_l^{0.49}}{\sigma^{0.5} \mu_l^{0.29} h_{fg}^{0.24} \rho_l^{0.24}}\right] \Delta T_{sat}^{0.24} \Delta P_{sat}^{0.75} \qquad \text{(Equation 6.10)}$$

with,

$$S = \frac{1}{1 + 2.53 \times 10^{-6} \left(\frac{G(1-x)D_h}{\mu_l}\right)^{1.17} F^{2.42}} \qquad \text{(Equation 6.11)}$$

The mass flux calculated by TEMPEST was used for the above calculations. The equilibrium quality x is calculated at the exit of the hottest fuel element using the following equation;

$$x = \frac{\dot{Q}}{\dot{m} h_{fg}} \qquad \text{(Equation 6.12)}$$

where $\dot{Q}$ = Total heat transfer rate

$\dot{m}$ = Mass flux

h_{fg} = Enthalpy of vaporization

The above equations are applicable if the critical heat flux (CHF) is not reached. Therefore, CHF calculated for phase 2 and 3 are compared with the operating heat flux to determine if CHF can ever reached. The correlation proposed by Y.Sudo and M.Kaminaga was used to calculate the CHF in phase 2 and phase 3.[1] Equation 6.13 is applicable in phase 2 where bulk recirculation exists (Figure 6.1b), Equation 6.14 is applicable for phase 3 where there exists no bulk recirculation (Figure 6.1c).

$$q^{*}_{CHF} = 0.005 G^{*0.611} \tag{Equation 6.13}$$

$$q^{*}_{CHF} = 0.7 \frac{A}{A_H} \frac{\sqrt{W / \lambda}}{\left(1 + (\rho_g / \rho_l)^{1/4}\right)^2} \tag{Equation 6.14}$$

with,

$$G^{*} = \frac{G}{\sqrt{\lambda g \rho_g (\rho_l - \rho_g)}} \tag{Equation 6.15}$$

$$q^{*}_{CHF} = \frac{q_{CHF}}{h_{fg} \sqrt{\lambda g \rho_g (\rho_l - \rho_g)}} \tag{Equation 6.16}$$

and

$$\lambda = \left(\frac{\sigma}{(\rho_l - \rho_g) g} \right)^{1/2} \tag{Equation 6.17}$$

The critical heat flux and operating heat flux are presented in the Table 6.1. The results of the calculations indicate that CHF will not be reached during phase 1 and 2. However, CHF may be reached during phase 3.

Table 6.1 Operating hear flux and critical heat flux

	Operating Power (kW)	Operating Heat Flux (kW/m^2)	Critical Heat Flux (kW/m^2)
Phase 1	300	18.4	484 ± 160
Phase 2	300	18.4	484 ± 160
Phase 3	300	18.4	25 ± 8.25

As the coolant continues to boil, the coolant level in the fission converter tank will drop. To determine the time required for the coolant to drop below the top edge of the down comer walls, a conservative assumption of no vapor condensation was used. Using this assumption, the time requirement was calculated to be 51 minutes. This region is classified as phase 3. The fission converter system may experience CHF because the operating heat flow of 18.4 kW/m^2 is within the CHF calculation of 25±8.25 kW/m^2.

In Figure 6.2, maximum clad surface temperature as a function of time for loss of coolant flow is shown. As illustrated in the figure, the maximum clad surface temperature of 106°C is maintained until 51 minutes into the transient before CHF may be reached. Therefore, there is sufficient time for safety intervention such as closing the cadmium curtain or shutting down the reactor.

6.1.2 Loss of Secondary Coolant Flow

If the secondary coolant flow is lost while the converter continues to operate, the primary coolant inlet temperature will begin to rise. For this analysis, it was assumed that there was instantaneous loss of secondary flow and that no heat was lost from the converter tank. With these assumptions, there would be no change in the primary inlet and outlet temperatures. Therefore, the analysis for lost of primary coolant flow (Section 6.1.1) is also valid for this situation.

6.1.3 Fission Converter Tank Failure

The fission converter uses a double walled tank. The double wall design will prevent coolant leakage in the event of inner wall failure. The inner tank is 1 inch (2.54 cm) in thickness except for the front plate which is ¾ inch (1.905 cm). The outer tank is ¼ inch (0.635 cm) in thickness. There is a ¼ inch (0.635 cm) gap between the inner and outer layers.

In the event of simultaneous double wall failure, the converter tank fluid level safety system (Section 8.1.3) will initiate an automatic fission converter shutdown by lowering the cadmium curtain. The complete loss of coolant requires a simultaneous massive rupture at the bottom of both the inner and outer tanks. This is a very unlikely scenario because there is no penetration of the tanks below the inlet pipes which are located near the top of the tank. The structures around the tank is made of heavy concrete and graphite. No sharp protruding object is identified near the tank. The primary safeguard against fuel overheating, due to this extreme failure, is radiation heat loss.

The following assumptions are made to perform the analysis for total loss of coolant:

1. Steady state power of 300 kW,
2. The coolant in the converter tank is completely emptied in 120 seconds and the fission converter is shutdown within this time. This is a conservative assumption since no credible scenario can be identified that can drain the converter tank in less than the time needed to fully close the cadmium curtain or scram the reactor,
3. The decay heat is either lost to outside structures by radiation heat transfer or used to increase the internal energy of the fuel and its clad,
4. q_2'' (see Figure 6.3) is assumed to be zero because the fuel plates resistance for radiation heat transfer is much higher in the Y direction compared to the resistance in the X direction. This assumption leads to a uniform temperature distribution in the Y direction,
5. The heat transfer along the plate (X direction) is by conduction,
6. The average temperature of the surrounding structure is 150 ^{0}C.

Since the temperature in the Y direction is assumed to be uniform, one fuel plate with average heat generation rate has been used to model the fuel elements. The model of a fuel plate is depicted in Figure 6.3. The temperature of the fuel plate *T(x,t)* is given by the following partial differential equation:

$$\rho C_p \frac{\partial T(x,t)}{\partial t} = k \frac{\partial^2 T(x,t)}{\partial x^2} + q'''(t)$$

where ρ = Density of fuel plate

C_p = Specific heat at constant pressure

k = Thermal conductivity

q''' = Average heat generation rate in a single fuel plate

$T(x,t)$ = Fuel plate temperature

The following boundary conditions are:

1. $k\frac{\partial T(x=0,t)}{\partial x} = 0$
2. $T(x=a,t)=T_W(t)$

with the initial condition of $T(x,t=0)$ = 106 ^{0}C.

The average heat generation rate in a single fuel plate is obtained by dividing total decay power by the total number of fuel plates. The q_1'' is related to the end plate temperature, $T_W(t)$, by the following equation:

$$q_1'' = F_{12}\sigma(T_w^4 - (150+273)^4)$$

Here F_{12} is a radiation transfer factor between the end plates and the surrounding heavy concrete.

The maximum clad temperature as a function of time for the cadmium curtain to fully close is shown in Figure 6.4. As indicated, the maximum clad temperature of 348°C is well below aluminum-6061 softening temperature of 460 ^{0}C. Therefore, fuel integrity is maintained. This demonstrates the conservative nature of the fission converter design.

6.2 The Fission Converter Automatic Shutdown System

The fission converter is equipped with multiple automatic shutdown circuits which are discussed in Section 8.1. Each circuit can lower the cadmium curtain. The automatic shutdown circuit will also close the water shutter and mechanical shutter in the collimator.

The position of the shutters are monitored at the medical control panel and in the reactor control room. In the event of cadmium curtain failure, the reactor operator can reduce reactor power or scram the reactor.

6.3 Accident Analysis

In the following subsections, various accident conditions are analyzed. The results of these analyses indicate the conservative nature of the design.

6.3.1 Loss of Primary Coolant Flow

For the conservative assumption of instantaneous failure of both primary pumps with total loss of primary flow, boiling does not occur for 3.5 minutes during continuous operation of the fission converter at 300 kW (Section 6.1.1). In the event the operator fails to implement safety measures, an increase in primary coolant temperature will activate the primary coolant temperature safety system (Section 8.1.2) before any fuel damage can occur. The safety limit (critical heat flux) may be reached 51 minutes into the transient with continuous operation at 300 kW. Therefore, there is sufficient time for safety intervention in the event of cadmium curtain failure by reducing reactor power.

6.3.2 Pipe Breakage in the Primary Coolant System

The primary coolant system (including pumps, heat exchanger, clean-up loop, pipes) is located on the reactor's top floor above the fission converter tank. Therefore, a siphon effect can not be generated by a major leak or pipe break in the primary coolant system. The pool of water above the fuel element will eliminate the decay heat once the cadmium curtain is closed or the reactor is shutdown, without threatening the integrity of the fuel.

6.3.3 Fission Converter Tank Failure

The fission converter tank is a double wall design. A break in the inner tank will not cause loss of coolant and therefore, does not jeopardizes the safety of the system or the patient. In the event of a simultaneous double wall failure, a decrease in fluid level will activate the converter tank fluid level safety system (Section 8.1.3) to shutdown the fission converter. As discussed in Section 6.1.3, even a massive simultaneous double wall failure below the fuel elements will not disrupt fuel integrity.

6.3.4 Loss of Secondary Coolant System

For the conservative assumption of instantaneous loss of secondary flow, boiling does not occur for 3.5 minutes during continuous operation of the fission converter at 300 kW (Section 6.1.1). In the event the operator fails to implement safety measures, an increase in primary coolant temperature will activate the primary coolant temperature safety system (Section 8.1.2) before any fuel damage can occur. The safety limit (critical heat flux) may be reached 51 minutes into the transient with continuous operation at 300 kW. Therefore, there is sufficient time for safety intervention in the event of cadmium curtain failure by reducing reactor power.

6.3.5 Spillage of Primary Coolant

Precautions to preserve the heavy water inventory in the unlikely event of a major breach in the primary coolant system have been taken in the fission converter design. Two scenarios of possible coolant leakage in the fission converter will is discussed. First, if the breach occurs in any of the fission converter components (pumps, heat exchanger, clean-up loop, make-up water tank), the coolant would collect on the floor of the water tight skid. Conductivity probes on the skid will signal the presence of a leak at the medical control panel and in the reactor control room. Second, in the event of a major breach of the fission converter tank, the heavy water would be contained in the thermal column and drained through the pipe tunnel to the MITR-II basement utility room. A sump is installed at the low point of the equipment room floor from which the coolant can be recollected. A leak detector in the pipe tunnel and the sump will set of an alarm in the reactor control room (MITR-II SAR Section 4.4). A seal around the filter will prevent any heavy water leakage into the medical therapy room.

6.3.6 Cadmium Curtain Failure

The position of the cadmium curtain is monitored from the reactor control room and the medical control panel. The safety limit (critical heat flux) may not be reached until 51 minutes with total loss of primary coolant flow and continuous operation of the fission converter at 300 kW. Therefore, there is sufficient time for safety intervention in the event of cadmium curtain failure by reducing reactor power.

6.3.7 Fire or Explosion

Fire alarm boxes are located in the reactor building in the basement setup area, the equipment room, and on the main floor. Portable carbon dioxide fire extinguishers are available at several locations.

Fire or mechanical damage to one or more adjacent electronic panels could possibly result in partial loss of the safety system (i.e., loss of all period amplifiers). However, such damage would most likely cause a loss of power. If the cadmium curtain cannot be lowered because of fire or mechanical damage, the reactor shutdown will be used as a back-up. If the damage extends into the reactor system, the loss of power will scram the reactor.

The use of a potentially explosive material is restricted as stated in MITR-II SAR Section 10.4.

6.3.8 Seismology

In MITR-II SAR Section 2.5, seismology study of the Cambridge area has been conducted. The Cambridge area lies in the Boston Basin which has been relatively free of earthquakes in recorded times. It is impossible to state that an earthquake will not occur in the Cambridge area and that it will not damage the fission converter facility. However, in view of the past seismology records and the conservative design of the fission converter (Section 6.1.3), it is unlikely that an earthquake damage poses any hazard. Furthermore, reactor shutdown is expected to occur in the event of a significant earthquake and therefore, would also shutdown the fission converter.

6.3.9 Lightning

As far as lightning is concerned, MITR-II Research Reactor containment shell is grounded to a heavy copper conductor buried below the natural water table. Lightning arrestors are attached to the ventilation exhaust stack, and are grounded to the buried copper conductor. Consequently, lightning is not expected to directly affect the facility. However, an electrical power outage may occur. During an electrical power outage, the reactor is automatically scrammed and, thus, would shutdown the fission converter.

6.3.10 Loss of Electric Power

Loss of electrical power will scram the reactor. The water and the mechanical shutters are designed to automatically close in the event of power failure (Section 4.1.2.1 and 4.1.2.2 respectively). Emergency power is supplied by MITR-II as specified in MITR-II SAR Section 8.2. Emergency power for at least 1.5 hours will be provided for the following equipment and instruments:

1. medical therapy room radiation monitor,
2. intercom between the medical therapy room and the medical control panel area,
3. emergency lighting of the medical therapy room and the medical control panel area.

6.4 Fuel Self Protecting

To provide fuel self protection, the fission converter will be operated to maintain >100R/hr one meter from the fuel elements.

6.5 Design Based Accident

The fission converter is located inside the MIT Research Reactor Containment Building and uses MITR-II fuel elements. The proposed design based accidents for both the fission converter and MITR-II are coolant blockage. Accordingly, analysis for the design based accident for MITR-II is also applicable to the fission converter. The summary of the MITR-II design based accident analysis is discussed in Section 6.5.1.

A review of the primary coolant flow system indicates that a flow blockage in a fuel element is very unlikely. The coolant flows from the pool, above the converter tank, through small diameter tubes in the heat exchanger, and then through the pumps before entering the converter to flow up through the fuel elements. Any foreign material that might start to circulate in the system must be small enough to pass through the heat exchanger tubes before reaching the fuel elements. Therefore, the object would be too small to cause a significant flow blockage.

The possibility of blockage can occur if a foreign object falls to the bottom of the tank during refueling. When the pumps are started, the flow would pick up this object and block the entrance of the fuel element coolant channel. In order for this to happen, the object would have to fall through the fuel housing matrix when a fuel element is removed. The size of the opening of the fuel housing matrix would restrict the dimension of the object to that of the fuel element or smaller. If the material is small enough to enter the triangular entrance in the element nozzle, it might possibly reduce the flow by more than a factor of three in a maximum of five coolant channels. Since the fuel plates on the outer regions of the flow blockage will be cooled from one side, the only fuel melting that might occur would be on the inner four fuel plates. To prevent foreign material from failing into the tank, continuous visual observation during the refueling procedure is provided.

Experiences with fuel plate melting both at the Material Testing Reactor (MTR) and at the Oak Ridge Research Reactor have shown that fuel plate melting due to flow blockage does not propagate beyond the affected flow channels. Although the nearby plates were discolored, cooling by the unaffected channels was sufficient to prevent propagation of the melting.[2,3]

6.5.1 Summary of the MITR-II Design Based Accident Analysis

A study has been conducted to calculate the maximum radiation dose to an individual located at the exclusion area boundary of the reactor during the first two hours of MITR-II's

Design Based Accident.[4] The design based accident for MITR-II is postulated to be a coolant flow blockage in the hottest channel of the center fuel element. This will lead to an overheating of four fuel plates maximum. It is conservatively assumed that the entire active portions of all four plates will melt completely to release their inventory of fission products to the coolant water.

Escape of fission products to the containment due to fuel melting is restricted by the pool of water above the fuel elements. The following approaches were used for the design based accident to evaluate the major release pathways to the exclusion area:

1. An analysis of the reactor system was made to determine the fission product released from the containment shell. The dose from the leakage was calculated using a standard Guassian diffusion model and local meteorological data,
2. A determination of gamma radiation reaching the boundary area by direct penetration of the containment shell was made from standard shielding calculations. A Compton scattering model was developed and applied to photons scattering from air (skyshine) and from the steel containment roof.
3. A check for radiation streaming was conducted for the truck airlock which is the largest containment penetration.

For the MITR-II accident analysis, the fission products in the fuel at the time of the accident are assumed to be in equilibrium at steady state reactor power of 5 MW. This is a conservative assumption for the fission converter for the following reasons. First, the fission converter operates at a maximum power of 251 kW. At this power level, each fuel element generates 22.8 kW, compared to 208 kW per fuel element for the MITR-II core. Second, irradiation time for treating a patient with the fission converter beam is less than 5 minutes.

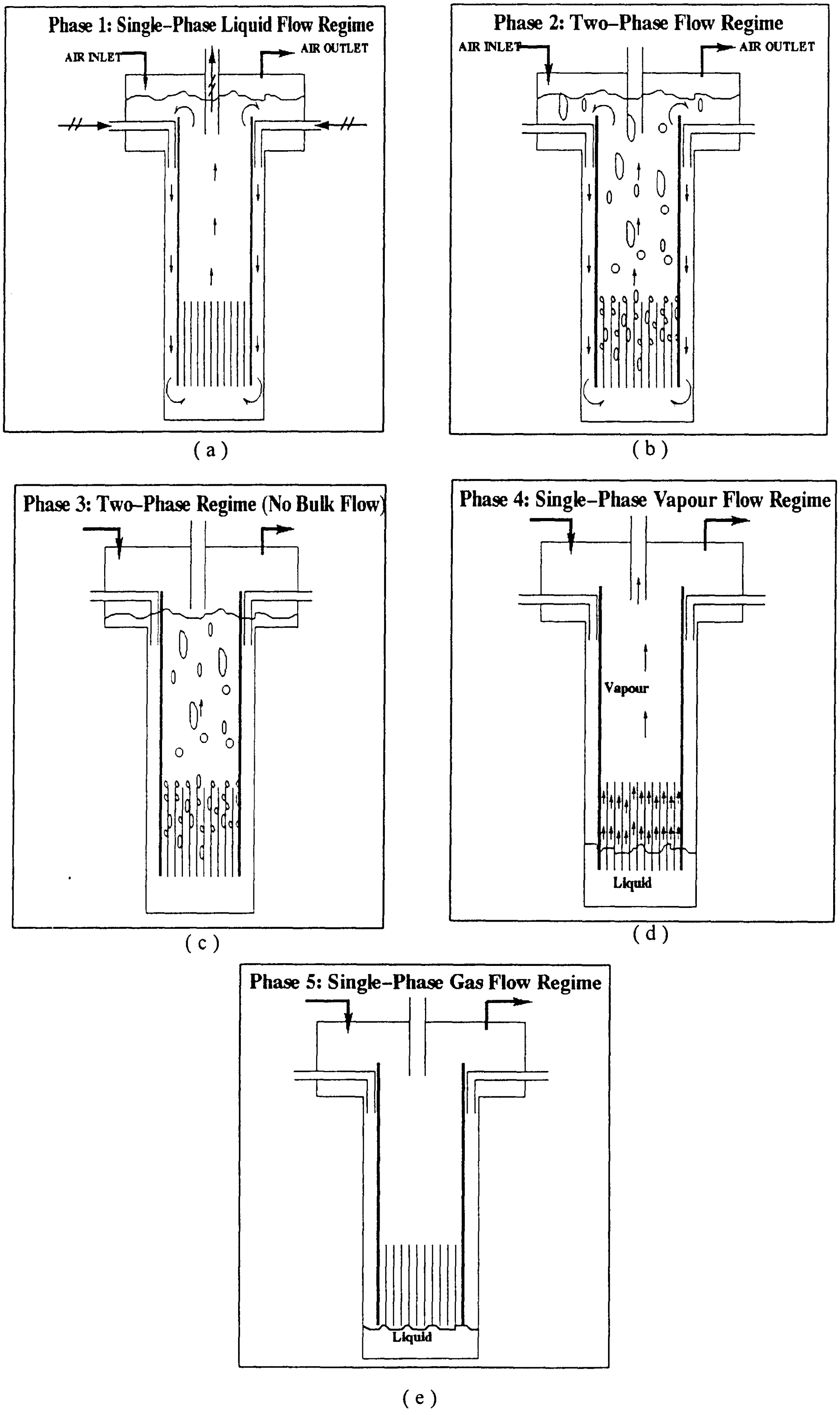
Given this short operating cycle, most of the important fission products, including I^{131}, will not reach saturation.

The calculated results for the MITR-II design based accident are given in Figure 6.5. A summary of the estimated doses are listed in Table 6.2. Even with the conservative assumptions, the estimated maximum dose to an individual located at the exclusion area during the first two hours of the MITR-II design basis accident would be 5.95E-01 rad to the whole body and 1.18E-01 rad to the thyroid. Because the fission converter operates at ≤10% of the MITR-II's power density and has a much lower capacity factor, the dose is expected to be considerably lower. According to 10 CFR 100, the limits are 25 rem to the whole body or 300 rem to the thyroid. Based on the results of the analysis, it can be concluded that the reactor containment shell meets this requirement.

Table 6.2 Estimated Doses from all Modes of Radiation Release during a MITR-II Design Based Accident.[4]

Component of the Dose	**Dose** (rad) 8 m	21 m
Whole body:		
Containment Leakage	2.66E-02	2.66E-02
Steel Dome Penetration	3.49E-03	2.71E-02
Shadow Shield Penetration	4.33E-02	2.05E-02
Air Scattering	1.14E-01	1.47E-01
Steel Scattering	1.92E-01	3.73E-01
Total	3.79E-01	5.95E-01
Thyroid:		
Containment Leakage	1.18E-01	1.18E-01

Figure 6.1



(a) (b) (c) (d) (e)

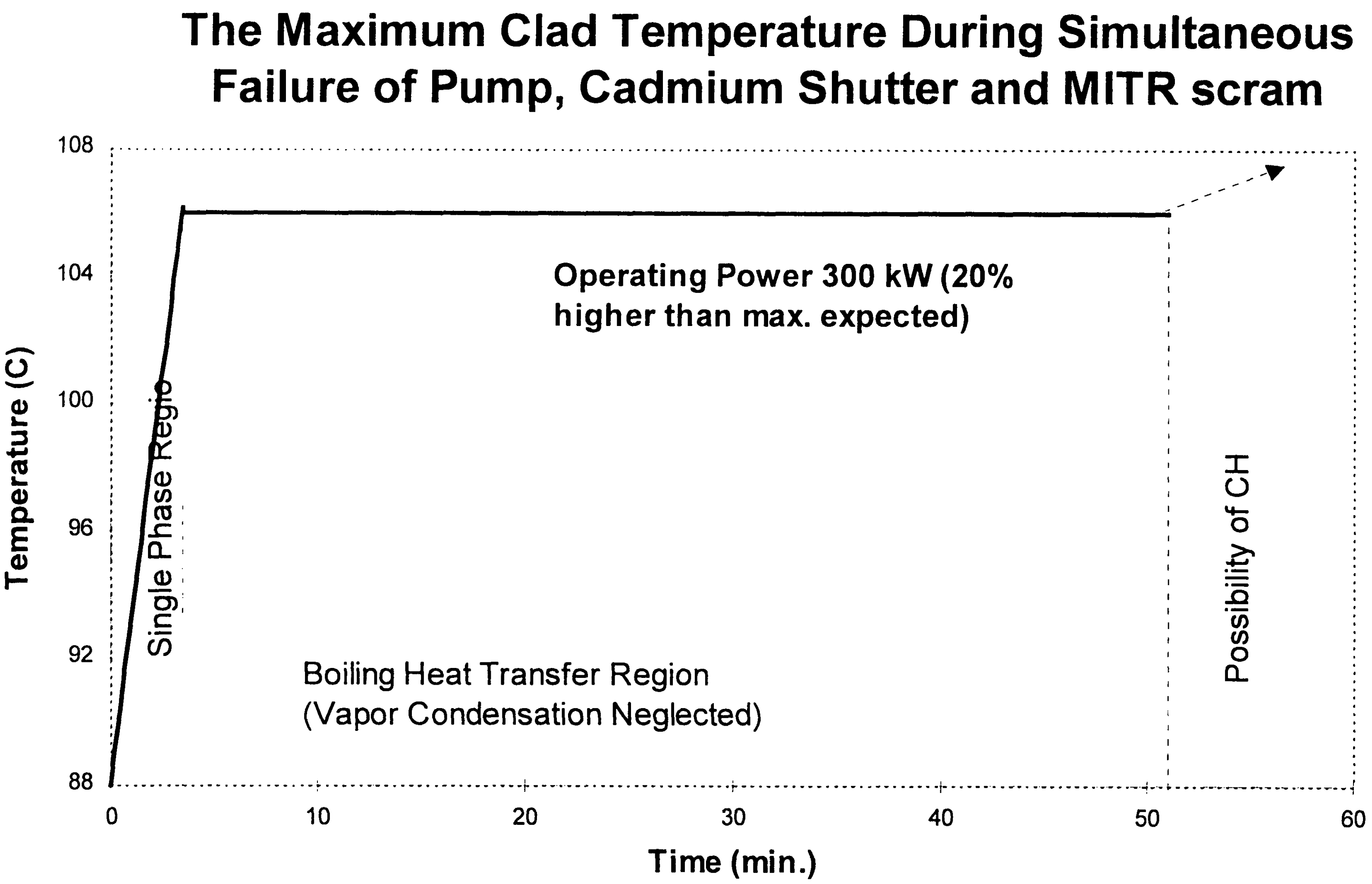

The Maximum Clad Temperature During Simultaneous Failure of Pump, Cadmium Shutter and MITR scram
108
104
100
96
92
88
Temperature (C)
0
10
20
30
40
50
60
Time (min.)
Single Phase Regio
Operating Power 300 kW (20% higher than max. expected)
Boiling Heat Transfer Region
(Vapor Condensation Neglected)
Possibility of CH

Figure 6.2

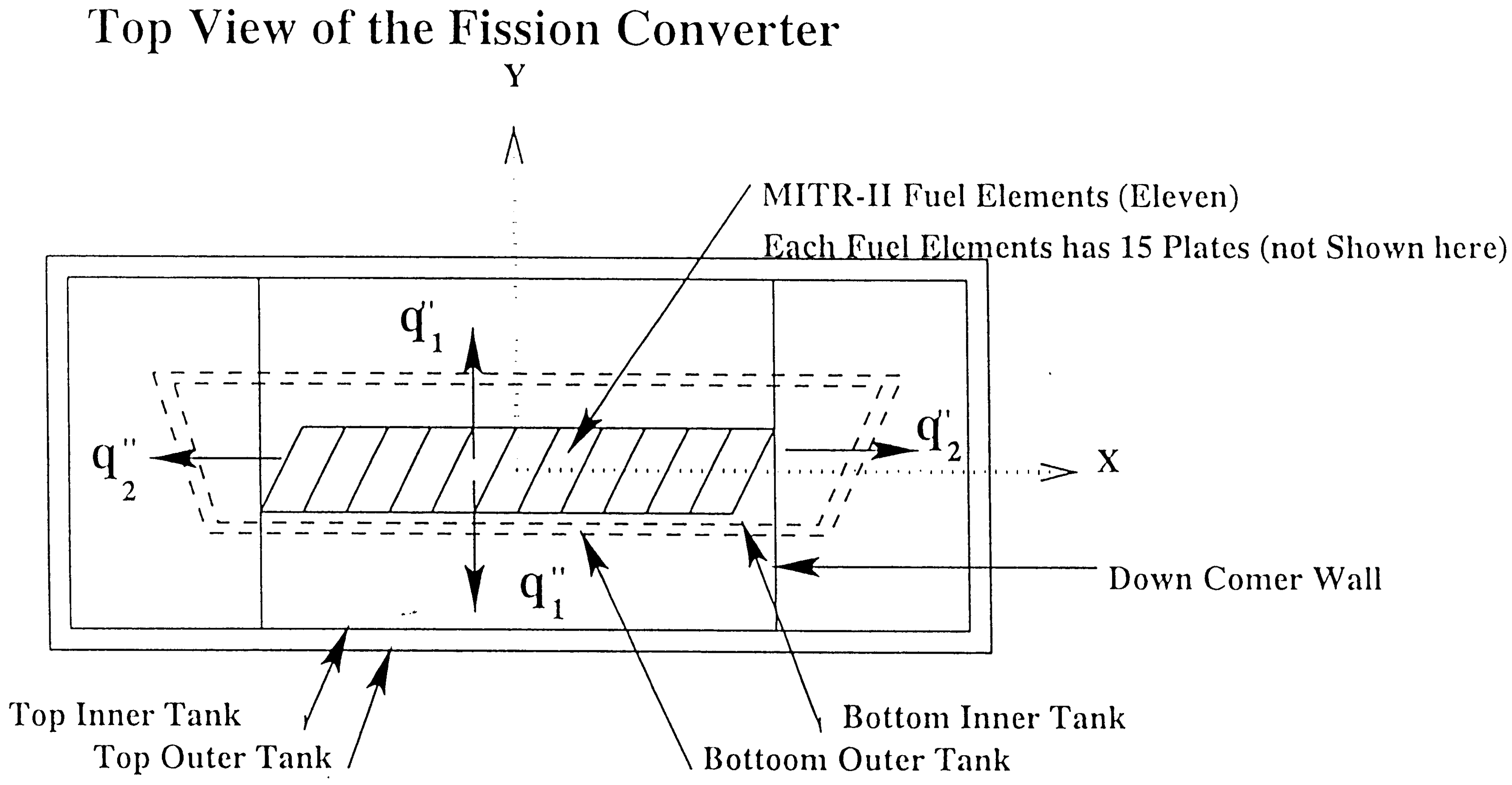


Figure 6.3 Top View of the Fission Converter

Figure 6.4 Instantaneous Double Wall Failure

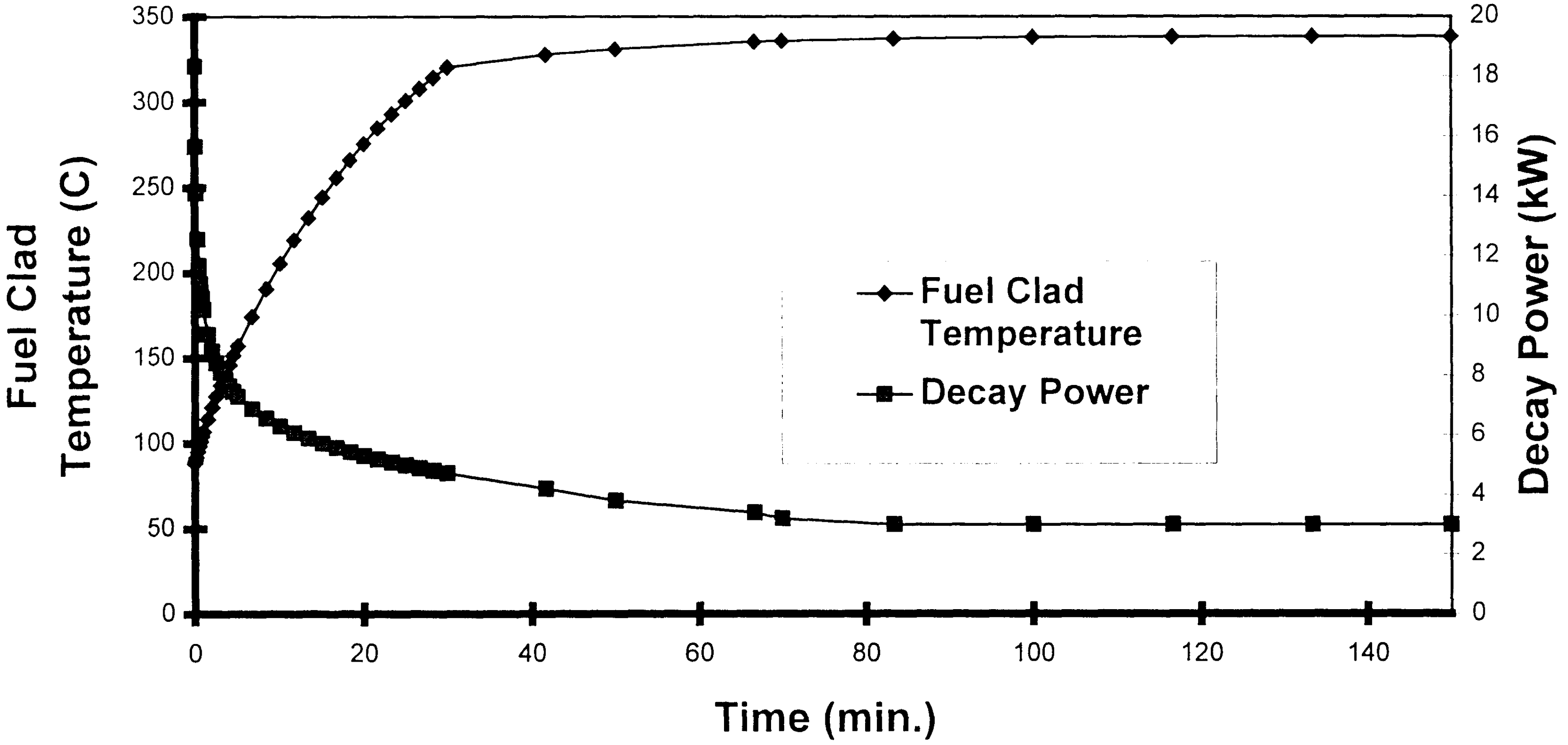
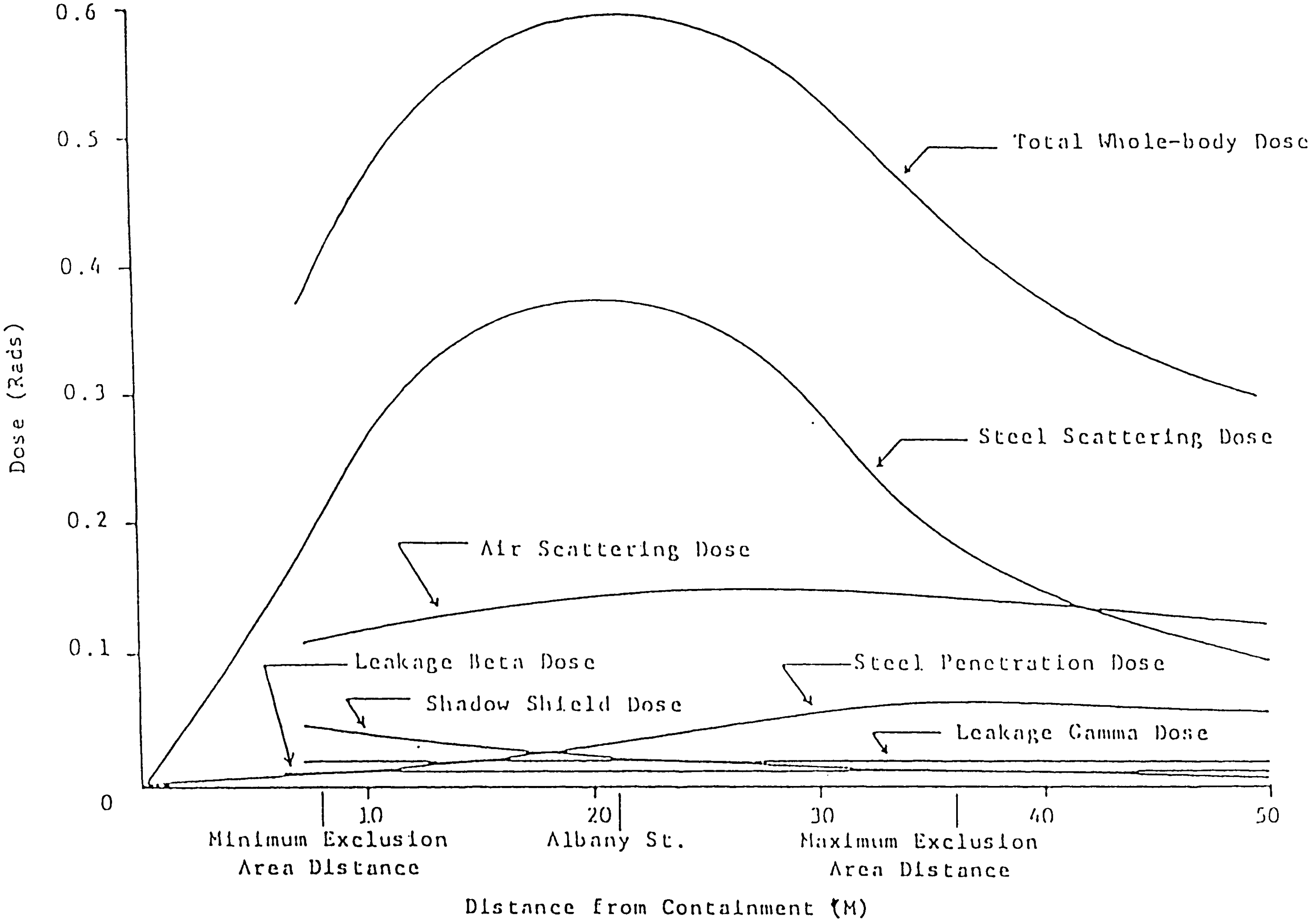


Figure 6.5 Total two hour whole body dose results



6 References

1. B. Sutharshan, *Engineering Design of Fission Converter Based on Epithermal Beam for Neutron Capture Therapy at the MITR,* PhD Thesis, MIT, 1997.

2. Dykes, J.W., et al., "A Summary of the 1962 Fuel Element Fission Break in the MTR", IDO-17064, February 1965.

3. Tabor, W.H., "Fuel Plate Melting at the Oak Ridge Research Reactor", ANS Transactions 8 Supplement, 36 (July 1965).

4. R. Mull, *Exclusion Area Radiation Release During the MIT Reactor Design Basis Accident,* MS Thesis, MIT, 1983.

7 Safety Analysis - Patient

The design of the fission converter has been made with emphasis on safety of the facility as well as safety to the patient and medical personnel. Safety analysis for the facility was discussed in Section 6. In this section, the safety analysis for the patient and the personnel are discussed.

7.1 Redundant Mechanism for Beam Shutoff

In order to provide adequate termination of the medical beam at any time, the buttons for closing the fission converter shutters are located in the medical therapy room and at the medical control panel. In addition, reactor control room is equipped with cadmium curtain closure button. It shall also be possible to initiate a minor scram of the reactor from the medical control panel. In the event that the medical facility minor scram is inoperable, the reactor control room scram can be used via communication.

7.2 Shutter Failure

The positions of the cadmium curtain, water shutter, and the mechanical shutter are monitored from the medical control panel and in the reactor control room. Furthermore, the radiation level in the medical therapy room is continuously monitored. Hence, any shutter failure will be promptly detected and the radiation level in the medical therapy room known.

The MITR-II Emergency Plan covers the fission converter facility. The various possible recovery tasks including safe evacuation of the patient are discussed in the MITR-II Emergency Plan.

7.3 Physical Safety

In order to prevent any injury to the patient, all equipment able of causing harm will be held firmly in place by a mechanical device or by gravity. The restraining forces will be substantially greater than those created during any credible malfunction. The patient will be secured to the therapy bed during the treatment period to prevent a fall.

7.4 Patient Monitoring System

It shall be possible to observe the patient by two independent means: 1) two closed circuit TV cameras with different power sources, or 2) one closed circuit TV camera and a viewing port. Both methods of patient visualization shall be operable at the outset of any patient irradiation. Adequate lighting to permit such viewing shall be assured with the provision of emergency lighting. There will also be an intercom system between the therapy room, the medical control panel, and the reactor control room.

7.5 Access to the Medical Therapy Room

As discussed in Section 4.4, access to the therapy room is provided by a shielded door. This door is motor driven and is normally controlled by push buttons stationed just inside and outside of the door and at the medical control panel. In an emergency, the door can be hand operated by disconnecting the drive mechanism from either side of the door.

8 Instrumentation and Electrical System

Instrumentation and control (I&C) of the fission converter system are vital to ensure consistency in safe operations. The controls and monitoring of the fission converter will be located at the medical control panel. Redundant safety monitoring and controls are located in the reactor control room. The fission converter monitoring system is made up of three types of channels: neutronic, thermal hydraulic, and auxiliary. To ensure that safety is paramount, the I&C system must be reliable, redundant, and fast acting.

The fission converter instrumentation and controls are completely independent from the MITR-II instrumentation and controls.

8.1 Protective Systems

The protection system includes all channels which initiate the fission converter automatic shutdown system and/or activate engineering safeguards. The function of the protection system is to close the cadmium curtain in the event of abnormal functioning by any essential component of the fission converter. The protective system also closes the water shutter and mechanical shutter in the collimator. The position of the shutters are monitored by the medical control panel and the reactor control room. In the event of cadmium curtain failure, the reactor operator can reduce reactor power or scram the reactor.

The fission converter automatic shutdown system is made up of two types of channels: nuclear and thermal hydraulic. In addition, the fission converter protective system includes channels which actuate engineering safeguards. These are individually discussed below.

All electronics and wiring for the safety system with the exception of detectors and connecting wiring are located at the medical control panel. Redundant safety monitoring and controls are located in the reactor control room where there is an operator present at all times during reactor operation.

The abnormal and accident circumstances which are considered possible include reduction or loss of electrical power, fire, and electrical or mechanical damage to parts of the protective system. The possible effects of these abnormal conditions are discussed in Section 6.

8.1.1 Nuclear Safety System

The nuclear safety system monitors the fission converter power by sensing the thermal neutron flux at several locations. In the event the converter power exceeds the operating limit, the nuclear safety system must shutdown the fission converter by closing the cadmium curtain. At least one independent power level channels must be in operation before the fission converter can be started up or operated. Each neutron detector has an independent D.C. power supply. Each level channel consists of a thermal neutron detector, located near the outer edge of the converter tank, which supplies a neutron flux level signal to a automatic shutdown amplifier.

In addition to the neutron detectors for the fission converter, the nuclear safety system of the MITR-II monitors the reactor power and its rate of change (MITR-II SAR Section 7.1.1). In the event either of these parameters exceeds operating limits, the nuclear safety system will shutdown the reactor by inserting the control blades before the integrity of the fuel clad is compromised. Subsequently, the nuclear safety system described above is a redundant system to prevent fission converter power excursion. Startup check of the protective system prior to operation of the fission converter ensures prompt detection of any abnormal situation.

8.1.2 Primary Coolant Temperature Safety System

To prevent the safety limit (Section 3.3.3) of the fission convert from being reached, the primary coolant temperature above the hottest fuel element (which will be determined during pre-operational test in Section 12 of this report) will be monitored by a redundant on-line system. The coolant temperature is converted into an electrical signal that will open the automatic shutdown network when the limiting safety system setting is exceeded (Section 3.3.2). As discussed in Section 6.1, the safety limit (critical heat flux) does not occur until 47 minutes after the onset of nucleate boiling. Therefore, there is adequate time for the safety system to shutdown the fission converter before a threat to fuel integrity occurs.

At least one independent temperature channel must be in operation before the fission converter can be started up or operated. Startup check of the protective system prior to operation of the fission converter ensures prompt detection of any abnormal situation.

8.1.3 Converter Tank Fluid Level Safety System

In normal operation, the fluid level in the converter tank is monitored by redundant on-line detectors. A decrease of fluid level is sensed by a submerged conductive probe. When the fluid level falls below a preset limit, the fluid level safety system will open the fission converter automatic shutdown circuit.

At least one independent fluid level channel must be in operation before the fission converter can be started up or operated. Startup check of the protective system prior to operation of the fission converter ensures prompt detection of any abnormal situation.

8.2 Medical Therapy Room Radiation Monitor

The basis radiation monitoring equipment consists of an ionization chamber mounted at one corner of the therapy room. This survey meter is simultaneously displayed in the reactor control room and at the medical control panel. The detector automatically switches to the emergency power system during electrical power loss. Radiation level inside the medical therapy room is recorded continuously in the reactor control room.

In an event radiation level exceeds the preset limit in the therapy room, the following indications will be given:

1. a warning lamp at the medical control panel and in the reactor control room,
2. an radiation sign outside the shielded door,
3. an audible signal in the therapy room which may be muted if patients find it objectionable.

8.3 Medical Beam Monitoring System

The purpose of the beam monitors and associated readout systems is to assure that the desired dose is delivered during irradiation. Beams used for neutron capture therapy are comprised of mixed radiation fields which include slow, epithermal, and fast neutrons, as well as gamma rays. By using multiple detectors and independent signal processing modules, sudden failure of a particular detector, a cable, or a nuclear electronics module will not cause a total loss of the monitoring system.[1]

The current beam monitoring system used in the M67 medical beam has been designed by O.K. Harling and D.J. Moulin.[1,2] It has been investigated for the use in the new higher intensity fission converter beam by H. Takahashi.[3] It was concluded that no major modification is needed for the current beam monitoring system to be used for the fission converter beam.

8.3.1 Medical Beam Monitor Calibration

The beam monitoring system will be calibrated annually against an experimental characterization of the beam using a realistic phantom.[4] The beam monitoring output readings and the in-phantom measurements of fast neutrons, total gamma-ray dose rates, and thermal neutrons are made at the same time. These measurements are used for accurate cross calibrations.

8.4 Tests and Surveillance

To ensure that all systems operate properly and all indicators are kept accurate, a test and surveillance system is used. The surveillance consists of routine calibrations as specified in Table 8.1. Startup checks are specified in Tables 8.2. The startup checks listed in Table 8.2 and the interlocks listed in Table 8.3 will be tested or checked (and adjusted if required) at least monthly in any month the facility is in used. In the event of a hiatus in the scheduled performance of any given surveillance, that surveillance shall be performed prior to operation of the fission converter during the interval in question.

Table 8.1 Routine Surveillance Tests

Test	Frequency	Specification
1. Neutron level channels calibration	Annual	Detector circuits and plateau characteristics normal
2. Safety channel response and time for the cadmium curtain to fully close	Annual	≤ 1.0 min
3. Primary coolant temperature above the hottest fuel element and recorder calibration	Annual	± 2°C
4. Medical therapy room radiation monitor source check	Quarterly	Normal
5. Manual operation of medical therapy shielded door	Semi-annually	Normal

Table 8.2 Startup Checks

Function	Surveillance
1. Neutron level channels	fission converter automatic shutdown test
2. Primary coolant temperature above the hottest fuel element	fission converter automatic shutdown test
3. Converter tank fluid level	operation test
4. Medical therapy room radiation monitor	level set and trip point test

Table 8.3 The following interlocks or channels shall be tested at least monthly and prior to treatment of human patients if the interlock or channel has been repaired or deenergized.

Interlock or Channel	Surveillance
Medical therapy facility minor scram	Reactor scram test
Shutters will not open unless shield door is closed	Operation test
Shutters close upon both manual and automatic opening of shield door	Operation test
Shutters close on loss of electrical power and reduction of pressure in pneumatic or hydraulic operators, if applicable	Operation test
Shutters can be closed manually from within the facility	Operation test
Shutter status lights	Operation test
Radiation monitor alarm	Operation test
Radiation monitor and/or alarm enabled upon opening of shield door	Operation test
Intercoms	Operation test

8.5 Calibration of Safety Channels

Each safety channel is calibrated periodically to establish the relationship between its reading or trip point and the value of the parameter associated with its protective function. The parameters involved are fission converter power, primary coolant temperature, and converter tank fluid level.

8.5.1 Nuclear Safety System

The nuclear power level channels are calibrated against thermal power as indicated by the temperature difference between the inlet and outlet coolant and the primary coolant flow rate. The final level channel readings and thermal power readings for one operating cycle are used as the initial calibration for the next operating cycle. The nuclear power level channels are calibrated annually.

8.5.2 Primary Coolant Temperature Safety System

The primary coolant temperature measurement channels are calibrated annually. A pre-calibrated thermal couple is placed inside the converter tank next to the temperature channel to be calibrated. The measurement from the pre-calibrated thermal couple will be used to calibrate the temperature channel.

8.5.3 Converter Tank Fluid Level Safety System

Converter tank level scram is checked before each startup. The calibration (actual tank level at the trip point) is fixed by the physical location of the probes and is not subject to change. The operational test is all that is required to insure adequate performance of these channels.

8.6 Electrical System

The electricity for the fission converter facility is supplied by MITR-II. See MITR-II SAR Section 8.1 for normal electrical power supply and MITR-II SAR Section 8.2 for Emergency Power Supply. In Section 6.3.10 of this report, the loss of electric power is discussed.

8 References

1. O.K. Harling, et al., "On-line beam monitoring for neutron capture therapy at the MIT Research Reactor", Nuclear Instruments and Methods in Physics Research B101 (1995) 464-472.

2. D.J. Moulin, M.S. Thesis, Department of Nuclear Engineering, Massachusetts Institute of Technology, September 1991.

3. H. Takahashi, "Design of a new beam monitoring system for fission converter neutron beam", MIT, 1996.

4. R.D. Rogus, Ph.D. Thesis, Department of Nuclear Engineering, Massachusetts Institute of Technology, February 1994.

9 Radioactive Waste and Radiation Protection

9.1 Radioactive Waste

Radioactive waste from the fission converter is in solid, liquid and gaseous forms. Solid waste consists mainly of contaminated paper towels and gloves, small components, such as resin from the ion columns, and experimental waste. Spent fuel handling is described in Section 5. The primary components of liquid wastes are corrosion products from the fission converter systems such as Co^{60}, Cr^{51}, Fe^{59} etc. The gaseous effluent is mostly Ar^{41}, formed from activation of air in the medical therapy room, and small amounts of tritium resulting from leakage if D_2O coolant is used. Because the fission converter will be a part of the MITR-II Research Reactor Facility, the radioactive waste disposal system of the MITR-II will be utilized.

9.2 Effluent Radioactivity Production and Control

Neutrons and gamma rays from the fission converter causes the production of some radioactive effluents. The primary activity in the gaseous effluent is Argon-41. To minimize Argon-41 production, air is excluded from the high flux regions. CO_2 is used to flood the thermal column region where the fission converter tank will be located. The supply of CO_2 is discussed in MITR-II SAR Section 9.8. Water shutter in the collimator may be filled with helium when the water is drained from the shutter to reduce the production of Argon-41.

In addition to the Argon-41 activity, a small amounts of tritium (if D_2O coolant) and some detectable traces of other isotopes (such as noble gas fission products) may be released from the facility. These effluents are both gaseous and liquid which come from the very small leaks of the primary system. Care is taken to keep the primary system sealed to prevent the loss of coolant and to control the tritium effluent. In all cases, the intent of the operation is to maintain the radioactive effluent releases from the fission converter as low as practicable in accordance with 10 CFR Part 20.

9.3 Shielding

The medical therapy room will be shielded by concrete on all sides, except for the door opening which is shielded by a lead door. The radiation levels outside the medical therapy room are kept as low as reasonably possible. The exposure to personnel shall be kept well below the NRC limits given in 10CFR20.

The fission converter tank is located between the reactor's graphite reflector and the thermal column. The shielding for the fission converter is provided by the reactor's biological shield (MITR-II SAR Section 3.2.2). The shielding at the top of the fission converter will consist of shield blocks and the water reservoir in the converter tank. An air tight cover-gas system is provided to prevent radiolytic decomposition species from escaping.

9.4 Radiation Protection

The radiation protection program for the MITR-II will also serve as the radiation protection program for the fission converter. Refer to MITR-II SAR Section 12.3 for complete description.

9 References

1. B. Sutharshan, *Engineering Design of Fission Converter Based on Epithermal Beam for Neutron Capture Therapy at the MITR*, PhD Thesis, MIT, 1997.

10 Conduct of Operations

The MITR Fission Converter based Epithermal Neutron Beam is designed for use in Neutron Capture Therapy. The radiation treatments provided by the MITR Fission Converter Facility medical beam will be administered by a physician authorized user as discussed in the Fission Converter Technical Specification Section 6. The operation of the fission converter facility, other then radiation treatment of patients, will be conducted by the MIT Research Reactor Division as discussed in the MITR-II SAR Section 13.

11 Quality Assurance

The MITR Fission Converter Facility is designed for use in Neutron Capture Therapy. The Quality Management Program for human therapy is discussed in the Fission Converter Technical Specification Section 7. The quality assurance program including design, construction, maintenance, and operation activities, other then human therapy, will be conducted by the MIT Research Reactor Division as discussed in MITR-II SAR Section 11.

12 Initial Tests and Operation

12.1 Introduction

This section is divided into three major parts. First, a series of acceptance tests are outlined which are designed to determine that the fission converter has been constructed in accordance with the MIT plans for the fission converter as presented in this Safety Analysis Report. These tests are to prove that the components operate in a safe and satisfactory manner. Second, the initial operation of the fission converter is described. Third, an experiment to determine the neutron characteristics of the fission converter medical beam is described. These experiments will provide information needed for the safe operation of the fission converter. Furthermore, the results of these experiments will give information about the medical beam characteristics. Therefore, the initial tests and experiments are necessary in assuring that the MITR Fission Converter is a safe and useful tool for research.

The basic rules for the pre-operational period are as follow:

1. The provisions of Chapter 10, "Conduct of Operations" shall be used,
2. A startup check for the safety systems shall be made once a day before operation begins (process equipment which is not in operation for the initial experiments will not need to be included in the "startup check"),

The three sections of this report contain the following information. Section 12.2 is an outline of the pre-operational tests. Section 12.3 is a description of the first approach to operation of the fission converter. Included in Section 12.3 is a discussion of the first calibrations of the control system which will be needed in order to proceed with the rest of the startup experiment in a safe manner. In Section 12.4, initial characterization of the medical beam is discussed. Section 12.5 contains an outline of the variety of experiments which may be performed during this startup program. This summary list of startup experiments has been included to illustrate the principles to be used in these experiments and their general scope.

12.2 Pre-Operational Tests

After the construction has been completed, the pre-operational tests will be made to assure that the entire installation will operate as designed. These tests will be used to establish initial compliance with the approved technical specifications. The tests include:

A) Leak checking and performance testing of the coolant system: This will be conducted using H_2O in the primary coolant system. If D_2O primary coolant is planned for use, the H_2O in primary system will be drained after all leak and performance tests are conducted. The system will be thoroughly dried and a deuterized ion column installed before adding the D_2O. An isotopic analysis of the D_2O will be made before and after the D_2O is charged into the system. The following systems will be checked for leaks and performance:

   1) primary coolant system
   2) secondary coolant system
   3) water shutter system
   4) Helium cover-gas system

B) Performance testing and inspection of the fission converter control and instrumentation system:

   1) cadmium curtain, water shutter, and mechanical shutter controls and instrumentation
   2) nuclear instrumentation
   3) beam monitor system
   4) medical therapy room radiation monitoring system

C) Operator Retraining

An operations manual for the fission converter will be generated to incorporate the information in this SAR and the Technical Specifications for the MITR Fission Converter Facility. The manual will be written by members of the Reactor Operations group, MIT Neutron Capture Therapy Principle Investigator, and medical staff (the medical physicists and the physician authorized user). As the manual is completed, all persons involved in reactor operation, MIT Neutron Capture Therapy Principle Investigator, and the medical staff will be given a copy for review and comment. Comments and corrections will be returned to the author for final revision. The final draft will be approved by the Reactor Director, Director of Reactor Operations, MIT Neutron Capture Therapy Principle Investigator, and the medical staff.

12.3 First Approach to Fission Converter Operation

The first approach to operation will be made after all pre-operational testing has been satisfactorily completed. The procedure for the first approach to operation will be the fission converter fuel loading. The reactor will be shutdown and the cadmium curtain fully closed before any fueling of the fission converter begins. The pattern for loading the fuel will be kept symmetric.

At the start of each new operating period, a startup checksheet procedure will be used to assure that:

1. fission converter instruments are in their proper operating condition,
2. the control and safety systems are operational,
3. and all safety trip settings are properly adjusted.

Redundant neutron detecting pulse counters will be positioned near the sides of the converter tank. Each level channel consists of a thermal neutron detector, located near the outer edge of the converter tank, which supplies a neutron flux level signal to a fission converter scram amplifier. The detector positioning and sensitivities are chosen to provide linear response to fission converter power from low power up to the scram point.

The procedure for the first approach to operation will be the standard technique involving plots of the inverse counting rate as the fuel elements are loaded. Initial counting rates will be measure after the fifth fuel element is loaded and after each additional fuel element. The reactor at low power may be used as the neutron source. After the counting rates are measured, a plot of the inverse counting rate versus the mass of U-235 loaded into the converter will be made. This plot will be extrapolated after each loading. The fission converter is a subcritical facility and, therefore, criticality is not expected to be achieved (Section 2.3.1). The reactor will be shutdown and the cadmium curtain fully closed before any fuel additions are made. Fuel additions during this first approach to operation will not be more than one fuel element at one time. Each element will be checked to assure that it is properly installed into the correct position in the fuel housing.

After the fission converter has been brought to steady state power for the first time, a set of initial calibrations will be made. These calibrations will be used as a basis for safe operation in the next phase of the pre-operational experiments.

12.3.1 Calibration of the Cadmium Curtain

The limiting rate on raising the cadmium curtain will be limited by the reactor period. Reactor controls can be used to compensate for the change in reactor power due to the presence of the fission converter as long as the reactor period is above 50 seconds. Therefore, the standard period measurement techniques will be performed. This consists of measuring the period of the reactor at two positions of the cadmium curtain and relating the periods to the change in reactivity by using the "inhour" equation. This is continued in a stepwise manner over the entire length of travel. The period will be kept above 50 seconds for each step. Using these measurements, the limit on the rate of raising the cadmium curtain during fission converter operation will be set.

At the initial startup of the fission converter, reactor period will be measured. After any future significant change in fuel design or fuel loading is made, the limiting speed for opening the cadmium curtain will be re-evaluated.

12.4 Initial Characterization of the Medical Therapy Beam

A characterization of the beam shall be performed as part of the pre-operational test. Characterization of the beam refers to the process of obtaining the dose-versus-depth profile in phantoms as described in Reference 1 and 2 or an equivalent process. Fast neutron, thermal neutron, and gamma ray components are determined in the characterization. These results are then used to normalize the beam monitors. The characterization of the medical beam will be compared with the design calculations.

12.5 Summary of Pre-Operational Experiments and Stepwise Power Tests

This summary list of pre-operational experiments has been included to illustrate the principles to be used in these experiments and their general scope. These experiments will be scheduled so that the number of actual reloadings of the converter will be minimized as mush as possible.

12.5.1 Stepwise Rise to Fission Converter Operating Power

The neutron flux from the MITR-II controls fission converter power. Therefore, the fission converter power depends on the reactor power, the position of the cadmium curtain, the type of primary coolant, and the type of fuel used in the fission converter as discussed in Section 2.3.3. In this section, an outline for stepwise increase in the fission converter power is presented.

1. All process systems and radiation monitoring systems will be put into their normal operating condition with instruments checked out and calibrated. Relative flows through each fuel element will be checked at normal operating primary coolant flow rate of 2.24 kg/sec.
2. The fission converter facility will be checked to assure that all experimental materials have been removed and that proper shielding of the medical facility and the converter top has been installed.
3. The cover-gas system will be checked for proper seal in order to reduce the potential for Ar^{41} production and release.
4. The converter power will be raised in steps. Checks on the radiation levels and system temperatures will be made at each step. The first power level step will be 20 kW. Measurements listed in step 5, as discussed below, will be made once steady state is achieved. This procedure will be repeated at converter power stepwise increments of every 40 kW until normal operating power is reached.
5. For the fission converter steady state power operation listed in step 4, the following measurements will be made:
    a) Temperature Distribution Measurements

    As the power is escalated in a stepwise manner, the temperature distribution will be measured by thermocouples above the coolant channels. The measured temperatures will be used to confirm the heat transfer design. The temperature distribution will be measured at fission converter power of 60 kW. The results at this power will be used to predict the coolant temperature at normal operating power. If the predicted maximum fuel plate temperature is below the incipient boiling temperature for the specified operating limits (Section 3.3.1), then the stepwise rise to full power can continue.

The results of the temperature distribution measurements will be used to locate the hottest fuel element. At least one thermocouple placed above the hottest fuel element will be used during normal operation to monitor the primary coolant temperature. These measurements are used to set the automatic shutdown trip point.

b) Radiation Surveys: A complete radiation survey on the outside of the fission converter facility as well as inside the medical therapy room will be made.

c) Instrumentation Adjustments and Calibrations

    i) The safety channels will be adjusted to scram the converter if the power rises 20% above the planned steady state power.

    ii) The power calibration on the basis of ΔT times flow will be made and compared with the power measured with the neutron detectors.

    iii) Warning alarm settings on all radiation monitors in the fission converter facility will be established.

d) Loss of Primary Coolant Measurements

    At fission converter power of 60 kW and at normal operating power, thermocouple above the hottest fuel element will be used to measure the coolant temperature as a function of time during loss of primary coolant flow. The fission converter will be shutdown before the onset of boiling. The resulting temperature transient will be compared with predicted results. The results of the last step will be used to predict the next step before another experiment is made.

Finally, there will be a general performance inspection of all components. Planned fission converter automatic shutdown to simulate possible failures will be made. These tests are to prove that the converter and components operate satisfactorily.

12 References

1. Choi, R.J., "Development and Characterization of an Epithermal Beam for Boron Neutron Capture Therapy at the MITR-II Research Reactor," Ph.D. Thesis, Nuclear Engineering Department, Massachusetts Institute of Technology, April 1991.

2. "Mixed Field Dosimetry of Epithermal Neutron Beams for Boron Neutron Capture Therapy at the MITR-II Research Reactor," R.D. Rogus, O.K. Harling and J.C. Yanch, *Medical Physics* **21** (10) (October 1994) 1611-1625.

Section 2

TECHNICAL SPECIFICATIONS
OF THE
MITR FISSION CONVERTER FACILITY
FOR
NEUTRON CAPTURE THERAPY
AND
EPITHERMAL NEUTRON RESEARCH

Included in this document are the Technical Specifications and the "Bases" for the Technical Specifications. The basis, which provides the technical support for the individual technical specifications, are included for information purposes only. They are not part of the Technical Specifications, and they do not constitute limitations or requirements to which the licensee must adhere.

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1. Definitions

2. Safety Limits and Limiting Safety System Settings

3. Limiting Conditions for Operation

4. Surveillance Requirements

5. Design Features

6. Experiments

1 Definitions

1.1 Fission Converter Plate

The fission converter plate is an array of MITR-II fuel elements in the fuel housing assembly located in the fission converter tank. The fission converter plate can contain up to eleven MITR-II fuel elements.

1.2 Fission Converter Secured

The overall condition where there is no fuel in the fission converter or all of the following conditions are satisfied:

1. the fission converter is shutdown
2. the medical control panel key switch is in the off position and key is in proper custody
3. there is no work in progress within the converter tank involving fuel

1.3 Fission Converter Shutdown

The condition where the cadmium curtain is closed or the MIT Research Reactor is shutdown. The fission converter is considered to be operating whenever these conditions are not met.

1.4 The True Value

The true value of a parameter is its actual value at any instant.

1.5 The Measured Value

The measured value of a parameter is the value of the parameter as it appears on the output of a measuring channel.

1.6 A Measuring Channel

A measuring channel is the combination of sensor, line amplifiers, and output devices which are connected for purpose of measuring the value of a parameter.

1.7 A Safety Channel

A safety channel is a measuring or protective channel in the fission converter safety system.

1.8 The Fission Converter Safety System

The fission converter safety system is that combination of safety channels and associated components which forms the protective system for the fission converter.

1.9 Operable

A component or system is considered operable when it is capable of performing its intended function in its normal manner.

1.10 Operating

A component or system is operating when it is performing its intended function in a normal manner.

1.11 Immediate

Immediate is defined as the required action to be initiated without delay in an orderly manner by using written procedures where applicable.

1.12 Channel Test

A channel test is the introduction of an input signal into the channel to verify that it is operable.

1.13 Channel Check

A channel check is a qualitative verification of acceptable performance by observation of channel behavior. This verification may include comparison of the channel with other independent channels or systems measuring or responding to the same variable.

1.14 Channel Calibration

A channel calibration is an adjustment of the channel such that its output responds, within an acceptable range and accuracy, to known values of the parameter which the channel measures.

1.15 Shutters That Control Beam Delivery

The medical therapy facility is equipped with shutters that are used to control beam delivery. They include cadmium, light water with or without boronation, and a high Z material such as lead and may contain hydrogenous material as described in Section 4.1 of the Fission Converter SAR. It is conceivable that these designations may if it is desirable to alter the beam configuration. Accordingly, the phrase "shutters that control beam delivery" refers either to the aforementioned three existing shutters or to any future shutter or group, thereof, that would provide a reduction in beam intensity adequate for irradiation control. Shutter-effect analyses shall be documented through the standard safety review process including, where necessary, a Fission Converter SAR revision and submission to NRC under 10 CFR 50.59.

1.16 Medical Beam Calibration Check

The term 'calibration check' refers to the process of checking the beam intensity and quality via one or more of the following: foil activation; use of a fission chamber; use of an ion chamber; or an equivalent process. The purpose of a calibration check is to ensure that the beam has not changed in a significant way (e.g., energy spectrum or intensity) from the beam that was characterized.

1.17 Functional Check of the Medical Beam Monitors

The term 'functional check of the beam monitors' shall consist of verifying that system output is consistent (±10%) with previously measured values upon normalization to a common neutronic power level.

1.18 Medical Beam Characterization

The term 'characterization' refers to the process of obtaining the dose-versus-depth profile in phantoms as described in Reference 1 and 2 or an equivalent process. The dose-verses-depth profile from the surface of the phantom to a depth at least equivalent to the total thickness of the body part to be treated on a central axis is deemed adequate for a characterization. Fast neutron, thermal neutron, and gamma ray components are determined in a characterization and monitors are normalized by this characterization.

1.19 Calibration of the Medical Beam Monitors

The term 'calibration of the beam monitors' refers to the process whereby the beam monitors are calibrated against instruments that measure dose including a tissue-equivalent chamber and a graphite or magnesium wall ionization chamber (or the equivalent to any of these three) that have in turn been calibrated by a secondary calibration laboratory.

1.20 Radiation Fluence

The term 'radiation fluence' means the measured neutron counts by the on-line detectors. The dose-verses-depth characterization as discussed in Specification 1.18 of this report is used to determine the ratios of gamma, fast neutron, and thermal neutron fluences to the on-line neutron counts. Knowledge of these ratios allows the total radiation fluence to be monitored by the on-line detectors. Compliance with the limits specified on radiation fluence by Specification 6.2-11 is determined by reference to the fluence monitored by these detectors.

1.21 Misadministration of a Radiation Therapy

The term 'misadministration' means the administration of a radiation therapy:

(a) Involving the wrong patient, wrong mode of treatment, or wrong treatment site; or

(b) When the treatment delivery is not in accordance with Specification 6.2-11.

1.22 Written Directive

The term 'written directive' means an order in writing for a specific patient, dated and signed by a physician authorized user prior to the administration of radiation and which specifies the treatment site, the total radiation fluence and radiation fluence per fraction.

1.23 Human Therapy

a) The term 'human therapy' means radiation treatments that are expected to be of direct therapeutic benefit to the patient.

b) During investigatory studies involving humans, the term 'human therapy' means experimental irradiation of human subjects.

1.24 Physician Authorized User

The term 'physician authorized' user means a medical physician approved for neutron capture therapy by an NRC-approved medical use licensee.

1.25 Certified Medical Physicist

The term 'certified medical physicist' means a medical physicist certified in either radiological physics or therapeutic radiation physics by the American Board of Radiology, or in therapeutic radiation physics by the American Board of Medical Physics and who also has specific training in neutron dosimetry and neutron capture therapy.

1.26 Medical Beam Design Modification

The term 'design modification' as applied to the medical therapy facility beam refers (a) to a change that is shown to alter the dose-verses-depth profile of the fast neutrons, thermal neutrons, or gamma rays in the beam as indicated by the calibration check and (b) to a change that has the potential to increase significantly the amount of activation products in the medical therapy facility when the beam is to be used for the treatment of human patients.

1.27 Reportable Occurrence

A reportable occurrence for the fission converter facility is any of the following:

1. Any actual safety system setting less conservative than specified in these Technical Specifications except during periods with the fission converter shutdown.
2. Operation in violation of a limiting condition for operation.
3. Safety system component malfunction or other component or system malfunction which could, or threaten to, render the system incapable of performing its intended function.
4. Release of fission products from a fuel element in a quantity that would indicate a fuel element cladding failure.
5. An uncontrolled or unanticipated change in reactor power due to opening of the cadmium curtain resulting in reactor period of less than 50 seconds.
6. An observed inadequacy in the implementation of either administrative or procedural controls, such that the inadequacy could have caused the existence or development of an unsafe condition in connection with the operation of the fission converter.

1.28 Recordable Event

The term 'recordable event' for human therapy means the administration of:

1. A radiation treatment without a written directive; or
2. A radiation treatment where a written directive is required without reporting to the medical use licensee in writing each fluence given within 24 hours of the treatment; or
3. A treatment delivery for which the administered radiation fluence for any given fraction is 15% greater than prescribed.

1.29 Review and Approve

The terminology "shall review and approve" is to be interpreted as requiring that the reviewing group or person shall carry out a review of the matter in question and may then either approve or disapprove it. Before it can be implemented, the matter in question must receive an approval from the reviewing group or person.

1.30 Inadmissible Sample Materials

Those materials defined by the MIT Reactor Safeguard Committee as not allowable within the Fission Converter Facility, MIT Reactor, or restricted from the Reactor Building such as unapproved amounts of combustible, corrosive, or explosive materials.

1.31 Fission Converter Safety Analysis Report (SAR)

The Fission Converter Safety Analysis Report (SAR) is the document submitted to the NRC entitled, "Safety Analysis Report of the MITR Fission Converter Facility for Neutron Capture Therapy and Epithermal Neutron Research".

1.32 Frequency

Each required surveillance test or other function shall be performed within the specified time interval with:

1. a maximum allowable extension not to exceed 25% of the specified surveillance interval, unless otherwise stated in these Technical Specifications,
2. a total maximum combined interval time for any three consecutive surveillance intervals not to exceed 3.25 times the specified surveillance interval.

Surveillance tests may be waived when an instrument, component or system is not required to be operable, but any such instrument, component or system shall be tested prior to being used as required operable instrument, component or system.

1 References

1. Choi, R.J., "Development and Characterization of an Epithermal Beam for Boron Neutron Capture Therapy at the MITR-II Research Reactor," Ph.D. Thesis, Nuclear Engineering Department, Massachusetts Institute of Technology, April 1991.

2. "Mixed Field Dosimetry of Epithermal Neutron Beams for Boron Neutron Capture Therapy at the MITR-II Research Reactor," R.D. Rogus, O.K. Harling and J.C. Yanch, *Medical Physics* **21** (10) (October 1994) 1611-1625.

2 Safety Limits and Limiting Safety System Settings

2.1 Safety Limits

Applicability

This specification applies to the variables associated with the fission converter thermal and hydraulic performance. These variable are:

L = the height of the primary coolant in the converter tank.

P = fission converter power

Objective

To establish limits to maintain the integrity of the fuel clad.

Specification

The measured values of the safety limits on the height of the primary coolant above the fuel elements, L, and the power of the fission converter P, shall be as follows:

L = 2.59 meters above the top edge of the fuel elements (minimum height of the coolant)

P = 300 kW (maximum)

Basis

In Section 3.3.3 of the Fission Converter SAR, it is noted that critical heat flux is a conservative limit beyond which fuel damage may occur from overheating. Therefore, the onset of critical heat flux is a conservative condition for setting the Safety Limits.

In Section 6.1 of the Fission Converter SAR, the condition for critical heat flux has been derived for total loss of primary coolant flow and continuous operation of the fission converter power at 300 kW. During the first phase of the transient, the coolant in the converter tank continues to recirculate by natural convection. The coolant temperature will begin to rise with time due to continual operation of the fission converter at 300 kW. When the surface clad temperature reaches 106°C, onset of nucleate boiling will occur on the fuel plates. Bulk recirculation of the coolant continues until the liquid level in the fission converter drops below the top edge of the down comer walls 51 minutes into the transient. Critical heat flux is possible once the fluid level drops below the down comer walls. Therefore, the safety limit for the fluid level is set at the height of the down comer wall (2.54 meters above the top edge of the fuel elements) to prevent the possibility of reaching critical heat flux.

The above analysis was conducted for fission converter power of 300 kW. Therefore, the fission converter power shall be limited to 300 kW.

2.2 Limiting Safety System Settings (LSSS)

Applicability

This specification applies to the set points for the safety channels monitoring primary coolant temperature above the hottest fuel element and the height of primary coolant in the converter tank.

Objective

To assure that automatic protective action will prevent incipient boiling in the fission converter and to prevent the fission converter from exceeding the Safety Limits.

Specification

The measured values of the limiting safety system settings on primary coolant temperature above the hottest fuel element, T, and the height of primary coolant above the fuel elements, L, shall be as follow:

T = 94°C (maximum)

L = 2.65 meters above the top edge of the fuel elements (minimum height of the coolant)

Basis

It is desirable to establish fission converter operating conditions that will prevent incipient boiling which could result in higher fuel clad corrosion rates. Maximum coolant temperature limit of 94°C above the hottest fuel element provides an adequate margin to prevent onset of incipient boiling. Onset of nucleate boiling occurs at a clad temperature of 106°C corresponding to the coolant temperature above the hottest fuel element of 96°C. Therefore, a margin between the operating limit and the onset of nucleate boiling is provided. Incipient boiling is always initiated prior to the initiation of critical heat flux. Therefore, the prevention of incipient boiling will assure that the Safety Limits are not exceeded.

In Section 6.1 of the Fission Converter SAR, the transient analysis during total loss of primary coolant flow and converter power at 300 kW is discussed. The possibility of critical heat flux is not approached until the coolant height drops below the top edge of the down comer walls. The 2.65 meter limit for the height of the coolant maintains the primary coolant 6.0 cm above the top edge of the down comer walls, thus, preventing the possibility of critical heat flux.

3 Limiting Conditions for Operation

3.1 Temperature and Fluid Level Limits

Applicability

This specification applies to the primary coolant temperature and fluid level in the fission converter tank.

Objective

To assure that the temperature of the primary coolant and fluid level during fission converter operation will conform within the basis of the thermal and hydraulic Specification 2.2.

Specification

The measured values of the limiting conditions for operation on primary coolant temperature above the hottest fuel element, T, and the height of primary coolant above the fuel elements, L, shall be as follow:

T = 88°C (maximum)

L = 2.74 meters above the top edge of the fuel elements (minimum height of the coolant)

Basis

The primary coolant temperature profile is discussed in Section 3.2.2 of the Fission Converter SAR. The maximum coolant temperature occurs at the center of the fission converter plate. The hottest fuel element will be evaluated as discussed in Section 12.5.1 of the Fission Converter SAR. By monitoring the coolant temperature above the hottest fuel element, every fuel element in the fission converter plate can be predicted to be below the monitored temperature. Onset of nucleate boiling occurs at a surface clad temperature of 106°C, which corresponds to coolant temperature above the hottest fuel element of 96°C. Therefore, the temperature limit of 88°C above the hottest fuel element assures that onset of incipient boiling will be prevented.

In Section 6.1 of the Fission Converter SAR, the condition for critical heat flux has been derived for total loss of primary coolant flow and continuous operation of the fission converter power at 300 kW. During the first phase of the transient, the coolant in the converter tank continues to recirculate by natural convection. The coolant temperature will begin to rise with time due to continual operation of the fission converter at 300 kW. When the surface clad temperature reaches 106°C, onset of nucleate boiling will occur on the fuel plates. Bulk recirculation of the coolant continues until the liquid level in the fission converter drops below the top edge of the down comer walls 51 minutes into the transient. Critical heat flux is possible once the fluid level drops below the down comer walls. The limit of 2.74 meter for the height of the coolant maintains the primary coolant 15.24 cm above the top edge of the down comer walls, thus preventing the possibility of reaching critical heat flux.

3.2 Reactor Period Limit during Fission Converter Operation

Applicability

This specification limits the reactor period during fission converter operation.

Objective

To assure that the integrity of the reactor fuel is maintained during operation of the fission converter.

Specification

The opening speed of the cadmium curtain shall be limited to a reactor period of longer than 50 seconds.

Bases

MITR Technical Specifications provide several approaches for limiting the reactivity associated with an experimental facility. MITR Technical Specification 6.1 imposes limits depending on whether the experiment is classified as moveable, non-secured, or secured. MITR Technical Specification 6.4 imposes a limit on the allowed period for experiments related to reactor control research. The latter approach provides more flexibility because it permits any combination of reactivity provided that a certain minimum period is not exceeded. Accordingly, this approach is used for the fission converter. The fission converter will be exempt from MITR Technical Specification 6.1. The reactor period limit of 50 seconds is used instead, as discussed in Section 12.3.1 of the Fission Converter SAR will apply. Reactor controls can be used to compensate for the change in reactor power due to the presence of the fission converter as long as reactor period is longer than 50 seconds during opening of the cadmium curtain.

At the initial startup of the fission converter, reactor period will be measured. After any future significant change in fuel design or fuel loading is made, the limiting speed of opening the cadmium curtain will be re-evaluated.

3.3 Limiting Conditions for Fission Converter Operation

Applicability

This specification applies to fission converter operating conditions.

Objective

To assure that fission converter conditions are maintained within the bounds used to establish the operating limits.

Specification

1. The fission converter shall not be operated unless:
    a. All positions in the converter plate are filled with either a fuel element or another approved unit.
    b. The fission converter top shield is in position or administrative controls are in place to limit personal exposure.

Basis

All fuel elements must be in position to prevent mechanical damage of the components and to assure proper flow distribution and cooling. As discussed in Section 3.5.2 of the Fission Converter SAR, the fuel restraint is based on a closed-packed fuel elements in a sturdy casing with fixed upper and lower matrix with side walls. The fuel elements are held down by gravity and the hydraulic lift at maximum coolant flow is negligible.

The fission converter top shield acts as a biological shield.

3.4 Fission Converter Safety Systems

Applicability

This specification applies to the safety systems necessary for the operation of the fission converter.

Objective

To assure that the operator has sufficient indication of the primary coolant temperature, converter tank fluid level, and that automatic protective actions are provided.

Specification

1. The fission converter shall not be operated unless the safety channels are operating and the safety system is operable in accordance with Table I of this specification.
2. Emergency power with the capacity to operate the equipment listed in Table II of this specification shall be available whenever the fission converter is operating and capable of operation for at least one half hour following a loss of normal power to the facility.

Basis

The parameters listed in Table I are monitored by the fission converter safety system. This system automatically initiates action to assure that the appropriate safety limits and the limiting conditions of operation are not violated.

The use of emergency power is not necessary for the fission converter because loss of electric power automatically scrams the reactor and the primary coolant will continue to cover the converter fuel elements to prevent damage to the fuel clad. Also, the shutters between the fission converter and the medical room close automatically during loss of electric power to reduce the radiation dose inside the medical therapy room. The choice of a minimum of one half hour is based on time necessary to provide personnel information to assure that the patient in the medical therapy room can be safely evacuated.

Table I Required Safety Channels

Channel	**Action**	**Limiting Setpoint**	**Min No. Required**
1. primary coolant temperature above the hottest fuel element	automatic shutdown	88°C	1
2. primary coolant fluid level in the converter tank	automatic shutdown	2.74 meters above the top edge of the fuel elements	1

Table II Minimum Equipment to be Supplied by Emergency Power

1.	medical therapy room radiation monitor
2.	intercom between the medical therapy room and the medical control panel area
3.	emergency lighting of the medical therapy room and the medical control panel area

3.5 Radioactive Effluents and Radiation Monitors

Applicability

This specification applies to radioactive effluents released from the fission converter and the radiation monitors.

Objective

To assure that the release of radioactive effluents to the environment are within the limits of 10 CFR Part 20.

Specification

The release of radioactive effluents from the reactor site which includes the fission converter facility shall be as specified in MITR Technical Specification 3.8.

3.6 Fuel Element and Fission Converter Component Handling and Storage

Applicability

This specification applies to the operations of storing and handling fuel elements and fission converter components.

Objective

To assure that fuel elements and fission converter components will be handled at all times in a manner that will protect the health and safety of reactor personnel and the public.

Specification

1. Fuel elements shall be stored in accordance with MITR Technical Specifications 3.10-1, 3.10-2, and 3.10-3.
2. Handling of fuel elements shall be in accordance with MITR Technical Specification 3.10-4 with the following exception:

   Prior to transferring an irradiated element, the element shall not have been operated at a power level above 100 kW for at least four days shall not apply for the fission converter.
3. Removal of cadmium curtain: Whenever the fission converter contains fuel elements, the cadmium curtain may be removed from the thermal column only after the reactor has been shutdown.

Basis

Basis for fuel element storage is discussed in MITR Technical Specification 3.10.

The main problems with spent fuel handling are those of shielding personnel from the emitted fission product gamma rays and preventing fuel melting from the heat generated by fission products. The shielding requirement is met by utilizing a shielded transfer cask for movements and temporary storage.

In Section 6.1.3 of the Fission Converter SAR, fuel cladding and fuel centerline temperatures were calculated for heat transfer by radiation alone after the fission converter has been operating at a steady state power of 300 kW. The maximum clad temperature was calculated to be 348°C which is well below aluminum-6061 softening temperature of 460°C. Therefore, radiation heat transfer alone is sufficient to prevent fuel damage.

The basis for reactor shutdown before removal of the cadmium curtain is to ensure that the radiation exposure to personnel will be kept as low as reasonably achievable whenever the fission converter contains fuel elements.

4 Surveillance Requirements

4.1 Fission Converter Safety System Surveillance

Applicability

This specification applies to the surveillance of safety systems whose operation is important to fission converter safety.

Objective

To assure the reliability and accuracy of the instrumentation important for safe operation of the fission converter.

Specification

1. The following instruments or channels for the fission converter safety system will be tested at least monthly in any month the facility will be used. In the event of a hiatus in the scheduled performance of any given surveillance, that surveillance shall be performed prior to operation of the fission converter during the interval in question.

Instrument or Channel	Surveillance
1. Primary coolant temperature above the hottest fuel element	fission converter automatic shutdown test
2. Converter tank fluid level	operational test

2. The following instrument shall be calibrated and trip points verified when initially installed and at least annually: primary coolant temperature channel above the hottest fuel element

Basis

The fission converter instruments important for safe operation will be tested according to the specification above to ensure proper operation of the fission converter for the interval specified.

As discussed in Section 8.7.3 of the Fission Converter SAR, the calibration of the converter tank fluid level safety channel is fixed by the physical location of the probes and is not subject to change. The operational test is all that is required to insure adequate performance of these channels.

4.2 Response Time Surveillance

Applicability

This specification applies to the surveillance of the response time to the automatic safety systems.

Objective

To assure that fission converter safety systems function as required with adequate response time.

Specification

Testing shall be performed at least annually to measure the response time from when the fission converter automatic shutdown signal initiates to when the cadmium curtain closes. The response time shall be less than 120 seconds.

Basis

The response time for the safety systems is based on the analysis of total loss of primary coolant flow as discussed in Section 6.1 of the Fission Converter SAR. The 120 second response time is a conservative value because the possibility of critical heat flux will not be reached before 51 minutes into the transient with continuous operation of the fission converter at 300 kW.

In Section 6.1.3 of the Fission Converter SAR, an analysis of a massive simultaneous double wall failure of the converter tank below the fuel elements has been discussed. The results of the calculation indicate that the integrity of the fuel cladding is maintained even after complete loss of primary coolant once the fission converter is shutdown. The 120 second limit for the cadmium curtain to close is a conservative value because no credible scenario can drain the converter tank within that time can be identified.

In the event of failure of the automatic shutdown system to close the cadmium curtain in 120 seconds, the MIT Research Reactor's power can be decreased or shutdown to maintain fuel integrity in the fission converter.

5 Design Features

5.1 Primary Coolant System

Applicability

This specification applies to the design of the fission converter primary coolant system.

Objective

To assure compatibility of the primary coolant system with the safety analysis.

Specification

The fission converter primary coolant system shall consist of a converter tank, a single cooling loop containing one or more heat exchanger, and appropriate pumps and valves. The primary system can either utilize H_2O or D_2O coolant. All materials, including those of the converter tank, in contact with primary coolant, shall be aluminum alloys, stainless steel or other materials that are chemically compatible with H_2O and D_2O coolant, except for small non-corrosive components such as gaskets, filters and valve diaphragms. The converter tank shall be designed in accordance with the ASME Boiler & Pressure Vessel Code Section IV. It shall be designed for a working pressure of 10 psig and 80°C. Heat exchangers shall be designed for 60 psig and a temperature of 80°C. The connecting piping shall be designed to withstand a 60 psig hydro test.

Basis

The fission converter coolant system has been described and analyzed in the Fission Converter Safety Analysis Report as a single loop system containing one or more heat exchangers. Materials of construction, being primarily aluminum alloy and stainless steel, are chemically compatible with D_2O and H_2O coolants. The failure of the gaskets and valve bellows, although undesirable, would not result in catastrophic failure of the primary system; hence, strict material limitations are not required for technical specifications. Provisions have been made to contain D_2O in the event of leakage as discussed in Section 6.3.5 of the Fission Converter SAR.

The design temperature and pressure of the converter tank and other primary system components provide adequate margins over operating temperatures and pressures, and it is believed prudent to retain these margins in order to further reduce the probability of a primary system failure. The converter tank was designed to meet Section IV of the ASME Boiler & Pressure Vessel Code, 1996 edition. Subsequent design changes should be made in accordance with the most recent edition of this code.

The safety analysis is based on the current design with current margins, and therefore, it is considered necessary to retain this design and these margins or redo the analysis.

6 Experiments

6.1 General Experiment Criteria other than for Human Therapy

Applicability

This specification applies to experiments using the fission converter other than for human therapy.

Objective

To assure that experiments using the fission converter facility do not affect the safety of the fission converter.

Specifications

All experiments other than for human therapy shall comply with the General Experiment Criteria discussed in MITR Technical Specification 6.1.

Basis

Refer to MITR-II Technical Specification 6.1.

6.2 Generation of Medical Therapy Facility Beam for Human Therapy

Applicability

The specification applies solely to the generation of the medical therapy beam used for the treatment of human patients. It does not apply to any other use of the medical therapy facility and/or its beam. Surveillances listed in this specification are only required if human therapy is planned for the interval of the surveillance. However, in the event of a hiatus in the scheduled performance of any given surveillance, that surveillance shall be performed prior to the initiation of human therapy during the interval in question.

Objective

To provide for the protection of the public health and safety by ensuring that patients are treated in accordance with the treatment plan established by the physician authorized user and that the ALARA principle is observed for all non-therapeutic radiation exposures.

Specification

1. Patients accepted for treatment shall have been referred by written directive from a physician authorized user of NRC Medical Use Licensee No. 20-03857-06 or NRC Medical Use Licensee No. 20-00289-07 or of any other medical use licensee that has been similarly authorized by NRC (or the Commonwealth of Massachusetts should the latter become a common agreement state) to utilize the MITR Fission Converter's Medical Therapy Facility beam for neutron capture therapy for humans.

2. All medical treatments, including irradiations and analyses of the neutron capture agents in the patients, are the responsibility of the physician authorized user in charge of the therapy and the medical physicists from the NRC-licensed medical center. The

Massachusetts Institute of Technology is only responsible for providing current and accurate beam characteristic parameters to the medical use licensee and for delivery of the desired radiation fluence as requested in the written directive. Before the start of a therapy, both the certified medical physicist and the MIT principal investigator for BNCT, or his designate, must agree that the therapy can be initiated. The physician authorized user is responsible for monitoring the therapy and for directing its termination. However, a radiation therapy can also be terminated at any time if either the physician authorized user or the MIT principal investigator for BNCT, or their designates, judge that the therapy should be terminated.

3. It shall be possible to initiate a minor scram of the reactor from a control panel located in the medical therapy facility area. In the event that the medical facility minor scram is inoperable, it shall be acceptable to use one of the control room scrams via communication with the reactor operator as a temporary means of satisfying this provision. Use of this temporary provision is limited to ten consecutive working days.

4. Access to the medical therapy facility shall be controlled by means of the shield door located at its entrance.

5. The following features and/or interlocks shall be operable:
    (a) An interlock shall prevent opening of the shutters that control beam delivery unless the medical therapy facility's shield door is closed.
    (b) The shutters that control beam delivery shall be interlocked to close automatically upon opening of the medical facility's shield door.

   (c) The shutters between the fission converter and the medical therapy room shall be designed to close automatically upon failure of either electric power or on loss of pressure if the shutters are operated pneumatically or hydraulically.
   (d) Shutters that control beam delivery and that are normally pneumatically or hydraulically operated shall, in addition, be designed for manual closure.
   (e) It shall be possible to close the shutters that control beam delivery from within the medical therapy facility.

6. Each of the shutters that controls beam delivery shall be equipped with a light that indicates the status of the shutter. These lights shall be visible at the medical therapy facility's local control panel. In the event of a status light malfunction, it shall be acceptable to use the affected shutter provided that an alternate means of verifying position is available. Use of this alternate means of shutter position verification is limited to ten consecutive working days.

7. The medical therapy facility shall be equipped with a monitor that provides a visual indication of the radiation level within the facility, that indicates both within the facility and at the local control panel, and that provides an audible alarm both within the facility and at the local control panel.
   (a) This radiation monitor shall be equipped with a backup power supply such as the reactor emergency power system or a battery.
   (b) This radiation monitor shall be checked for proper operation by means of a check source on the calendar day of and prior to any patient irradiation.
   (c) This radiation monitor shall be calibrated quarterly.

(d) The audible alarm shall be set at or below 50 mR/hr. This monitor and/or its alarm may be disabled once the medical therapy room has been searched and secured, such as is done immediately prior to initiation of patient therapy. If this is done, the monitor and/or its alarm shall be interlocked so that they become functional upon opening of the medical therapy facility's shield door.

(e) In the event that this monitor is inoperable, personnel entering the medical therapy facility shall use either portable survey instruments or audible alarm personal dosimeters as a temporary means of satisfying this provision. These instruments/dosimeters shall be in calibration as defined by the MITR Research Reactor's radiation protection program and shall be source-checked daily prior to use on any day that they are used to satisfy this provision. Use of these instruments/dosimeters as a temporary means of satisfying this provision is limited to ten consecutive working days.

8. An intercom or other means of two-way communication shall be operable both between the medical therapy facility control panel and the reactor control room, and also between the medical therapy facility control panel and the interior of the facility. The latter is for the monitoring of patients.

9. It shall be possible for personnel monitoring a patient to open the medical therapy facility's shielded door manually.

10. It shall be possible to observe the patient by two independent means. This requirement can be provided by either two closed circuit TV cameras with different power supplies or one closed circuit TV camera and a viewing port. Both methods of patient visualization

shall be operable at the outset of any patient irradiation. Should either fail during the irradiation, the treatment may be continued at the discretion of the physician authorized user. Adequate lighting to permit such viewing shall be assured by the provision of emergency lighting.

11. The total radiation fluence delivered by the medical therapy facility beam as measured by on-line beam monitors shall not exceed that prescribed in the patient treatment plan by more than 20%. If the treatment is delivered in fractions in accordance with standard practice for human therapy, 20% criterion shall apply to the sum of the radiation fluences associated with all fractions in a given treatment plan. A criterion of 30% applies to the difference between the administered and prescribed fluence for any given week (seven consecutive days). Finally, if the treatment consists of three or fewer fractions, then a criterion of 10% on the total fluence shall apply.

12. The following interlocks or channels shall be tested at least monthly and prior to treatment of human patients if the interlock or channel has been repaired or deenerigized:

Interlock or Channel	**Surveillance**
a) Medical therapy facility minor scram	Reactor scram test
b) Shutters will not open unless shield door is closed	Operation test
c) Shutters close upon both manual and automatic opening of shield door	Operation test
d) Shutters close on loss of electrical power and reduction of pressure in pneumatic or hydraulic operators, if applicable	Operation test
e) Shutters can be closed manually from within the facility	Operation test
f) Shutter status lights	Operation test
g) Radiation monitor alarm	Operation test
h) Radiation monitor and/or alarm enabled upon opening of shield door	Operation test
i) Intercoms	Operation test

In addition to above, the medical therapy facility minor scram shall be tested prior to reactor startup if the reactor has been shutdown for more than sixteen hours.

13. Manual operation of the medical therapy facility's shield door in which the door is opened fully shall be verified semi-annually.

14. Use of the medical therapy facility beam shall be subject to the following:
    a) A calibration check of the beam and a functional check of the beam monitors that are described in provision 11 of this specification shall be made weekly for

any week that the beam will be used for human therapy. These checks shall be made prior to any patient irradiation for a given week. In addition, a calibration check shall be performed prior to any patient irradiation in the event that any component of a given beam design has been replaced. Finally, a calibration and a functional check shall be performed prior to any patient irradiation in the event of a design modification.

b) A characterization of the beam shall be performed every twelve months for any twelve-month interval that the beam will be used for human therapy. This twelve-month characterization shall be made prior to any patient irradiation for a given twelve month interval. A characterization shall also be performed prior to any patient irradiation in the event of a design modification. As part of the characterization process, the proper response of the beam monitors that are described in provision 11 of this specification shall be verified.

c) A calibration of the beam monitors that are described in provision 11 of this specification shall be performed at least once every two years for any two-year interval that the beam will be used for human therapy. The two-year calibration shall be made prior to any patient irradiation during any given two-year interval.

15. Maintenance, repair, and modification of the medical therapy facility shall be performed under the supervision of a senior reactor operator who is licensed by the U.S. Nuclear Regulatory Commission to operate the MIT Research Reactor. The 'medical therapy facility' includes the beam, beam shutters, beam monitoring equipment, medical therapy facility shielding, shield door, and patient viewing equipment. All modifications will be reviewed pursuant to the requirements of 10 CFR 50.59. The patient support and positioning equipment, medical instruments, and other equipment used for the direct

medical support of the patient are not considered part of the medical therapy facility for purposes of this provision, except insofar as radiation safety (i.e., activation and/or contamination) is concerned.

16. Personnel who are not licensed to operate the MIT Research Reactor but who are responsible for either the medical therapy or the beam's design including construction and/or modification may operate the controls for the medical therapy facility beam provided that:
    a) Training has been provided and proficiency satisfactorily demonstrated on the design of the facility, its controls, and the use of those controls. Proficiency shall be demonstrated annually.
    b) Instructions are posted at the medical therapy facility's local control panel that specify the procedure to be followed:
        i) to ensure that only the patient is in the treatment room before turning the primary beam of radiation on to begin a treatment;
        ii) if the operator is unable to turn the primary beam of radiation off with controls outside the medical therapy facility, or if any other abnormal condition occurs. A directive shall be included with these instructions to notify the reactor console operator in the event of any abnormality.
    c) In the event that a shutter affects reactivity (e.g., the cadmium curtain), personnel who are not licensed to operate the MIT Research Reactor but who have been trained under this provision may operate the shutter provided that verbal permission is requested and received from the reactor control operator immediately prior to such action. Emergency closures are an exception and may be made without first requesting permission.

Records of the training provided under subparagraph (a) above shall be retained in accordance with the MIT Research Reactor's training program or at least for three years. A list of personnel so qualified shall be maintained in the reactor control room.

17. Events defined as 'recordable' under definition in Specification 1.28 shall be recorded and the record maintained for five years. Events defined as 'misadministrations' under definition in Specification 1.21 shall be reported to the U.S. Nuclear Regulatory Commission (24 hours verbal, 15 day written report). The 24 hour verbal reports will be made to the Regional Administrator, Region I, or his designate. The 15 day written reports will be sent to the NRC Document Control Desk with a copy to the Regional Administrator, Region I, or his designate.

18. The requirements of the Quality Management Program (QMP) for the Generation of Medical Therapy Facility Beam for Human Therapy at the Massachusetts Institute of Technology Research Reactor shall be observed for any human therapy. (Note: The presence of this commitment to observe the QMP in these specifications does not preclude modifying the QMP as provided in that document. Any such modifications are not considered to be a change to the MITR Fission Converter Technical Specifications.)

Basis

The stipulation that patients only be accepted from NRC Medical Use Licensee No. 20-03857-06 or NRC Medical Use Licensee No. 20-00289-07 or from any other medical use licensee that has been similarly authorized by NRC (or by the Commonwealth of Massachusetts should the latter become a common agreement state) to utilize the MITR Fission Converter's

Medical Therapy Facility beam for human therapy, ensures that medical criteria imposed by NRC on such licensees for the use of the MIT Research Reactor's medical therapy facility beam for human therapy will be fulfilled. The second provision delineates the division of responsibilities between the Massachusetts Institute of Technology and the medical licensee that refers the patient. Also, it establishes administrative authority and protocol for initiating and terminating a radiation therapy.

The requirement that it be possible to initiate a minor scram from a control panel located in the medical therapy facility area assures the attending physician and/or medical physicist, and the MIT principal investigator or his designate of the capability to terminate the treatment immediately should the need arise. The provision that access to the medical therapy facility be limited to a single door ensures that there will be no inadvertent entries. The various interlocks for the shutters that control beam delivery ensure that exposure levels in the medical therapy facility will be minimal prior to entry by personnel who are attending the patient. The shutter-indicating lights serve to notify personnel of the beam's status. The provision for a radiation monitor ensures that personnel will have information available on radiation levels in the medical therapy facility prior to entry. The purpose of this monitor's audible alarm is to alert personnel to the presence of elevated radiation levels, such as exist when the shutters that control beam delivery are open. This monitor and/or its alarm may be disabled once the medical therapy facility has been searched and secured so that it will (1) not disturb a patient and (2) not distract attending personnel. The monitor and/or its alarm are interlocked with the shield door so that they are made functional upon opening that door, and hence prior to any possible entry to the medical therapy facility. One intercom provides a means for the prompt exchange of information between medical personnel and the reactor operator(s). The second intercom is for monitoring the patient.

The provision for manual operation of the medical therapy facility's shield door ensures access to any patient in the event of a loss of electrical power. The presence of two independent means of viewing the patient provide the attending physician authorized user and/or medical physicist redundancy in monitoring the patient visually.

The specification that the total radiation fluence for a therapy (i.e., the radiation fluences for the sum of all fractions specified in a given treatment plan) not exceed that proscribed in the patient treatment plan by 20% establishes a trigger limit on the delivered fluence above which NRC has to be notified of a misadministration. The 20% criterion is based on the definition of misadministration (clause 4(iv) as given in 10 CFR 35.2). The criterion that the difference between the administered and prescribed fluence for any seven consecutive days is set at 30%. This is also in accordance with the definition of misadministration (clause 4(iii) as given in 10 CFR 35.2). Finally, if a treatment involves three of fewer fractions, then a more stringent criterion, 10%, applies to the difference between the total radiation fluence for a therapy and that prescribed in the treatment plan (10 CFR 35.2(4ii)). The surveillance requirements for beam calibration checks and characterizations provide a mechanism for ensuring that the medical therapy facility and its beam will perform as originally designed. Similarly, the surveillance requirements on the beam monitors ensure that these instruments are calibrated by a means traceable to the National Institute of Standards and Technology. The chambers specified (tissue-equivalent, and graphite or magnesium-wall) were chosen because they measure dose as opposed to fluence.

The specification on maintenance and repair of the medical therapy facility ensures that all such activities are performed under the supervision of personnel cognizant of quality assurance and other requirements such as radiation safety. The provision on the training and proficiency of non-licensed personnel ensures that all such personnel will receive instruction equivalent to that given to licensed reactor operators in regards to the use of the medical therapy facility beam. (Note: Licensed reactor operators may, of course, operate the medical therapy facility beam.) Also, this provision provides for the posting of instructions to be followed in the event of an abnormality.

The specification on 'recordable events' and 'misadministrations' provides for the documentation and reporting to the U.S. Nuclear Regulatory Commission of improper events regarding the generation and use of the medical therapy facility beam. The requirement that the Quality Management Program (QMP) be observed ensures that radiation treatments provided by the medical therapy facility beam will be administered as directed by the physician authorized user.

7 Quality Management Program

for Generation of Medical Therapy Facility Beam for Human Therapy

1. Purpose: The objective of this quality management program is to ensure that radiation treatments provided by the MITR Fission Converter's Medical Therapy Facility beam will be administered as directed by a physician authorized user.

2. Authorized Medical Use Licensees: Use of the MITR Fission Converter's Medical Therapy Facility beam, for the treatment of human subjects, is limited to the physician authorized users authorized under:
   a) NRC Medical Use Licensee No. 20-03857-06 or NRC Medical Use Licensee No. 20-00289-07.
   b) Any other medical use licensee that has been similarly authorized by NRC (or by the Commonwealth of Massachusetts should the latter become a common agreement state) to utilize the MITR Fission Converter's Medical Therapy Facility beam for human therapy.

3. Program Requirements: The following requirements are established as part of this quality management program:
   a) A written directive will, except as noted in subparagraph (iv) below, be prepared by a physician authorized user of the NRC-approved medical use licensee prior to the administration of any radiation therapy. This directive shall be written, signed, and dated by the physician authorized user and it shall include the following information:
      i) Name and other means of identifying the patient.

ii) Name of the physician authorized user and certified medical physicist in charge of the therapy.

iii) The total radiation fluence to be administered, the radiation fluence per fraction, and the treatment site.

iv) If, because of the patient's condition, a delay in order to provide a written revision to an existing written directive would jeopardize the patient's health, an oral revision to an existing written directive will be acceptable, provided the oral revision is documented immediately in the patient's record and a revised written directive is signed by a physician authorized user within 48 hours of the oral revision.

    Also, a written revision to an existing written directive may be made for any therapeutic procedure provided that the revision is dated and signed by a physician authorized user prior to the administration of the next fraction.

    If, because of the emergency nature of the patient's condition, a delay in order to provide a written directive would jeopardize the patient's health, an oral directive will be acceptable, provided that the information contained in the oral directive is documented immediately in the patient's record and a written directive is prepared within 48 hours of the oral directive.

v) In order to ensure that the Staff of the MIT Research Reactor has the most recent written directive from the medical use licensee and the correct directive for the patient in question, a copy of that directive shall be hand-delivered to the MITR Staff by the Staff of the medical use licensee who accompany the patient to MIT. This copy shall then be checked against the most recent previous transmission. Any discrepancy shall be resolved by the medical use licensee prior to the initiation of patient irradiation.

vi) The MIT principal investigator for BNCT, or his designate, will date and sign the written directive to verify that current and accurate beam characteristic parameters were provided to the NRC-approved medical use licensee prior to irradiation. The MIT principal investigator for BNCT, or his designate, will date and sign the written directive after the irradiation to verify that the correct fluence was delivered. A copy of this signed directive shall be provided to the medical use licensee within twenty-four hours of a treatment.

b) Prior to each administration of any radiation, the patient's identity will be verified by more than one method as the individual named in the written directive. An authorized representative of the MIT Nuclear Reactor Laboratory will use any two or more of the following acceptable methods of identification:

    i) Self-identification by patients who are conscious upon arrival at the MIT Research Reactor. Information provided by the patient shall include any two of the following: name, address, date of birth, or social security number. The information provided by the patient is to be compared to the corresponding information in the patient's record.

    ii) Hospital wrist band identification with the wrist band information to be compared to the corresponding information in the patient's record.

    iii) Visual identification against photographs provided with the written directive.

    - iv) Other methods as specified in U.S. Nuclear Regulatory Commission Regulation Guide 8.33, "Quality Management Program."

c) The plan of treatment is certified by the certified medical physicist to be in accordance with the written directive. In this regard, the Massachusetts Institute of Technology is responsible for calibrating the output of the beam monitoring instrumentation versus dose in phantom and for providing a central axis dose versus depth profile. This information will then be used by personnel at the NRC-approved medical use licensee to generate a plan of treatment. Conformance of the beam to its design characteristics is confirmed through the measurements specified in MITR Fission Converter Technical Specification Section 6.2, "Generation of Medical Therapy Facility Beam for Human Therapy". The beam is characterized dosimetrically every twelve months (provision 14b), the ion chambers used for the dose depth measurements are calibrated by a secondary calibration laboratory every two years and their proper operation is verified semi-annually (provision 14c), and calibration checks are made of the beam at least weekly for any week that the beam will be used for human therapy (provision 14a).

d) Each administration of radiation is in accordance with the written directive subject to the tolerances established in provision 11 of MITR Fission Converter Technical Specification 6.2, "Generation of Medical Therapy Beam for Human Therapy".

e) Any unintended deviations from the written directive shall be identified and evaluated, and appropriate action taken. Such action shall include informing the medical use licensee of the deviation. These reviews shall be performed monthly for any month in which human therapy was conducted. For each patient case reviewed, it shall be determined whether the administered total fluence and fluence per fraction were as specified in the written directive. In the event of any deviation from the written directive, the licensee (MIT) shall identify its cause and the action required to prevent recurrence. These actions may include new or revised policies, new or revised procedures, additional training, increased supervisory review of work, or other measures as deemed appropriate. Corrective actions shall be implemented as soon as practicable.

4. Program Implementation: The following practices shall be observed in order to ensure proper implementation of the quality management program:
   a) A review shall be conducted of the quality management program. This review shall include, since the last review, an evaluation of:
      i) A representative sample of patient administrations,
      ii) All recordable events, and
      iii) All misadministrations.

      The objective of this review is to verify compliance with all aspects of the quality management program. For purposes of this review, the term 'representative' in statement (i) above is defined as 100% sampling up to twenty patients; a sample of twenty for twenty-one to one hundred patients, and 20% sampling for more than one hundred patients. In order to eliminate any bias in the sample, the cases to be reviewed should be selected randomly.
   b) The procedure for conducting the above review is as follows:
      i) The review shall be performed by the Director of the MIT Radiation Protection Program or his designate.
      ii) The review shall be performed annually.

iii) Patient administrations selected for review shall be audited to determine compliance with each of the requirements listed in paragraphs (3) above.

iv) The review shall be written and any items that require further action shall be so designated. Copies of the review shall be provided to the NRL Director, MIT principal investigator for BNCT, and to the MIT Reactor Safeguards Committee who will evaluate each review and, if required, recommend modifications in this quality management program to meet the requirements of paragraph (3) above. A copy of these reviews will also be provided to each medical use licensee.

c) Records of each review, including the evaluations and findings of the review, shall be retained in an auditable form for three years.

d) The licensee (MIT) shall reevaluate the Quality Management Program's policies and procedures after each annual review to determine whether the program is still effective or to identify actions required to make the program more effective.

5. <u>Response to Recordable Event</u>: Within thirty days after the discovery of a recordable event, the event shall be evaluated and a response made that includes:

a) Assembling the relevant facts, including the cause;

b) Identifying what, if any, corrective action is required to prevent recurrence; and

c) Retaining a record, in an auditable form, for three years, of the relevant facts and what corrective action, if any, was taken.

A copy of any recordable event shall be provided to the affected medical use licensee.

6. Records Retention: The following records shall be retained:
   a) Each written directive for three years; and
   b) A record of each administered radiation therapy where a written directive is required in paragraph (3a) above, in an auditable form, for three years after the date of administration.

7. Program Modification: Modifications may be made to this quality management program to increase the program's efficiency provided that the program's effectiveness is not decreased. All medical use licensees shall be notified of any modifications and provided with a copy of the revised program. The licensee (MIT) shall furnish the modification to the NRC (Region I) within 30 days after the modification has been made.

8. Report and Surveillance Frequency: Any report or other function that is required to be performed in the Quality Management Program at a specified frequency shall be performed within the specified time interval with:
   a) a maximum allowable extension not to exceed 25% of the specified surveillance interval, unless otherwise stated in the Quality Management Program;
   b) a total maximum combined interval time for any three consecutive surveillance intervals not to exceed 3.25 times the specified surveillance interval.

9. Applicability: This Quality Management Program applies solely to the generation of the medical therapy facility beam for the treatment of human subjects. It does not apply to any other use of the medical therapy facility and/or its beam. Reports and surveillances listed in this specification are only required if human therapy was conducted during the referenced interval.

8 Administrative Controls

Applicability

Operation of the Fission Converter is subject to administrative control. Measures specified in this section provide for the assignment of responsibilities, review and audit mechanisms, procedural controls, and reporting requirements. Each of the measures are applicable as the minimum requirements throughout the fission converter facility's life.

Objective

To assure that adequate management controls are available for safe facility operation.

Specification

The MIT Research Reactor Administrative Controls in MITR Technical Specifications Section 7 shall assure that adequate management controls for the safe operation of the fission converter will be provided.

Basis

Refer to MITR-II Technical Specification 7.

Section 3

COST ANALYSIS
OF THE
MITR FISSION CONVERTER FACILITY
FOR
NEUTRON CAPTURE THERAPY

Table of Contents

Chapter 2 Cost of Components

1 Introduction

The fission converter facility will be part of the MIT research reactor and therefore, the cost of fabrication will be capitalized. Thus, the equipment cost will be exempt from overhead. The equipment cost includes cost for components, reactor downtime, and MIT staff labor. Items subject to overhead are contractor's cost for the first $25,000 (Section 3), graduate student's cost, Prof. Harling's salary, engineer's salary, and furniture (if less than $500).

2 Cost of Components

2.1 Cost of Coolant Components

Item	Source	Cost	
1) Primary Coolant Pumps 2 pumps at $3000 each 2 check valves at $500 each	estimate from Gordon Kohse	7000	
2) Piping a. 1.5 inch ID sch 40 SS b. $12/ft for 100 ft	Metropolitan Piping	1200	The stainless steel will be used for the primary coolant system.
3) Fittings a. female elbows (14 at $166 each) b. female tee (10 at $226 each) c. female hex coupling (14 at $70 each)		5564	
4) Heat exchanger a. heat exchanger ($4270) b. filter ($3000)	Gustavo Preston	7270	
5) valves 1.5" ball valve (5 at $536 each)		2680	
6) Converter tank a. Al 6061 b. leak test Additions to the tank: i. air tight cover ii. pipe for the fluid level indicator iii. two pipes for the thermocouples iv. two pipes for the leak detector system and one opening for the moisture detector v. mounting area for float level detector vi. line for the helium cover gas system vii. fuel housing viii. lip to hold the converter tank	Ramsey Welding and Fabrication Inc.	55000	Current price is to build the converter tank to comply with ASME Code Section IX.. Need to work on which Section of the ASME Code the converter tank will comply with. The delivery time for the converter tank is between 12-15 weeks.

7) Fission Converter Top Lead 25.4 x 203.2 x 61 cm (11.36 g/cm^3) x (1 lb/2200 g) x ($0.88/lb) x 2 = 2861		2861	estimate (material cost x 2)
Total		**81575**	

2.2 Cost of Auxiliary Components

Item	Source	Cost	
1) Fuel transfer cask adapter concrete cylinder 5 ft diameter and height of 39 inch with a 7 inch center hole a. concrete cost ($1630) b. 4 m/d		2860	
2) Clean-up system a. Demineralizer housings (2 @ $155 each) b. Cartridges (4 @ $55 each) c. Filter housing ($150) d. Resistivity instruments ($444) i. cell ii. controller e. pump ($1000)		2124	
3) Surge tank a. volume 96 ft^3 = 715 gallons (U.S.) aluminum tank ($3690) b. sight gauge ($1000)	Ramsey Welding and Fabrication Inc.	4690	
4) Cover-gas cover system		2000	The cover gas system will consist of helium gas and gas holder. No blower or recombiner. Need overpressure blow off valve connected to the reactor's exhaust system.
5) Temporary shield a. 16930 lbs x $0.88/lb x 1.5 = $22348 b. $2000 for steel frame		24348	
6) Relocation of MITR-II make-up water system		500	$500 for equipment cost to move the MITR-II make up water system.
7) Pump for the secondary system		1500	
8) secondary piping and valves a. pipes $6/ft for 200 ft ($1200)		2238	Secondary coolant system will not use stainless steel. Therefore, the cost of

b. female elbow (8 at $66) c. female tee (4 at $$90) d. female hex coupling (5 at $$30)			copper piping will be 2.5 less expensive than stainless steel.
9) tools		10000	
Total		**50260**	

2.3 Instrumentation and Controls

ID	Process Variable	Display	Description	Cost	Time to Install Component (hours)
FT1	primary outlet temp (above hottest fuel element)	Display at the medical control panel and reactor control room. Alarm at the reactor control room and medical control panel. Fission converter automatic shutdown.	Thermocouple and mounting equipment ($200) The fission converter tank has to be designed to accommodate the thermocouple and the mounting equipment. signal converter ($300) display for the med control panel ($500) display for the reactor control room ($500)	1500	3
FT2	primary outlet temp (above hottest fuel element)	Display at the medical control panel and reactor control room. Alarm at the reactor control room and medical control panel. Fission converter automatic shutdown.	Thermocouple and mounting equipment ($200) The fission converter tank has to be designed to accommodate the thermocouple and the mounting equipment. signal converter ($300) display for the med control panel ($500) display for the reactor control room ($500)	1500	3
FT3	primary coolant temp after heat exchanger and before the ion column	Display at the medical control panel. Alarm at the medical control panel. General alarm at the reactor control room.	Need female tee (price included in Section 2) Thermocouple ($150) signal converter ($300) display for the med control panel ($500) General alarm in the reactor control room is a single alarm warning any of the multiple non-critical system malfunction. The cost for the general alarm is minimal and is not included in the cost analysis.	950	2

FT7	secondary outlet coolant temp.	local readout	dial thermometer ($150) need female tee (price included in Section 2)	150	1
FT8	secondary inlet coolant temp	local readout	dial thermometer ($150) need female tee (price included in Section 2)	150	1
FF1	primary outlet flow rate	Display at the medical control panel. General alarm at the reactor control room. Alarm at the medical control panel	Ultrasound flow meter and display. ($2500) Ultrasound is used because of the small diameter of the coolant pipes (1.5" ID).	2500	3
FF5	secondary coolant flow rate	local readout Display at the medical control panel. General alarm at the reactor control room. Alarm at the medical control panel	mechanical flow meter ($500) display and alarm ($500)	500	2
FL1	converter tank fluid level	Display at the medical control panel. Alarm at the reactor control room and medical control panel. Fission converter automatic shutdown.	The tube needed for this system will be part of the fission converter tank design. Sensor ($2000) display and alarm ($500) alarm at the reactor control panel ($50)	2550	5
FL6	converter tank fluid level (trip point)	Alarm at the reactor control room and medical control panel. Fission converter	Float level sensor ($200) The converter tank needs to be designed to have mounting area for the float level detector. Alarm at reactor control room ($50) alarm at the medical control panel ($50)	300	1

		automatic shutdown.			
FL8	converter tank level (over flow)	General alarm at the reactor control room. Alarm at the medical control panel	Float level sensor ($200) The converter tank needs to be designed to have mounting area for the float level detector. alarm at the medical control panel ($50)	250	1
FL2	inner converter tank leak detector	Alarm at the reactor control room and medical control panel	Two tubes for the helium (or CO_2) will be part of the fission converter tank design. Moisture sensor ($2000) The gas purge will be vented to the reactor exhaust system ($250 for hardware cost)	2250	5
FL3	storage tank level	local readout	Part of the storage tank design.		
FL4	gas holder level for helium cover system	local readout	The cover gas system will consist of helium cover gas and gas holder. No recombiner or blower.	500	5
FP1	primary system pressure (after heat exchanger)	local readout		200	2
FP2	primary system pressure (pump #1 outlet)	local readout		200	2
FP3	primary system pressure (pump #2 outlet)	local readout		200	2
FP4	secondary system pressure	local readout		200	2
FR1	neutron monitor A (not part of SAR or Tech Spec)	Display at the medical control panel.	BF_3 detector and mounting device ($5000)	5000	16
FR11	med room gamma monitor (need two)	local display and at the medical control room	Stand alone unit ($1500) Sensor with display at the reactor control room a) control room unit ($1450)	4370	16

			b) detector assembly ($945) c) remote display ($475)		
FC1 FC2	ion column inlet and outlet conductivity for the primary coolant system	Display at the medical control panel. General alarm at the reactor control room. Alarm at the medical control panel		2500	8
FC3 FC4	ion column inlet and outlet conductivity for the water shutter system	Display at the medical control panel. General alarm at the reactor control room. Alarm at the medical control panel		2500	8
FX1	Cd shutter position (fully open)	Display at the medical control panel	Part of Cd rail system. Limit switch ($100) Display at the medical control panel ($50)	150	3
FX4	Cd shutter position (fully closed)	Display at the medical control panel and reactor control room.	Part of Cd rail system. Limit switch ($100) Display at the medical control panel ($50) Display at the reactor control room ($50)	200	3
FX2	mechanical shutter position (fully open)	Display at the medical control panel	Part of the mechanical shutter design. Display at the medical control panel ($50)	50	2
FX5	mechanical shutter position (fully closed)	Display at the medical control panel and reactor control room.	Part of the mechanical shutter design. Display at the medical control panel ($50) Display at the reactor control room ($50)	100	2
FX3	water shutter	Display at the	Conductivity probe located at the outlet pipe of the water	700	3

	tank level (fully open)	medical control panel	shutter tank ($200) Display unit ($500)		
FX6	water shutter tank level (fully closed)	Display at the medical control panel and reactor control room.	Conductivity probe located at the air vent line of the water shutter ($200) Can use same display unit as above for the medical control panel. Display at the reactor control room ($50)	250	3
FX7 FX8	med room door position (open and close)	Display at the medical control panel and reactor control room. Interlock with shutters.	Display at the reactor control room (open) ($50) Display at the reactor control room (close) ($50) Display at the medical control panel (open) ($50) Display at the medical control panel (close) ($50) Interlock system ($25) Automatic stop mechanism in the event something or someone is interfering with door operations. ($250)	475	5
FZ1	Cd shutter control (change in speed with be done by changing the gearing)	Controls in the reactor control room (close only), med room (close only) and medical control panel.	Control at the reactor room (close only) ($50) Control at the medical room (close only) ($50) Control at the medical control panel (open) ($50) Control at the medical control panel (close) ($50)	200	5
FZ2 FZ5	water shutter control (for valves)	Controls in the med room (close only) and medical control panel.	Control at the medical room (close only) ($50) Control at the medical control panel (open) ($50) Control at the medical control panel (close) ($50)	150	5
FZ3	mechanical shutter control	Controls in the med room (close only) and medical control panel.	Control at the medical room (close only) ($50) Control at the medical control panel (open) ($50) Control at the medical control panel (close) ($50)	150	5
FZ4	med room door control		local control		
FZ9	reactor minor scram		Minor scram control at the medical control panel ($50)	50	2
FL9 to	leak tapes	General alarm at the reactor control	If the pumps, heat exchanger, etc. are placed on a skid, instead of using leak tapes on individual pipes, several conductivity	600	10

FL20		room. Alarm at the medical control panel	probes located on the tray can be used.		
	primary pump #1 control		Control switch at the medical control panel ($150) Controller ($500)	650	3
	primary pump #2 control		Control switch at the medical control panel ($150) Controller ($500)	650	3
	secondary pump control		Control switch at the medical control panel ($150) Controller ($500)	650	3
	valve controls		The valves for the coolant system will be controlled manually.		
	Hardware for reactor control room		Hardware cost to display instruments in reactor control room ($300) Time needed to machine control panel (20 hours)	300	20
	control panel hardware		Hardware cost for control panel ($1875) Time needed to machine control panel (20 hours)	1875	20
	TOTAL			**35470***	**185 hrs 23 days****

* This only represents the cost of instrument components and does not include installation. The total cost presented here does not include beam monitor components (Section 2.4).

** The time for installation of the instruments are only used as a guide to determine the construction time-line of the fission converter facility and is not used to calculate the labor cost. The labor cost will be determine by using the construction time-line as discussed in Section 7 of this report.

2.4 Beam Monitor Components

FR5	beam monitor fission counter A	Display at the medical control panel			
FR6	beam monitor fission counter B	Display at the medical control panel			
FR7	beam monitor fission counter C	Display at the medical control panel			
FR8	beam monitor ion chamber A	Display at the medical control panel			
FR9	beam monitor ion chamber B	Display at the medical control panel			
	computer, software, etc.				
	Total		**Estimated by Prof. Harling**	**56000**	

2.5 Cost of Beam Components

Item	Source	Cost	
1) Filter a. Al & AlF_3 mixture ($210000) based on $60/kg b. Al block then a separate AlF_3 block ($87500) i. Al1100 block 70x105x105cm ($14500) or ii. Al6061 block 70x105x105cm ($11310) iii. $AlFl_3$ block 20x107x107cm ($72000) c. Al block then a separate Al_2O_3 block ($176500) i. Al1100 block 70x105x105cm ($14500) or ii. Al6061 block 70x105x105cm ($11310) iii. Al_2O_3 block 30x107x107cm ($162000) d. bismuth (dimensions: 8x130x130 cm) ($14500) e. cadmium (dimensions: 0.05x130x130 cm) ($30)	VTT Industrial Al City Metal Industrial Al City Metal Coors Ceramic Co. Alfa Aesar	172530	Items a, b, and c are averaged to a price of $158000. Items d and e are added to this number to get the total.
2) Lead reflector 4 lead blocks with dimensions: 10x106x125cm (estimated weight 13264 lb x $0.88/lb x 1.5 = 17508)		17508	The lead reflector needs to be made in either one piece or with steel casing for strength.
3) Collimator a. lead (estimate. 9573 lb x $0.88/lb x 1.5 = 12636 + cost of aluminum tank ($5000)	Ramsey Welding and Fabrication Inc. (for the water tank)	17636	
4) Water shutter system a. plastic tanks (300 gal) (2 at $325 each) b. 1.5" ID copper piping (50 ft at $3/ft) c. fittings i. valves (2 at $300 each) ii. female elbows (8 at $35 each)) iii. pumps ($1000) d. clean up system ($300) e. air ventilation system i. ¼ inch piping ($200) ii. valves (2 at $50 each)		3280	Opening and closing time of 2 minutes by gravity. The volume of the water shutter is 0.3 m^3.
5) Mechanical Shutter, drive system, and controls		46500	

6) Cadmium Curtain a. cadmium curtain b. rails		10000	
7) Air table to move the filter and collimator units.		15000	$10000 for air table and $5000 for rental of air compressor.
Total		**282454**	

2.6 Cost of Medical Therapy Room Components

Item	Source	Cost	
1) Concrete blocks	Brooks Brothers	75000	
2) med room door	Atomic International	15000	
3) intercom, TV monitors		3000	
4) lighting		500	
5) ventilation system		1500	Inlet from the reactor floor. The outlet ventilation can be connected to the experimental exhaust system on the reactor top or to the equipment room where the outlet can be connected to the existing medical room's ventilation blower.
6) patient positioning device		5000	
Total		**100000**	

2.7 Cost of D_2O

D_2O a. volume of 508.2 gallons (converter tank) + 127 gallons (25% for surge tank) + 20 gallons (system volume) b. $400(Canadian)/L @ 99.78% purity with $1.38 trading	AECL	718658	Not part of the cost analysis. Will borrow D_2O from DOE.

2.8 Summary of Cost of Components

Section 2.1 Total Cost of Coolant Components	81575
Section 2.2 Total Cost of Auxiliary Components	50260
Section 2.3 Total Cost of Instrumentation and Controls	35470
Section 2.4 Total Cost of Beam Monitor Components	56000
Section 2.5 Total Cost of Beam Components	282454
Section 2.6 Total Cost of Medical Facility Components	100000
Total	**605759**

3 Cost of Contractors

Item	Source	Cost	
1) Engineering Drawings $45/hr + $20/hr for computer time a. fuel transfer adapter (5 hrs) b. converter tank (40 hrs) c. water shutter system (8 hrs) d. mechanical shutter (20 hrs) e. medical therapy room (20 hrs) f. system drawings (50 hrs) g. as built drawings (40 hrs) Engineering Review $120/hr a. fuel transfer adapter (1 hr) b. converter tank (16 hrs) c. water shutter system (4 hrs) d. mechanical shutter (8 hrs) e. medical therapy room (6 hrs) f. system drawings (40 hrs) g. as built drawings (10 hrs)	Stone & Webster	35131	Cost includes overhead (59%). ($22095x1.59)=35131
2) Crane Test	The Shaughnessy Companies	6360	Cost includes overhead. $4000 x 1.59 = 6360
3) Remove concrete blocks out of the reactor containment building	The Shaughnessy Company	15900	Cost includes overhead. $10000 x 1.59 = 15900
4) certified welder for Primary Coolant system ($500/day)		5565	5 days worth of welding to assemble the coolant system skid. 2 days to attach the primary system from the coolant system skid to the converter tank. Cost includes overhead.

			$3500 x 1.59 = 5565
5) Electrical contractor for power, circuit box, and conduit from reactor top to medical control panel and to the reactor control room.		48250	Contractor's cost is $33500. Cost includes overhead for the first $25000. ($25000 x 1.59) + $8500 = 48250
6) Contractor to drill holes in the reactor floor ($1000/hole) a. one hole for the water shutter b. one hole for the secondary coolant pipe c. two holes for the mechanical shutter hydraulic system		6360	Cost includes overhead. $4000 x 1.59 = 6360
7) Contractor to measure thermal column area before the converter tank is built.			
Total		**117566**	

4 Radiation Waste Disposal Cost

Item	**Cost**
1) Thermal Column Graphite disposal i. use two 90 ft^3 box ($300 each) ii. cost for disposal of the two boxes ($50000 based on $2000 for 55 gallon barrow)	50600
2) miscellaneous	25000
Total	**75600**

5 Regulatory Approval

Cost = $0

6 Pre-Construction Preparation

Item	Labor	Total Labor Time	Time Line	Reactor Shutdown	Comments
1) assemble filter component i. up to two aluminum (AlF_3, Al & AlF_3, or Al & Al_2O_3) blocks ii. titanium iii. bismuth iv. cadmium v. lead vi. lead reflector around filter	in house 2 men team (10 m/d)	10 m/d	5 days	no	The lead reflector needs to be made as one piece or have aluminum or steel casing. This will allow handling of the filter as one piece.
2) assemble collimator unit i. lead collimator ii. water shutter tank a. inlet pipe b. outlet pipe c. air vent line iii. supporting concrete a. need to make casing for concrete	in house 2 men team (30 m/d)	30 m/d	15 days	no	
3) assemble mechanical shutter unit i. lead shutter ii. end of the collimator iii. concrete support	in house 2 men (20 m/d)	20 m/d	10 days	no	
4) crane test	contractor			no	By The Shaughnessy Company for $4000.
5) remove material/equipment attached to BTF a. 2% UO_2 fuel bundle and barrels at 6CH1 and 2CH1 (5 m/d) b. Cooling water unit for ICE (3 m/d) c. Helium bottles for instruments (1 m/d) d. Pneumatic sampling system shielding (2 m/d)	in house 2 men team (51.5 m/d)	51.5 m/d	26 days	no	

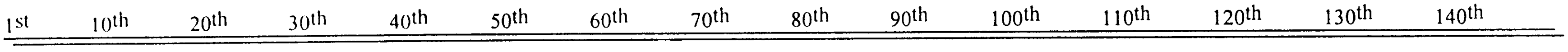
e. cut the belly bands (0.5 m/d) f. remove items on top right of BTF (3 m/d) g. remove reactor instrumentation on the top left of the BTF (10 m/d) h. auxiliary reactor drain sump (4 m/d) i. ventilation conduit (1 m/d) j. tool storage rack (4 m/d) k. decking (3 m/d) l. emergency cooling line on right (5 m/d) m. ICE instrument lines on right (10 m/d)					
6) relocate MITR-II make-up water tank (20 m/d)	in house 2 men team (20 m/d)	20 m/d	10 days	no	
7) assemble coolant system "tray" i. heat exchanger ii. clean up loop iii. pumps iv. make-up water tank v. instruments vi. controls vii. upper water tank for the water shutter viii. test for operation and leaks	in house 2 men team (30 m/d) plus Paul to install instruments (10 m/d)	40 m/d	15 days	no	One week for certified welder for the primary system. The cost for the welder is included in Section 3 of this report.
Total		**171.5 m/d**			**Total labor cost = $60025[*] (with overhead)** **Total labor cost = $37730 (without overhead)**

[*] Refer to Section 9 of this report for calculation of labor cost.

7 Construction Time-Line for Fission Converter Facility

green = reactor operating
black = reactor shutdown
▬ reactor shutdown

Team 1 = 1 RPO, 1 maintenance, 1 operations
Team 2 = 1 RPO, 1 maintenance, 1 operations
c = contractor



1) site preparation (day 1-2, 2d, RPO)
2) removal of aluminum gas box and cadmium curtain (day 3-9, 5d, Team 1)
3) secondary coolant system (day 3-8, 4d, Team 2)
4) water shutter system (only those components that will be located in the basement) (day 9-11, 3d, Team 2)
5) take measurements of the thermal column and order converter tank (day 10, 1d, c)
6) installation of temporary shielding (day 11-17, 5d, Team 1)
7) reinstall regulating rod mechanism (day 18, 1d, Team 1)
8) removal of existing facility (day 19-29, 7d, Team 1 and Team 2)
9) removal of material inside primary shielding (day 30-37, 6d, Team 1 and Team 2)
10) measure space where the filter and collimator will be located and make adjustments as needed (day 38-43, 4d, Team 1 and Team 2)
11) install filter (day 44-51, 6d, Team 1 and Team 2)
12) install collimator unit (day 52-53, 2d, Team 1 and Team 2)
13) gas seal (day 54-57, 2d, Team 1)
14) construct medical room (day 58-78, 15d, Team 1 and Team 2 + c)
15) install water shutter mechanism (day 79-85, 5d, Team 1 and Team 2)
16) install mechanical shutter (day 86-92, 5d, Team 1 and Team 2)
17) install coolant system skid (day 93-94, 2d, Team 1 and Team 2)
18) reactor control room (day 95-100, 4d, Paul + 1 man)
19) beam monitor (day 95-108, 10d, Guido)
20) remove temporary lead shield (day 95-100, 4d, Team 1)
21) medical control area (day 101-107, 5d, Paul + 1 man)
22) remove lead in the 14 inch window (day 101, 1d, Team 1)
23) install converter tank (day 102-116, 11d, Team 1)

Table 7.1 Construction Time-Line for the Fission Converter Facility

Item	Labor	Total in house Labor Time	Time-Line	Reactor Shutdown	Comments
1) site preparation a. Establish controlled material storage area (1 m/d) b. Establish work area boundaries (1 m/d)	in house 1 RPO (2 m/d)		2 days	no	
2) removal of aluminum gas box and cadmium curtain a. remove steel plates around regulating rod shim motor (0.25 m/d) b. remove regulating rod shim motor (0.25 m/d) c. remove loose shielding (0.25 m/d) d. remove concrete shielding blocks (0.25 m/d) e. remove the gas box and cadmium curtain (9 m/d) f. verify composition of blocks in the 14 inch window	in house 2 men (10 m/d) plus RPO (5 m/d)	10 m/d	5 days	yes	Need to work out how to test for the composition of the 14 inch window prior to start of construction. Also need to practice with mock ups.
3) Secondary coolant system i. pump ii. bring piping from basement to reactor top iii. drill hole in the reactor floor for secondary pipe	in house 3 men (12 m/d)	12 m/d	4 days	yes	Drilling a hole in the reactor floor will be done by a contractor. The cost for the contractor is included in Section 3 of this report.
4) Water shutter system (only for those components that will be located in the basement equipment room) i. install lower water tank in the basement equipment room.	in house 2 men (6 m/d)	6 m/d	3 days	yes	Drilling a hole in the reactor floor will be done by a contractor. The cost for the contractor is included in Section 3 of this report.

ii. install pump in the basement iii. install pipes iv. drill hole in the reactor floor					
5) take measurements of thermal column and order converter tank	contractor plus 2 men (2 m/d) plus RPO	2 m/d	1 days	yes	Delivery time is 12-15 weeks.
6) Installation of Temporary Shielding i. install cadmium curtain (4 m/d) ii. install temporary lead shield (5 m/d) a. need to hang the lead shield from one of the shielding blocks iii. replace concrete blocks (1 m/d)	in house 2 men (10 m/d) plus RPO (5 m/d)	10 m/d	5 days	yes	
7) reinstall regulating rod mechanism a. install steel plates around regulating rod shim motor b. install regulating rod shim motor c. install loose shielding d. install concrete shielding blocks	in house 2 men (2 m/d) plus RPO (1 m/d)	2 m/d	1 days	yes	
8) Removal of the existing facility a. remove top concrete blocks (2.24 m/d) i. remove center plug unit (A) (0.39 m/d) ii. remove concrete block B (0.37 m/d) iii. remove concrete blocks C1 and C2 (0.75 m/d) iv. remove concrete block D (0.37 m/d) v. remove concrete block E (0.37 m/d) b. remove Fast Spectrum Facility Access (1.5 m/d) i. remove concrete block F (0.38 m/d)	in house 4 men (28 m/d) plus RPO (7 m/d)	28 m/d	7 days	yes	See figure 7.1 for block location. Place the concrete blocks in the established control area. The blocks will be moved later to the back of NW13 by The Shaughnessy Company for $10000. Some of the blocks will be incorporated into the new medical therapy room's wall.

ii. remove concrete block G (0.37 m/d) iii. remove concrete block H1 and H2 (0.75 m/d) c. remove Holraum material (1.87 m/d) i. remove graphite lining I (0.5 m/d) ii. remove graphite lining J (0.62 m/d) iii. remove graphite lining K (0.75 m/d) d. removal of Holraum support and internals (2.25 m/d) i. remove steel door gearing mechanism (0.25 m/d) ii. remove concrete block L (0.39 m/d) iii. remove concrete block M (0.37 m/d) iv. remove concrete block N (0.37 m/d) v. remove graphite block O (0.5 m/d) vi. remove steel doors P (0.37 m/d) e. remove gun barrels (4 m/d)					
9) removal of material inside primary shield i. remove thermal column Q ii. remove lead shield R iii. remove graphite S iv. clean area	in house 4 men (24 m/d) plus 2 RPO (12 m/d)	24 m/d	6 days	yes	Need extra planning to achieve ALARA.
10) measure space where the filter and collimator will be located and make adjustments as needed	in house 4 men (16 m/d) plus 2 RPO (12 m/d)	16 m/d	4 days	yes	Think of ways to easily modify the filter and collimator dimensions after the measurements are made.
11) install filter a. install air table b. install filter	in house 4 men (24 m/d) plus 2 RPO	24 m/d	6 days	yes	Assuming air table will be used. Airfloat Platform a. platform dimensions 1m by 5 m b. smoothness 1/8 inch at 10 ft c. two blocks - 1 m^2 area, 10 ton each

	(12 m/d)				d. air flow rate 60-100 cfm (for concrete finish) e. price $10,000 for platform (does not include the 25 hp air compressor) Think of other ways of installing filter, i.e. assemble the filter piece at a time.
12) Install collimator unit	in house 4 men (8 m/d) plus 2 RPO (4 m/d)	8 m/d	2 days	yes	Think of other ways of installing collimator, i.e. assemble the filter piece at a time.
13) gas seal around the collimator unit	in house 2 men (4 m/d) plus RPO (1 m/d)	4 m/d	2 days	yes	
14) Construct Medical Room a. concrete blocks b. lighting c. ventilation system d. radiation monitor e. medical room door	in house 4 men (60 m/d) plus contractor	60 m/d	15 days	no	The old blocks from the existing facility will be incorporated into the new medical room shielding. Contractor to form and pour the concrete. The cost for the contractor is included in Section 2.6 of this report.
15) Install water shutter mechanism i. upper tank on top of medical room ii. pipes iii. valves iv. air ventilation system v. water filter vi. conductivity probes vii. controls	in house 4 men (20 m/d)	20 m/d	5 days	no	Water shutter - fully closed conductivity probe located at the air vent line of the water shutter and the fully open conductivity probe located at the outlet pipe of the water shutter tank.

16) Install mechanical shutter i. guide rails ii. hydraulics iii. controls iv. instruments	in house 4 men (20 m/d)	20 m/d	5 days	no	
17) Install coolant system skid	in house 4 men (8 m/d)	8 m/d	2 days	no	Assumption is that all components will be located on reactor top or on top of the new medical therapy room. The coolant system skid will be pre-made as discussed in Section 6.
18) Reactor control room	in house 1 man (4 m/d) plus Paul (4 m/d)	8 m/d	4 days	no	
19) Beam monitor	BNCT Group				
20) remove temporary lead shield a. remove steel plates around regulating rod shim motor b. remove regulating rod shim motor c. remove loose shielding d. remove concrete shielding blocks e. remove temporary lead shield	in house 2 men (8 m/d) plus RPO (4 m/d)	8 m/d	4 days	yes	
21) medical control area	in house 1 man (5 m/d) Paul (5 m/d)	10 m/d	5 days	no	
22) remove lead in the 14 inch window	in house 2 men (2 m/d)	2 m/d	1 day	yes	

	plus 2 RPO (2 m/d)				
23) Install converter tank and cadmium curtain i. install outer tank ii. install inner tank iii. establish air seal between inner and outer tank iv. install instruments v. connect coolant system vi. cover gas system with overpressure blow off valve vii. fill with water viii. fit cover ix. place shielding	in house 4 men (44 m/d)	44 m/d	11 days	yes	The cost of certified welder for the primary system is included in Section 3 of this report. The cadmium curtain rails will be part of the outer converter tank.
Total		**326 m/d*** **(total)** **126 m/d (when reactor is up)**		55 weekdays of reactor shutdown (from time line) 77 total days (includes weekends)	

* Does not include RPO labor.

Table 7.2 Calendar

M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49
50	51	52	53	54	55	56
57	58	59	60	61	62	63
64	65	66	67	68	69	70
71	72	73	74	75	76	77
78	79	80	81	82	83	84
85	86	87	88	89	90	91
92	93	94	95	96	97	98
99	100	101	102	103	104	105
106	107	108	109	110	111	112
113	114	115	116	117	118	119
120	121	122	123	124	125	126
127	128	129	130	131	132	133
134	135	136	137	138	139	140
141	142	143	144	145	146	147
148	149	150	151	152	153	154
155	156	157	158	159	160	161
162	163	164	165	166	167	168
169	170	171	172	173	174	175
176	177	178	179	180	181	182
183	184	185	186	187	188	189
190	191	192	193	194	195	196
197	198	199	200	201	202	203
204	205	206	207	208	209	210
211	212	213	214	215	216	217
218	219	220	221	222	223	224
225	226	227	228	229	230	231
232	233	234	235	236	237	238
239	240	241	242	243	244	245
246	247	248	249	250	251	252
253	254	255	256	257	258	259
260	261	262	263	264	265	266
267	268	269	270	271	272	273
274	275	276	277	278	279	280
281	282	283	284	285	286	287

8 Pre-Operational Testing

Item	Labor	Total Labor	Time Needed for Task	Reactor Shutdown
1) leak check with H_2O	in house 3 men (9 m/d)	9 m/d	3 days	no
2) fill with D_2O (need to dry out H_2O)	in house 2 men (4 m/d) plus RPO (2 m/d)	4 m/d	2 days	no
3) fueling	in house 6 men (30 m/d) plus 2 RPO (10 m/d)	30 m/d	5 days	yes
4) performance test of all systems i. instruments ii. controls iii. interlocks iv. safety systems v. etc.	in house 2 men (10 m/d)	10 m/d	5 days	no
5) calibration of cadmium curtain	in house 3 men (3 m/d)	3 m/d	1 day	at low power, but will be included in calculating reactor downtime
6) temperature distribution measurement at low power	in house 3 men (9 m/d) plus RPO	9 m/d	3 days	at low power, but will be included in calculating reactor downtime

	(3 m/d)			
7) step wise power escalation i. measure maximum coolant temperature ii. measure coolant temperature during loss of coolant flow iii. radiation survey	in house 3 men (9 m/d) plus 2 RPO (6 m/d)	9 m/d	3 days	at low power, but will be included in calculating reactor downtime
8) Beam calibration	BNCT group		4 weeks	
Total		**74 m/d*** **(total)** **23 m/d (when reactor is up)**		**12 weekdays of reactor downtime**

* Does not include RPO labor time.

9 Labor Cost

Table 9.1 Labor available for construction of the fission converter.

	Reactor up	**Reactor down**
Maintenance	1-2	2-3
Operations	2-3	6-8
Radiation Protection	1	2
Two Graduate students	1	1
engineer	1	1
Prof. Harling	0.35	0.35

Table 9.2 Labor Cost per Day

	Cost per Day including benefits and overhead ($/day)	**Cost per Day including benefits but no overhead ($/day)**
maintenance	390.62	245.67
operations	308.79	194.21
average cost	350.00	220.00

Table 9.3 In House Labor Cost for Construction of the Fission Converter Facility

Personnel	**Hours**	**Cost**
1) Prof. Harling (35% of his salary) + 1 full time engineer ($60000 salary)	2 years	480000 (includes benefits and overhead)
2) one Ph.D. level graduate student	2 years	80000 (includes benefits and overhead)
3) one Master's level graduate student	1 year	40000 (includes benefits and overhead)
4) secretary 50% of time for 2 years	2 years	100000 (includes benefits and overhead)
5) Section 6 Pre-Construction Preparation 171.5 m/d * $350/m/d = 60025 (with overhead) 171.5 m/d * $220/m/d = 37730 (without overhead)	171.5 m/d	37730
6) Section 7 Construction of Fission Converter 326 m/d (total) * $350/m/d = 114100 (with overhead) 326 m/d (total) * $220/m/d = 71720 (w/o overhead) 126 m/d (when reactor is up) * $350/m/d = 44100 (with overhead) 126 m/d (when reactor is up) * $220/m/d = 27720 (w/o overhead)	126 m/d	27720
7) Section 8 Pre-Operational Testing 74 m/d (total) * $350/m/d = 25900 (with overhead) 74 m/d (total) * $220/m/d = 16280 (w/o overhead) 23 m/d (when reactor is up) * $350/m/d = 8050 (with overhead) 23 m/d (when reactor is up) * $220/m/d = 5060 (w/o overhead)	23 m/d	8050
Total		**773500**

10 Cost of MIT Research Reactor Downtime

	number of days	**Cost ($6000/d)**
Section 7 Construction of Fission Converter	77	
Section 8 Pre-Operational Testing	12	
Total	**89 (includes weekends)**	
Capacity Factor Credit **In FY96, reactor operated 69.6% of total available time.** **Therefore, the reactor downtime cost is:** **89 days * $6000/day * 0.696 = 371664**		371664

11 Summary of the Cost Analysis Report

Section 2 Cost of Components	605759
Section 3 Cost of Contractors	117566
Section 4 Cost for Radiation Waste Disposal	75600
Section 5 Regulatory Approval Cost	0
Section 9 In House Labor Cost	773500
Section 10 Cost of MIT Reactor Downtime	371664
Total (for everything)	**1944089**
minus medical room cost (Section 2.6)	**-100000**
minus beam monitor (Section 2.4)	**-56000**
Total	**1788089**

APPENDIX 1

COMMUNICATIONS
and
PRICE QUOTES

COMPANIES

MIT fax # 617-253-7300

1. Stone & Webster: engineering expertise, architect review, Ron Boudreau @ 589-7762, fax # 589-1854.
2. Ramsey Welding and Fabricating: water box, surge tank, collimator(Al), hold tanks,Brent Marks @ 933-4900, fax # 933-5668
3. Nuclead: lead, Harold Feinberg @ 1-800-877-2244
4. LND: detectors, Bob Lehnert @ 516-678-6141
5. VTT Reactor Labs: aluminum flouride: Iiro Auterinen, Finland
6. Alcoa city metals: aluminum6061, Josua Deustch @ 1-800-461-6713
7. TGM: detectors, Dan Booten @ 201-887-8400 ex.252, fax # 201-887-4732
8. Canberra: signal processors, Reginald @ 1-800-243-4422 or 203-639-2346
9. Shaugnessy: riggers and crane load test, Mike Shaughnessy @ 268-3000
10. AECL: d2o, Tony Bennet @ 905-823-9040
11. Metropolitan pipe: piping, sch40
12. Cole Parmer: ion exchanger,
13. CPI: flowmeters, Joanne Angelone @ 401-722-5900
14. NPS: recombination system, Tom Starr @ 508-898-0365
15. Alfa Aesar: bismuth, cadmium, Paul Zubio @ 1-800-343-0660
16. Graziano: concrete(normal)
17. Gustavo Preston: heat exchanger, 508-663-5555

MIT IMPORTANT NUMBERS

1. BNCT office: 617-253-5720
2. Dr. Harling: 617-253-4201
3. Clare Egan: 617-253-3814
4. Henry Bonda: 617-253-4199
5. Ed Block: 617-253-4205 or 4211
6. Tom Newton: 617-253-4211
7. Fred Mcwilliams: 617-253-4203
8. Registrar: 617-253-2658
9. Jennifer Gwynn: 617-253-5042
10. Reactor Floor: 617-253-4221
11. Neil Todreas: 617-253-5296
12. Gordon Kohse: 617-253-4298, home: 617-332-4565
13. Paul Menadier: 617-258-5861
14. John Bernard: 617-253-4202
15. Suichi Sakamoto home: 617-536-9487

THE SHAUGHNESSY COMPANIES

348 D STREET
BOSTON, MA 02127
Tel 617-268-3000 Fax 617-268-1993

Proposal

Company:	MIT Nuclear Reactor	Date:	7/8/96
Address:	Albany Street	Job Name:	Conc Block Removal
City/State/Zip:	Cambridge, MA	Location:	NW-12
Attention:	Joe Burns/ Ed Block	Estimated Date:	- - - - - -
Telephone:	(617) 253-0897	Fax No.:	(617) 253-7000

We are pleased to submit our estimate for:

Furnish labor and equipment necessary to assist with the removal and temporary storage of misc concrete blocks (weight varies) as directed:

Estimated Cost	$10,000.00

Additionally, we propose to load test the overhead crane for 125% of its rated capacity as follows:

Lump Sum Price:	$4,000.00

We look forward to assisting on the job and working with you towards it successful completion. Should you have any questions or require additional information, please call me at anytime.

We propose to furnish labor, equipment and material in accordance with above, for the sum of:

See above (\$- - - - - - -)

Payment Terms: Net 30 days

Signature: Mike Shaughnessy

Note: *This proposal may be withdrawn if not accepted within 30 days. All work to be completed in a workmanlike manner according to standard practices. Any alteration or deviation from above will be executed upon written orders and will become an extra charge over and above the estimate. All agreements contingent upon strikes, accidents or delays beyond our control. Our workers are covered by Workmens' Compensation Insurance.*

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(Message /afs/athena.mit.edu/user/w/o/worms/Mail/inbox:186)
Received: from PACIFIC-CARRIER-ANNEX.MIT.EDU by po9.MIT.EDU (5.61/4.7) id AA08303;
Received: from cliff.swec.com by MIT.EDU with SMTP
        id AA06333; Wed, 3 Jul 96 10:48:39 EDT
Received: from bos10.swec.com (bos10.swec.com [199.103.193.67]) by cliff.swec.com
From: ronald.boudreau@swec.com
Received: by bos10.swec.com; Wed, 3 Jul 96 10:50:25 EDT
Date: Wed, 3 Jul 96 9:17:25 EDT
Message-Id: <vines.ffY7+jWcqlA@bos10.swec.com>
X-Priority: 3 (Normal)
To: <WORMS@MIT.EDU>
Subject: CONVERTER WATER BOX
```

THE FOLLOWING ASSUMPTIONS WERE MADE IN PREPARING THIS ESTIMATE.

1. DRAFTING OF THE SKETCH WILL BE DONE USING A 3D CADD SYSTEM
2. STONE & WEBSTER WILL DO A CRITIQUE OF THE DRAWING MAKING SURE THE PROPER INFORMATION IS SHOWN TO HAVE THE PIECE FABRICATED
3. STONE & WEBSTER WILL NOT BE RESPONSIBLE FOR THE TECHNICAL ACCURACY OF THE INFORMATION USED IN DEVELOPING THE SKETCH

FISSION CONVERTER WATER BOX:

A. 8 TO 10 HOURS OF DRAFTING TIME DEPENDING ON THE ANOUNT OF DETAIL THAT NEEDS TO BE SHOWN.
DRAFTING TIME IS $45/hr COMPUTER TIME IS $20/hr NORMALLY
COMPUTER HOURS AND DRAFTING HOURS = 1:1

B. CRITIQUE OF DRAWINGS AND PRESENTATION TO THE AUTHOR OF THE RESULTS OF THE CRITIQUE.
8 TO 10HRS @ $120/hr
CRITIQUE AND PRESENTATION TIME MAY BE ABLE TO BE DECREASED WE PRESENTLY HAVE TWO PEOPLE WORKING IN YOUR FUSION LAB THAT COULD POSSIBLY BE AVAILABLE TO DO THE CRITIQUE IF THEY ARE NOT AVAILABLE I HAVE GIVEN YOU THE WORST SCENARIO.
PLEASE GIVE ME A CALL IF YOU IF YOU HAVE ANY QUESTIONS OR IF CAN PROVIDE FURTHER ASSISTANCE.

BEST REGARDS,
RON BOUDREAU
589-7762
FAX 589-1854

TGM DETECTORS, Inc.

5 Eastmans Road, Parsippany, NJ 07054
Tel: (201) 887-7100 Fax: (201) 887-4732

Facsimile Transmittal Sheet

Number of pages including cover sheet: 1

DATE:	7/10/96		
FROM:	Daniel E. Booton Director, Sales & Marketing	PHONE: FAX:	1 201/887-7100 x 252 1 201/887-4732
TO:	Joe Burns MIT Nuclear Reactor Laboratory 138 Albany Street Cambridge, MA 02139-4296	PHONE: FAX:	1 617-253-0879 1 617-253-7300

Classification: Routine

Reference: Our phone conversation earlier today

MESSAGE:

Thank you for your inquiry today. The following is our quotation (price & delivery) for our FC4A/100 U235 Fission Chamber:

PART NUMBER	QTY	PRICE (ea.)	DELIVERY
FC4A/100	4	S 3575.00	14 - 16 Wks ARO

If you have any questions concerning this quote or the Fission Chamber, please do not hesitate to contact me at your earliest convenience.

Best regards,

Dan Booton

(Computer transmission, no signature)

CITY METALS

TEL: (718) 726-2496 – (800) 461-6713
FAX: (718) 726-2499 – (800) 461-6925

JUNE 20, 1996

MIT - FAX: 16172537300

ATTN: JOE BURNS

WE ARE PLEASED TO OFFER THE FOLLOWING QUOTATION:

ALUMINIUM TYPE 6061-F
PER QQ-A-367 & MIL-STD-2154 CL B

? 2 PCS. 70 +/- 1cm X 105 +/- 1cm X 105 +/- 1cm
97.9 Al, .6 Si, 28 Cu, 1.0 Magnesium, .2 Cr

@S14,533.00 PER/PC.

DELIVERY: 12 WEEKS

FOB LA, CA.

THANK YOU

JOSHUA DEUTSCH

[illegible] STREET, ASTORIA, NEW YORK [illegible]-4675

Gustavo Preston Company
Engineered Fluid Handling
Since 1881

555 Boston Road Suite 1A
Billerica, MA 01821
(508) 553-5555
Fax: (508) 553-3153
New Hampshire - (603) 355-5

QUOTATION

Attention: LING WEN HU
MIT NUCLEAR
617 · 258 5860
253 · 7300

Number 96-9166-MMP REV.1
Date 7/22/96
Reference:
* PLEASE REFER TO OUR QUOTE # WHEN ORDERING

ITEM NO.	QTY.	MODEL NUMBER	DESCRIPTION	UNIT NET PRICE	TOTAL PRICE

I finally got a response from Sweden on budgetary N-stamp costs for the semi-welded M6-MWFG for MIT. I also got it for a fully gaskated M6-MFG.

M6-MWFG: Equipment Costs - $7250
Documentation and testing for ASME Section 3 - $87,600 —
N-stamp - $18,000 —

M6-MFG: Equipment Costs - $4470
Documentation and testing for ASME Section 3 - $65,325
N-stamp - $18,000

The equipment costs include seismic feet and nuclear qualified materials. Documentation and testing includes complete tracing of the materials to the source, increased QA requirements, renewal of the Alfa Laval Thermal N-stamp, and several types of leak and weld testing. The N-stamp cost is to have a nuclear qualified inspector witness the hydrotest.

Please call me with any questions.

Regards,

Maureen

Edwin,

This is the information on the heat exchanger from LING WEN. She said that you should look at equipment costs only (others are for extra). 7/22 Shinichi

TERMS ____________

F O B ____________

SHIP VIA ____________

BY: Maureen [illegible]

To: JOE BURNS MIT

NUCLEAR REACTOR LABORATORY
AN INTERDEPARTMENTAL CENTER OF
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

O. K. HARLING
Director

138 Albany Street, Cambridge, Mass. 02139-4295
Telefax No. (617) 253-7300
Telex No. 92-1473-MIT-CAM
Tel. No. (617) 253-4220

J. A. BERNARD, JR.
Director of Reactor Operations

FAX COVER SHEET

BRENT MARKS
Name Title

From: RAMSEY WELDING and FABRICATING
Company

City State or Country

FAX NUMBER TO WHICH SENT: 933 5668

JOE BURNS

To:

ACCOUNT NUMBER: ______

DATE: 06 24 96
Month Day Year

SUBJECT: Cost Estimate for
- Collimator Unit EST $22,700.00 1pc Aluminum
- Surge Tank EST. $3690.00 1pc
- 2 Al Storage Tanks EST. $4768.00 EA

6-25-96

NUMBER OF PAGES, INCLUDING COVER SHEET 3

MITNRL FAX NO. (617) 253-7300

MITNRL TELEX NO. 92-1473-MIT-CAM

LND, INC.
3230 LAWSON BLVD., OCEANSIDE, NEW YORK 11572
516-678-6141 • FAX 516-678-6704

DESIGNERS & MANUFACTURERS OF NUCLEAR RADIATION DETECTORS

Facsimile Title Page • Fax # 5667

TO:	MIT	REF:	TELECON RE LND 732
ATT:	JOE BURNS	DATE:	JULY 2, 1996
FROM:	ROBERT W. LEHNERT	# OF PAGES SENT INCLUDING TITLE PAGE:	2

Dear Joe:

1) Per our telecon we can supply an *LND* 732 5 days after receipt of order at a unit price of $455.00 each.

2) Your requirement for an in line gamma detector may be filled by the 49529 series Flow Thru Gas Sampling Detectors. These units can be made available 60/90 days after receipt of order at a unit price of $930.00 each.

If we can be of any further service please do not hesitate calling upon us.

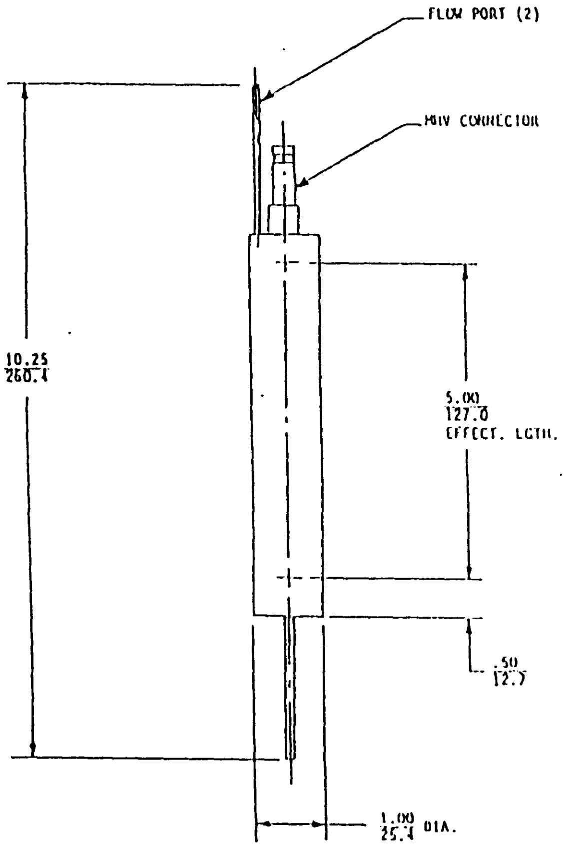
Sincerely,
Robert W. Lehnert

49529 FLOW THRU GAS SAMPLING PROPORTIONAL COUNTER

The LND 49529/49516 Series are Flow Thru Gas Sampling Proportional Counters with active volumes of 50 and 100 ml which have been specifically designed to measure low levels of activity. Those units are constructed entirely of OFHC Copper and specially designed Al_2O_3 insulators.

	DETECTOR TYPES	
GENERAL SPECIFICATIONS	**49529**	**49516**
Cathode Material:	OFHC Cu	OFHC Cu
Maximum Diameter: (Inche/mm)	1.0/25.4	1.0/25.4
Maximum Length: (inches/mm)	10.25/260.4	14/355.6
Active Volume: (ml)	50	100
Operating Temperature Range: (0C)	-50 to +150	-50 to +150
Connector:	MHV	MHV
ELECTRICAL SPECIFICATIONS		
Minimum Plateau Length: (volts)	300	300
Maximum Plateau Slope: (%/100 volts)	2	2

49529 FLOW THRU GAS SAMPLING PROPORTIONAL COUNTER



From: Alfa Aesar at 5085216358 06-27-96 03:59 pm 001 of 001

Alfa ÆSAR
A Johnson Matthey Company

Date: 06/27/96
Time: 15:56:43

FACSIMILE TRANSMISSION

To: Mr Joe Burns
MIT

617-2537300 USA

From: Paul Zubiel
Alfa Aesar
A Johnson Matthey Company
30 Bond St.
Ward Hill, MA 01835-8099
Fax#: 508-521-6366

Number of Pages
Including Cover Sheet: 01

If you have a problem with this transmission, please call:
508-521-6324

Sir,

I cannot offer you a formal quote at this time..but I have discussed if with the production people. They feel that the plate can be done you are looking at around 2900 lbs of Bismuth and 440 Lbs of Cadmium

Estimated cost $14,500 and $3300

We would be pleased to provide you with a formal quote if you so require.

Regards

THE FOXBORO COMPANY

QUOTATION NO.: 01699

Please refer to this number
when ordering.

QUOTATION

DATE: 06/27/96

PLEASE SEND YOUR
PURCHASE ORDER TO:

THE FOXBORO COMPANY
C/O CPI CONTROLS, INC.
29 MENDON AVENUE
PAWTUCKET, RI 02861

TO: M.I.T.

ATTN: JOE BURNS
617-253-4220 FAX: 7300

YOUR
INQUIRY:

Orders placed on or before the
expiration date shown will
be billed at prices quoted.

F.O.B. FOXBORO MA.

TERMS: Full payment 30 days
from date of invoices.

ESTIMATED SHIPMENT:
6-7 WEEKS ARO

THIS QUOTATION EXPIRES: 07/27/96

THE FOXBORO COMPANY

Joanne Angelone

JOANNE ANGELONE for:

NEIL CASSIDY

This Quotation is subject to the conditions printed on the attached form 2547

```
QUOTATION FROM THE FOXBORO COMPANY                       PAGE       1
QUOTATION NO.:  01699                                    DATE:    06/27/96
SO ORD NO:
CUSTOMER:     M.I.T.
REFERENCE:                                    PRICES IN U.S. DOLLARS
---------------------------------------------------------------------------


  ITEM      QUAN
    1          1    FOXBORO VORTEX FLOWMETER

                     BASE MODEL:       83W-A02S1SSTNF
                     PRODUCT SPECIFICATION SHEET: PSS 1-8A1 D,E

                     FUNCTION:
                      Measures Liquid, Gas Or Steam Flows By
                      Monitoring The Action Of Vortices Formed
                      In The Fluid Flow Through The Meter:
                      Wafer Style Construction ..................  83W
                     ELECTRONIC TYPE:
                      Analog/Pulse Electronics ..................    A
                     NOMINAL METER SIZE, BODY AND SHEDDER MATERIAL:
                      2-Inch (50 mm): ASTM A351-CF-8M
                      (316 ss) Cast Body And Shedder ............  02S
                     MOUNTING AND CENTERING SYSTEM:
                      ANSI Class 150 (No Hardware Required) ......    1
                     ISOLATION VALVES:
                      None ......................................    S
                     SENSOR:
                      Silicone Fill 0 To 400 Degrees F
                      (-20 To 200 C) Stainless Steel ............    S
                     MOUNTING FOR ELECTRONIC HOUSING:
                      Integral Top Mounted ......................    T
                     DISPLAY/OUTPUT INDICATOR:
                      None ......................................    N
                     ELECTRICAL CERTIFICATION:
                      FM Intrinsically Safe For Class I, II,
                      And III, Division 1, ia, ia Connection .....   F
                     ENCLOSURE CLASSIFICATION:
                      Meets The Requirements Of IEC IP66 And Provides
                      The Environmental Protection Of NEMA Type 4X.

   PRICE EACH:                     1,341.00   TOTAL:            1,341.00

   - CUSTOMER TAG:          ADVISE
     CUSTOMER ITEM:         ADVISE
     CALIBRATION INFO REQ   ADVISE
     K Factor Only EngrY/N  ADVISE
     K Factor Only MetY/N   ADVISE
      CALIBRATION TO CUST   ADVISE
       DATA MUST SPECIFY:   ADVISE
     FLOW RANGE:            ADVISE
     PROCESS FLUID:         ADVISE
     FLOW DENSITY:          ADVISE
     FLOW PRESSURE:         ADVISE
     FLOW TEMPERATURE:      ADVISE

                           CONTINUED ON NEXT PAGE
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QUOTATION FROM THE FOXBORO COMPANY                       PAGE      2
QUOTATION NO.:  01699                                    DATE:    06/27/96
BO ORD NO:
CUSTOMER:    M.I.T.
REFERENCE:                                PRICES IN U.S. DOLLARS
--------------------------------------------------------------------------

  ITEM       QUAN
    1          1   CONTINUED

        VISCOSITY:             ADVISE
        MAX FLOW AT 20 mA:     ADVISE
        MIN FLOW AT 4 mA:      ADVISE



                                       GRAND TOTAL NET:          1,341.00
```

Foxboro Vortex Meter Sizing

```
          Foxboro Vortex Flowmeter Sizing Program Version 2.1
eport Date     : Thu Jun 27 09:01:20 1996
ustomer Name   :
rder Number    :
ocation        :

ag Info        :
rocess Fluid   : Water
low Rate       :     200.0 GPM
ressure        :       5.0 PSI(G)
emperature     :      90.0 degrees C.
ensity         :    60.267 Lb/CuFt
iscosity       :     0.311 centipoise

eter Type      : Standard
ensor Type     : Standard Range
                                 1.5 in       2 in        3 in        4 in       6 in
                                   NO          YES         YES         YES        NO
                               ---------- ---------- ---------- ---------- ----------
    Flow (URL)          GPM       142.2#      237.2       520.6       916.6     2102.9
  ign URV               GPM       200.0       200.0       200.0       200.0      200.0
    Linear              GPM         4.6         5.9         8.8        12.1       35.2
   Flow Cutoff          GPM         1.8         3.0         6.5        12.1       35.2
in Analog URV           GPM         9.8        21.4        69.4       162.0      563.9#

Rangeability
  Maximum                                      80.0        80.0        75.6
  From URV                                     67.5        30.7        16.5
  Maximum Linear                               40.0        59.2        75.6
  Linear fr. URV                               33.7        22.8        16.5

At URV.
  Pressure Drop         PSI                    5.69        1.18        0.38
  Power Loss          kWatts                  0.495       0.103       0.033
  Reynolds Num.                1306300      1011600      682700      514600     339700

Fluid Velocity
 at URL               feet/s       25.8        25.8        25.8        25.8       25.8
 at URV               feet/s       36.2        21.7         9.9         5.6        2.5
 at Min Linear        feet/s        0.8         0.6         0.4         0.3        0.4
 at Minimum Flow      feet/s        0.3         0.3         0.3         0.3        0.4

Nom Freq at URV         Hz                   116.61       35.88       15.38

               Full scale Freq = Ref factor (pulses/ft^3) * 0.444
               Flow K-factor   = Ref factor * 0.133    pulses/Gallon
               (Multiply Ref Fac in Pulses/Gal by 7.4805 to get Pulses/ft^3.)
               Both multiplying factors are for flowing conditions
               and include corrections for temperature and density.

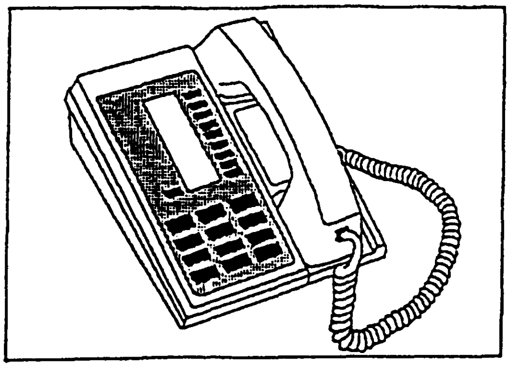
               Measurement which makes meter unusable is marked by '#'.
```

QUOTATION FROM THE FOXBORO COMPANY PAGE 1
QUOTATION NO.: 01699 BO ORD NO:
CUSTOMER: M.I.T. DATE: 06/27/95
REFERENCE: PRICES IN U.S. DOLLARS

Q U O T E S U M M A R Y P A G E

ITEM	QUAN	DESCRIPTION	TOTAL NET
1	1	Vortex Flowmeter 83W-A02S1SS1NF	1341.00

GRAND TOTAL NET: 1,341.00



BROOKHAVEN NATIONAL LABORATORY

REACTOR DIVISION

FACSIMILE TRANSMISSION

DATE: 10/29/96

TO: PROF. OTTO HARLING

FAX NUMBER: 617-253-7300

COMPANY: MIT

FROM: DAVE RORER

FAX NUMBER: (516)344-2560

Number of Pages (including this cover sheet):

COMMENTS:

OTTO: THIS IS SOME INFORMATION WE RECEIVED FROM COORS ON ALUMINUM OXIDE TILES LAST YEAR

Dave

If you have any problems reading this fax please call (516)344-4070.

CERASURF

FAX TRANSMISSION

TO FAX: 516 282 2560 SENT: 6/9/95
COMPANY: Brookhaven National Laboratory
4 PAGES
ATTN: Frank Patti
FROM: MITCH CLARK
PHONE: (303)-277-4040 FAX: 303-277-4596

IF TRANSMISSION IS NOT CLEAR, PLEASE CALL ABOVE NUMBER

SUBJECT: Your fax of May 24

We are pleased to quote per spec 800-900-001 for Coors AD-95 and Ad-995 tiles per your request. Price per tile is listed on attached copy of your size chart along with applicable tooling charges.

Thank you for the opportunity to quote.

Best Regards,

Mitch Clark
Mitch Clark

Coors
Coors Ceramics Company
Structural Products Group • 600 9th Street • Golden, CO 80401 • (303) 278-4000 • FAX (303) 277-4596

NUMBER OF TILES

9 x 9 Tiles

	LEVEL	9 x 9	9 x 6	9 x 3	9 x 2	9 x 1-1/2	OTHER	AD-96	AD-995
	1	4			4	4	1 - 3-1/2 x 3-1/2		
	2	4		4		4	1 - 4-1/2 x 4-1/2		
	3	4			8	4	1 - 5-1/2 x 5-1/2		
	4	4		4	4	4	1 - 6-1/2 x 6-1/2		
	5	4	4			4	1 - 7-1/2 x 7-1/2		
	6	4	4		2		1 - 8 x 8		
	7	9							
	8	9				6	1 - 1-1/2 x 1-1/2		
	9	9			6		1 - 2 x 2		
	10	9			6	6	1 - 3-1/2 x 3-1/2		
	11	9		6		6	1 - 4-1/2 x 4-1/2		
	Total	69	8	14	30	38	1 - 1-1/2 x 1-1/2 1 - 2 x 2 2 - 3-1/2 x 3-1/2 2 - 4-1/2 x 4-1/2 1 - 5-1/2 x 5-1/2 1 - 6-1/2 x 6-1/2 1 - 7-1/2 x 7-1/2 1 - 8 x 8	$ 194.40 " " " " " " "	$ 213.84 ea " " " " " " "
Price Each	AD-96	$68.31	$ 62.50	$ 53.10	$ 53.10	$ 35.53			
Price Each	AD-995	$ 78.14	$ 72.43	$ 61.38	$ 61.38	$ 39.90			

NOTE : 9 X 9 SIZE REQUIRES A ONE TIME TOOL CHARGE OF $16,325.00

NUMBER OF TILES

6 x 6 Tiles

	LEVEL	6 x 6	6 x 3	6 x 2	6 x 1-1/2	OTHER		
	1	9		6	6	1 - 3-1/2 x 3-1/2		
	2	9	6		6	1 - 4-1/2 x 4-1/2		
	3	9		12	6	1 - 5-1/2 x 5-1/2		
	4	9	6	6	6	1 - 6-1/2 x 6-1/2		
	5	16			8	1 - 1-1/2 x 1-1/2		
	6	16		8		1 - 2 x 2		
	7	16		8	8	1 - 3-1/2 x 3-1/2		
	8	16	8		8	1 - 4-1/2 x 4-1/2		
	9	16		16	8	1 - 5-1/2 x 5-1/2		
	10	25						
	11	25			10	1 - 1-1/2 x 1-1/2	AD-96	AD-995
	Total	166	20	56	66	2 - 1-1/2 x 1-1/2	$ 194.40	$ 213.84 each
Price each	AD-96	$ 29.70	$25.00	$ 23.60	$ 16.15	1 - 2 x 2	"	"
						2 - 3-1/2 x 3-1/2	"	"
Price each	AD-995	$ 32.67	$ 28.75	$ 27.14	$ 18.49	2 - 4-1/2 x 4-1/2	"	"
						2 - 5-1/2 x 5-1/2	"	"
						1 - 6-1/2 x 6-1/2	"	"

166 × $32.67 = $5423.22
20 × 28.75 = 575.00
56 × 27.14 = 1519.84
66 × 18.49 = 1220.34
10 × 213.84 = 2138.40
$10,876.80

$10,876.80 for AD 995
[illegible]
[illegible]

VTT CHEMICAL TECHNOLOGY

TELEFAX

Attention:	Joe Burns Nuclear Reactor laboratory MIT
Number:	990 1 617 253 7300

From:	Iiro Auterinen
Date:	30.8.1996
Number of page (incl. this page):	1

Message:

Dear Dr. Burns

Referring to your fax of 20.08.1996.

For your budget you can use following figures:

1) 51 x 105 x 105 cm in 4 blocks
   and
   4 layers of 4.25 x 107 x 107 cm in 8 blocks

material	US$ 180 000
cutting to dimensions	US$ 30 000

2) 20 x 107 x 107 cm in 3 blocks

material	US$ 60 000
cutting to dimensions	US$ 12 000

This is only a cost estimate for budgetary purposes and does not form any kind of binding offer from VTT.

The material (trade name FLUENTAL) is manufactured and sold by VTT only for experimantal purposes, not to be used for any kind of human irradiations. Use for human irradiations will require a licence from the patent holder, Radtek Inc.

Could you specify the purpose and possible standards for the material property data you have requested: mechanical strength, conductivity and heat transfer coefficients

Sincerely

VTT CHEMICAL TECHNOLOGY
Iiro Auterinen
Senior Research Scientist

Physics Bldg. Otakaari 3 A, Espoo
P.O.Box 1404
FIN-02044 VTT, Finland

Tel. +358 0 4566353
Fax +358 0 456 6390
e-mail: Iiro.Auterinen@vtt.fi

AUG 30 '96 10:42 358 0 4565330 PAGE.001

MATERIAL PROPERTIES
STANDARD 990

PROPERTIES*		UNITS	TEST	AD-85 Nom. 85% Al_2O_3	AD-90 Nom. 90% Al_2O_3	AD-94 Nom. 94% Al_2O_3	AD-96 Nom. 96% Al_2O_3	AD-99.5 Nom. 99.5% Al_2O_3	AD-99.9% Nom. 99.9% Al_2O_3	ALUMIN NITRIC
				ALUMINA						
DENSITY		g/cc (#/cu. in.)	ASTM C20-83	3.41 (0.12)	3.60 (0.13)	3.70 (0.13)	3.72 (0.13)	3.89 (0.14)	3.96 (0.14)	3.25 (0.1
SURFACE FINISH	AS-FIRED GROUND POLISHED	MICROMETRES (MICROINCHES) CLA	PROFILOMETER (0.75mm cutoff)	1.6 (63) 1.0 (39) 0.2 (8.0)	1.6 (63) 0.5 (20) 0.1 (3.9)	1.6 (63) 1.3 (51) 0.3 (12)	1.6 (63) 1.3 (51) 0.3 (12)	0.9 (35) 0.5 (20) 0.1 (3.9)	0.5 (20) 0.9 (35) <0.03 (<1)	<0.6 (<2 — —
CRYSTAL SIZE	RANGE AVERAGE	MICROMETRES (MICROINCHES)	THIN SECTION	2-12 (79-473) 6 (236)	2-10 (79-394) 4 (158)	2-25 (79-985) 12 (473)	2-20 (79-788) 11 (433)	5-50 (197-1970) 17 (670)	1-6 (39-236) 3 (118)	— —
WATER ABSORPTION		%	ASTM C373-72	0	0	0	0	0	0	0
GAS PERM.		—	**	0	0	0	0	0	0	0
COLOR		—	—	WHITE	WHITE	WHITE	WHITE	IVORY	IVORY	GRAY
FLEXURAL STRENGTH (MOR)	20°C	MPa (psi × 10³)	ASTM F417-78	296 (43)	338 (49)	352 (51)	358 (52)	379 (55)	552 (80)	300 (43)
ELASTIC MODULUS SHEAR MODULUS BULK MODULUS TRANS. SONIC VEL. POISSON'S RATIO	20°C	GPa (psi × 10⁶) GPa (psi × 10⁶) GPa (psi × 10⁶) m/sec. (ft/sec) —	ASTM C848-78	221 (32) 90 (13) 138 (20) 8.2 (27) × 10³ 0.22	276 (40) 113 (16) 158 (23) 8.8 (29) × 10³ 0.22	303 (44) 124 (18) 165 (24) 8.9 (29) × 10³ 0.21	303 (44) 124 (18) 172 (25) 9.1 (30) × 10³ 0.21	372 (54) 152 (22) 228 (33) 9.8 (32) × 10³ 0.22	386 (56) 156 (23) 228 (33) 9.9 (32) × 10³ 0.22	300 (43) — — — —
STIFFNESS/WEIGHT	20°C	GPa/g/cc	—	65	77	80	81	96	97	92
COMPRESSIVE STRENGTH	20°C	MPa (kpsi)	ASTM C773-82	1930 (280)	2482 (360)	2103 (305)	2068 (300)	2620 (380)	3792 (550)	—
HARDNESS		GPa (kg/mm²)	KNOOP 1000g ROCKWELL 45N	9.4 (960) 73	10.4 (1058) 79	11.5 (1175) 78	10.7 (1088) 78	14.1 (1440) 83	15.2 (1551) 90	— —
TENSILE STRENGTH	25° 1000°C	MPa (kpsi)	ACMA TEST #4	155 (22) — (—)	221 (32) 103 (15)	193 (28) 103 (15)	193 (28) 96 (14)	262 (38) — (—)	310 (45) 221 (32)	— —
FRACTURE TOUGHNESS	K_{IC}	MPa·m½	NOTCHED BEAM TEST	3-4	3-4	4-5	4-5	4-5	4-5	—
THERMAL CONDUCTIVITY	20°C	W/m·K (Btu·in/ft²·h·°F)	ASTM C408-82	16.0 (111)	16.7 (116)	22.4 (155)	24.7 (172)	35.6 (247)	38.9 (270)	115 (798)
COEFFICIENT OF THERMAL EXPANSION	25-1000°C	10⁻⁶/°C (10⁻⁶/°F)	ASTM C372-81	7.2 (4.0)	8.1 (4.5)	8.2 (4.6)	8.2 (4.6)	8.2 (4.6)	8.4 (4.7)	5.7 (3.2)
SPECIFIC HEAT	100°C	J/kg·°K (cal/g·°C)	ASTM C351-82	920 (0.22)	920 (0.22)	880 (0.21)	880 (0.21)	880 (0.21)	880 (0.21)	—
THERMAL SHOCK RESISTANCE	ΔTc	°C (°F)	NOTE 3	300 (570)	250 (480)	250 (480)	250 (480)	200 (392)	200 (392)	—
MAXIMUM USE TEMPERATURE		°C (°F)	No-load conds.	1400 (2552)	1500 (2732)	1700 (3092)	1700 (3092)	1750 (3182)	1900 (3452)	—
DIELECTRIC STRENGTH	6.35mm 3.18mm 1.27mm SPEC 0.64mm THICK 0.25mm	ac-kV/mm (ac-volts/mil)	ASTM-D116-76	9.4 (240) 13.4 (340) 17.3 (440) 21.6 (550) 28.3 (720)	9.2 (235) 12.6 (320) 17.7 (450) 22.8 (580) 29.9 (760)	8.7 (220) 11.8 (300) 16.7 (425) 21.6 (550) 28.3 (720)	8.3 (210) 10.8 (275) 14.6 (370) 17.7 (450) 22.8 (580)	8.7 (220) 11.4 (290) 16.9 (430) 22.8 (580) 33.1 (840)	9.4 (240) 12.8 (325) 18.1 (460) 23.2 (590) 31.5 (800)	— — — 26.5 (673) —
DIELECTRIC CONSTANT	1 kHz 1 MHz 1 GHz	25°C	ASTM D150-81 ASTM D2520-81	8.2 8.2 8.2	8.8 8.8 8.8	9.1 9.1 9.1	9.0 9.0 9.0	9.8 9.7 9.7	9.9 9.8 —	— 8.0-9.0 —
DISSIPATION FACTOR	1 kHz 1 MHz 1 GHz	25°C	ASTM D150-81 ASTM D2520-81	0.0014 0.0009 0.0014	0.0006 0.0004 0.0007	0.0007 0.0004 0.0010	0.0011 0.0001 0.0002	0.0002 0.0003 0.0002	0.0020 0.0002 —	— 0.0001 —
LOSS INDEX	1 kHz 1 MHz 1 GHz	25°C	ASTM D150-81 ASTM D2520-81	0.011 0.007 0.010	0.005 0.004 0.005	0.007 0.004 0.009	0.010 0.001 0.002	0.002 0.001 0.002	0.020 0.002 —	— 0.001 —
VOLUME RESISTIVITY	25°C 300°C 500°C 700°C 1000°C	ohm-cm/cm	ASTM D1829-66	>10¹⁴ 4.6 × 10¹⁰ 4.0 × 10⁸ 7.0 × 10⁶ —	>10¹⁴ 1.4 × 10¹¹ 2.8 × 10⁹ 7.0 × 10⁶ 8.6 × 10⁵	>10¹⁴ 1.2 × 10¹¹ 4.8 × 10⁸ 2.1 × 10⁷ 5.0 × 10⁵	>10¹⁴ 3.1 × 10¹¹ 4.0 × 10⁹ 1.0 × 10⁶ 1.0 × 10⁶	>10¹⁴ 1.6 × 10¹³ 2.1 × 10¹⁰ 4.4 × 10⁸ —	>10¹⁴ >10¹⁴ 3.3 × 10¹² 9.0 × 10⁹ 1.1 × 10⁷	>10¹⁴ 7.9 × 10¹⁰ — 1.0 × 10⁷ —
Te VALUE		°C (°F)	TEMP AT WHICH RESISTIVITY IS 1 MEGOHM-CM	850 (1562)	960 (1760)	950 (1742)	1000 (1832)	—	1170 (2138)	900 (1650)
CORROSION RESISTANCE	WEIGHT LOSS	mg/cm²/day	95% H_2SO_4 @20°C-NOTE 4 95% H_2SO_4 @100°C-NOTE 4	0.04 1.3	0.03 0.5	— —	— —	0.01 0.1	0.01 0.1	0.04 —
IMPINGEMENT		—	NOTE 5	1.00	0.45	0.52	0.63	0.47	0.14	—
RUBBING		—	NOTE 5	1.00	0.36	—	0.75	—	0.55	—

BENNETT ELECTRICAL, INC.

∞ *Electrical Contractors* ∞

FAX # 617-770-0131

ONE BENNETT LANE
QUINCY, MASSACHUSETTS 02169
617-471-8000

October 29, 1996

Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

Attn: Mr. Paul Menadier

Re: M.I.T. / Building NW12 Reactor
Bennett Electrical Estimate No. 96A-266

Dear Paul:

Thank you for giving Bennett Electrical, Inc. the opportunity to work with your institution on this budget proposal.

Our budget proposal per the site walk through is $ 33,500.00 (Thirty Three Thousand Five Hundred Dollars).

Our estimated amount of working days to complete project is 20 days. 2 [illegible]

All motor starters to be packaged within new motor control center.

If you should have any questions or require additional information, please do not hesitate to contact our office.

Yours truly,
BENNETT ELECTRICAL, INC.

Michael McKinnon

Michael McKinnon
Project Manager

MM/lar