GLOBAL MONITORING OF RADIONUCLIDES: AN EXAMINATION OF GEMS' PRIORITIES

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CONTENTS

Introduction ........................................... 1

GEMS Criteria and Priorities: An
   Improvable Muddle .................................. 2

Global Monitoring of Radionuclides .................. 6

Conclusions ............................................ 15
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INTRODUCTION

The United Nations Global Environmental Monitoring System (GEMS) is in its formative stages—a period during which competent planning might lead to the establishment of an important source of worldwide environmental data or, alternatively, one during which commitment to unnecessary monitoring activities could set damaging precedents and undermine confidence in the program's ability to meet its stated objectives. The GEMS program recently accorded high priority to monitoring radionuclides in the environment—in particular, to strontium-90 and cesium-137 contamination of foods. In view of our relatively advanced understanding of the sources, environmental behavior, and health effects of radionuclides, the wisdom of allocating a significant portion of GEMS' limited resources toward such an undertaking may be questioned.

We have examined the hazards posed by various radionuclides as measured in terms of GEMS' designated pollutant-evaluation criteria. Our conclusions are that the criteria themselves would benefit from revision and that the manner in which the criteria have been used is unsatisfactory but improvable. Systematic reevaluation of GEMS' monitoring priorities in the light of a revised set of criteria is desirable.
GEMS CRITERIA AND PRIORITIES: AN IMPROVABLE MUDDLE

In February of 1974 the United Nations Environment Program (UNEP) held an Intergovernmental Meeting on Monitoring in Nairobi which formulated a list of criteria to be used by the GEMS program in deciding which pollutants to monitor.¹

GEMS' Criteria

(a) The severity of actual and potential effects on man's health and well-being and on climate or on terrestrial or aquatic ecosystems, taking into account the stability of the systems involved.

(b) The persistence and resistance to degradation in the environment and accumulation in man and the food chains.

(c) The possibility of chemical transformation in physical and biological systems, resulting in secondary substances more toxic or more harmful than the parent compound.

(d) Ubiquity or mobility.

(e) Actual or projected concentration trends in the environment and/or in man.

(f) The frequency and/or magnitude of exposure.

(g) The feasibility of measurement at given levels in various media.

(h) The potential value of the information for assessing the state of the environment.

(i) Suitability, because of generalized distribution, for uniform measurements within a global regional or sub-regional programme within the framework of GEMS.

At the same meeting these criteria were applied to a candidate group of pollutants in order to assign each to one of eight different priority rankings.\(^2\)

**GEMS' List of Priority Pollutants**

<table>
<thead>
<tr>
<th>Priority Order</th>
<th>Pollutant</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>SO(_2) + suspended particulates</td>
</tr>
<tr>
<td></td>
<td>Radionuclides ((^{90})Sr + (^{137})Cs)</td>
</tr>
<tr>
<td>II</td>
<td>(0_3)</td>
</tr>
<tr>
<td></td>
<td>DDT and other organo-chlorine compounds</td>
</tr>
<tr>
<td>III</td>
<td>Cd and compounds</td>
</tr>
<tr>
<td></td>
<td>Nitrates, nitrites</td>
</tr>
<tr>
<td></td>
<td>(\text{NO}, \text{NO}_2)</td>
</tr>
<tr>
<td>IV</td>
<td>Hg and compounds</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
</tr>
<tr>
<td></td>
<td>CO(_2)</td>
</tr>
<tr>
<td>V</td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>Petroleum hydrocarbons</td>
</tr>
<tr>
<td>VI</td>
<td>Fluorides</td>
</tr>
<tr>
<td>VII</td>
<td>Asbestos</td>
</tr>
<tr>
<td></td>
<td>As</td>
</tr>
<tr>
<td>VIII</td>
<td>Mycotoxins</td>
</tr>
<tr>
<td></td>
<td>Microbial contaminants</td>
</tr>
<tr>
<td></td>
<td>Reactive hydrocarbons</td>
</tr>
</tbody>
</table>

\(^2\) UNEP Report, 1974, p.10.
This list of priorities was not accompanied by formal justification, and in fact the rankings were made without the benefit of any systematic analysis. We judge this to be a significant procedural lapse and recommend that the ranking system be revised in several respects:

(1) Eliminate the redundancy between criterion (b)—"accumulation in man and the food chain"—and criterion (e)—"concentration trends in the environment and/or in man."

(2) Clarify the meaning and intent of the phrases:
"...taking into account the stability of the systems involved," criterion (a); and
"Suitability, because of generalized distribution, for uniform measurements...," criterion (i).

(3) Add two new criteria:
(j) Potential irreversibility of environmental effects.
(k) Potential value of the information to scientists and/or decisionmakers.

(4) Consider whether GEMS should emphasize retrospective studies (working to understand, remedy or reverse past environmental mistakes) or anticipatory studies (working to anticipate or prevent adverse environmental effects).

(5) Insofar as it is possible, develop a rigorous analytic procedure within which the criteria are to be used. Particularly helpful would be guidelines suggesting how competing criteria are to be weighed relative to one another.
With regard to the last recommendation we believe that our suggested criterion \((k)\) above could serve as the focus for a cost-benefit comparison between candidate pollutants. Each proposed monitoring activity would be designed to help answer a well-formulated question of recognized importance to scientists or policymakers. Then the anticipated costs and benefits of undertaking the activity (including the potential costs of failure to monitor) could be assessed in terms of the other criteria and a more meaningful comparison made between competing pollutants. Where possible the assessments would be quantitative (e.g., measured in dollars, morbidity, or mortality); in other instances incomplete data would necessarily limit the analysis to qualitative arguments.\(^3\)

While not entirely eliminating subjective judgment from the process of allocating monitoring resources, this or another goal-directed system for determining priorities would enhance GEMS' ability to fulfill its primary objective of providing "information necessary to ensure, in conjunction with evaluation and research, the present and future protection of human health, well-being, safety and liberty and the wise management of the environment and its resources...."\(^4\)

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\(^3\) This is not to say that in the assignment of monitoring priorities quantitative estimates should necessarily carry greater weight than do qualitative arguments. On the contrary, if the costs and benefits of monitoring an environmental contaminant can be well quantified, that may actually indicate that new information is less urgently needed than for a pollutant about which so little is known that quantitative cost-benefit analysis is impossible.

\(^4\) UNEP Report, 1974, p.5.
GLOBAL MONITORING OF RADIONUCLIDES

The need for revision of GEMS' existing pollutant-selection criteria is well illustrated by an examination of the environmental hazards of dispersed radionuclides--currently accorded top priority in the GEMS' program.

Many radionuclides are introduced into the environment as a consequence of human activities. The principal sources to date have been atmospheric testing of nuclear weapons and various activities associated with nuclear reactor fuel cycles. Radioisotopes of particular regional and global concern include:

<table>
<thead>
<tr>
<th>Source</th>
<th>Radionuclide</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactors and Fuel Reprocessing:</td>
<td>Tritium (Tr)</td>
<td>12.3 yr</td>
</tr>
<tr>
<td></td>
<td>Carbon-14 ((^{14})C)</td>
<td>5600 yr</td>
</tr>
<tr>
<td></td>
<td>Krypton-85 ((^{85})Kr)</td>
<td>10.7 yr</td>
</tr>
<tr>
<td></td>
<td>Iodine-129 ((^{129})I)</td>
<td>(1.6 \times 10^7) yr</td>
</tr>
<tr>
<td>Nuclear Weapons:</td>
<td>Iodine-131 ((^{131})I)</td>
<td>8.0 days</td>
</tr>
<tr>
<td></td>
<td>Strontium-90 ((^{90})Sr)</td>
<td>28 yr</td>
</tr>
<tr>
<td></td>
<td>Cesium-137 ((^{137})Cs)</td>
<td>30 yr</td>
</tr>
</tbody>
</table>

A cursory evaluation of the human health impacts of these radionuclides demonstrates that most comply with a majority of the existing GEMS criteria:

(a) The severity of actual and potential effects on man's health and well-being and on climate or on terrestrial or aquatic ecosystems, taking into account the stability of the systems involved.
The qualitative effects of exposure to ionizing radiations are well documented and include various forms of cancer and genetic abnormalities. Quantitative estimates of future effects are complicated by uncertainty concerning the growth of the nuclear industry, the frequency of atmospheric nuclear weapons' tests, and the precise nature of radiation dose-effect relationships at low levels of exposure. During the heyday of atmospheric testing of nuclear weapons, whole-body radiation exposures ranged from 10 to 25 mrem/person-yr.\(^5\) This was in addition to the approximately 100 mrem/person-yr which are received as a result of naturally occurring background radiation. Exposure from weapons' fallout has declined since the Test Ban Treaty of 1963, but with occasional partial replenishment by French and Chinese nuclear bomb tests. Global and regional radiation exposures from nuclear reactor fuel cycles are currently well below 1 mrem/person-yr, although the number will grow along with the nuclear industry unless new effluent control technologies are perfected and deployed. Depending on the validity of the hypothesis which states that the effects of exposure to very high levels of radiation scale linearly down to low levels, resulting mortality could range from zero to hun-

dreds or even thousands of persons per year. Long-lived and hard-
to-control radionuclides such as $^{14}$C and $^{129}$I will continue to pro-
duce health effects for centuries—albeit at a very small rate.

If ocean-dilution were to become widely accepted as a means of radioactive waste disposal, a wide variety of radionuclides would become distributed throughout the biosphere.

As humans are relatively radiosensitive organisms, the impact of radionuclides on other species and on ecosystemic health in general is likely to be less severe than are direct human health effects.

G. J. MacDonald has recently postulated that future atmospheric accumulation of $^{85}$Kr could contribute to climatic change by ionizing the atmosphere, thereby reducing its electrical resistance and, in turn, altering rain formation and climate in an unpredictable fashion. However, his estimates suggest that the effect—if it exists—could not become significant until after at least several more decades of intensive global nuclear development.

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6 Playing the numbers-game is a risky and rarely profitable undertak ing. For purely representative confirmation of these estimates we can use the BEIR report's 1972 estimates, based on the linear hypothesis. (National Research Council-National Academy of Sciences, The Effects on Populations of Exposures to Low Levels of Ionizing Radiation [BEIR report] [Washington, D.C.: NRC-NAS, November 1972].) That report estimated that exposure of the entire U.S. Population to 170mrem/person-yr would most probably result in 6,000 cancer deaths annually. Hence, if we assume a 1mrem/person-yr dose to a global population of 4 billion with the same age distribution as exists in the United States, we obtain:

$$\frac{6,000 \text{ deaths/yr}}{2 \times 10^8 \text{ persons} \times 170 \text{ mrem/yr}} \times 4 \times 10^9 \text{ persons} \times 1 \text{ mrem/yr} = 700 \text{ deaths/yr}$$

7 Environmental Impacts of the Generation of Electricity (Draft TS, October 1, 1976), pp.32-36.
(b) The persistence and resistance to degradation in the environment and accumulation in man and the food chains.

\[ \text{Tr, } ^{14}\text{C}, ^{85}\text{Kr}, ^{129}\text{I}, \text{ and } ^{137}\text{Cs all have half-lives greater than ten years. Apart from natural radioactive decay, they resist all forms of environmental degradation. All except } ^{85}\text{Kr can become incorporated into biological tissue.} \]

(c) The possibility of chemical transformation in physical and biological systems, resulting in secondary substances more toxic or more harmful than the parent compound.

None of the listed isotopes decay into more harmful daughter products.

(d) Ubiquity or mobility.

The fission products released in nuclear explosions achieve global distribution. Tritium generally becomes incorporated into water molecules—ubiquitous and quite mobile.\(^8\) \( ^{14}\text{C} \) produced in nuclear reactors is likely to be released as CO or CO\(_2\).\(^9\) These gases circulate freely throughout the entire biosphere. Although \(^{85}\text{Kr} \) is distributed uniformly throughout the atmosphere, very little of it enters the oceans or terrestrial biological systems.\(^{10}\)

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(e) **Actual or projected concentration trends in the environment and/or in man.**

Both Tr and $^{14}$C gain entry into the food chain and become incorporated into all bodily tissues. Radiostrontium is biochemically similar to calcium, becomes incorporated into milk, and concentrates in bone tissues. Cesium is transferred to muscle and other soft tissues, sometimes with significant reconcentration above environmental levels.$^{11}$ Iodine is very effectively concentrated in the thyroid gland.

(f) **The frequency and/or magnitude of exposure.**

The frequency and magnitude of human exposures will vary depending upon future developments in nuclear weapons testing, the demand for nuclear power plants, and the evolution of radioactive effluent control technology. However, barring nuclear war or terrorism, regionally significant quantities of man-made radioisotopes will be dispersed only from governmentally regulated sources.

(g) **The feasibility of measurement at given level in various media.**

The ionizing radiations emitted by radioisotopes make their detection and measurement quite feasible in many media. However, depending on the required level of precision, measurements can be costly. In the past, accurate intercallibration between different monitoring stations has often been lacking.$^{12}$

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(h) The potential value of the information for assessing the state of the environment.

Owing to the relative ease with which they can be detected, numerous radionuclides are used as tracers to explore atmospheric and oceanic circulation patterns and the flow of nutrients through ecosystems.

(i) Suitability, because of generalized distribution, for uniform measurements within a global regional or subregional programme within the framework of GEMS.

The meaning of this criterion is uncertain.

This analysis could be expanded indefinitely; however, it already demonstrates that GEMS' criteria are insufficiently structured to offer sound guidance concerning the advisability of monitoring a given pollutant—in this instance, radionuclides. Many pollutants could satisfy most of the GEMS criteria. But the criteria fail to address a key issue: "Does the pollutant in question pose a significant environmental problem which monitoring can help resolve?"

In the case of radionuclides, the answer is probably a qualified "no." The location and magnitude of past and present sources of ionizing radiation are well-known. The environmental behavior of most radionuclides has been relatively well studied by numerous subnational, national, and international laboratories and organizations; the resulting literature is vast. Reduction of uncertainty concerning the seriousness of current and future health effects rests principally upon improved knowledge of the future population of
nuclear reactors, the frequency of nuclear weapons' tests, and better elucidation of low-level dose-effect relationships; monitoring will shed no light on these issues. Nor is monitoring likely to provide information which would aid in the design of programs to mitigate the long-term effects of dispersed radionuclides; by and large the ubiquity and mobility of the elements we have discussed renders unfeasible their avoidance.

This is not to argue that radionuclides pose no environmental hazards; rather it is to emphasize that better estimates of the magnitude of these hazards depend most critically on improved reliability in radiation dose-effect models. Whatever the hazards may be, we already know that they can best be reduced by lowering emissions from nuclear reactors and associated facilities and by halting all above ground detonation of nuclear explosives. The role of monitoring might then be to ensure compliance with international agreements in these areas.

Of course, one may envision other possible reasons for monitoring radionuclides. These might include:

(1) Regional baseline measurements against which to compare the growth of radionuclide contamination.

(2) Periodic confirmation of theoretical models of global radionuclide distribution.

(3) Detection of locally acute food and water contamination following nuclear weapons' tests.

However, the merit of undertaking such activities can only
be judged against competing claims made for other pollutants—a task beyond the scope of this paper.

The third suggestion above seems to have prompted the high priority currently accorded radionuclide monitoring in the GEMS program: "The representative of Peru was concerned...[with]...pollutants that were the result of atmospheric nuclear tests.... He added that the substances generated by such explosions should receive a high priority in the ranking of pollutants to be monitored, and should be monitored in all media."\(^{13}\)

The problem is real, although fortunately the frequency of surface and atmospheric nuclear tests is small now compared to pre-1963 levels. Poor pretest planning or an unanticipated shift in weather patterns can produce high levels of fallout in restricted areas—sometimes far removed from the site of detonation. For example, in an extreme case the fallout from a 15-megaton U.S. detonation in 1954 massively irradiated (whole-body doses of 170-700 rem) the crew of a Japanese fishing boat located over a thousand miles away.\(^{14}\) Long-distance elevated exposures also followed a 1953 explosion in Nevada—although with much less severe consequences; the highest recorded fallout levels in the entire

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United States occurred over 2,000 miles away in Troy, New York. Resulting gamma doses were about 100mrad/person.  

In such cases it may be advisable to restrict the intake of heavily contaminated foods; in extreme cases perhaps even to evacuate persons from an irradiated region. The difficulty in devising a monitoring program for these purposes is that an effective detection system must be extensive and hence costly.

In fact, it appears that the principal justification for according high priority to monitoring weapons' fallout would be to generate publicity and accompanying political pressure against nations which continue to detonate nuclear weapons above ground. It is hard not to empathize with such a motive; however, it is equally difficult to condone the politicization of a promising international scientific program. If GEMS becomes merely a forum for the expression of political outrage, its great social and scientific potential will largely have been squandered.

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15 Eisenbud, pp.357-59.
CONCLUSIONS

Our recommendation is that UNEP revise GEMS' pollutant-selection criteria; particular emphasis should be placed on developing an analytic procedure for assessing the relative value of the information that each proposed monitoring activity might obtain. GEMS' current monitoring priorities should be systematically reevaluated in order to ensure that limited resources are allocated in a manner which will most effectively advance GEMS' goals and objectives.