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A Criterion for Radioactive Waste Management:
A Case Study of
Intergenerational Justice*

by

Thomas B. Cochran

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I. Introduction

This report proposes a fundamental criterion for nuclear waste management and analyzes the basis for its development. The criterion proposed is a goal whose achievement should be the function of a waste disposal program.

The fundamental criteria related to the disposal of radioactive wastes are those that limit the release of the radionuclides to the biosphere and hence limit the induction by radiation of biological effects in the population. By limiting the dosage, they limit the induction of cancer and genetic damage in the population. Other specific criteria would be derived from these fundamental criteria.

Because many of the radionuclides have very long half-lives, they will be capable of irradiating populations for hundreds and thousands of years into the future. While the effects on one generation might be small, the cumulative effects over many generations may be substantial. Thus, the fundamental criteria for radioactive waste disposal must include consideration of this intergenerational irradiation and effects.

II. Waste Primer

During the last 35 years, large quantities of nuclear waste have been generated by military and civilian nuclear programs both in the U.S. and abroad. Although radioactive wastes are generated at each stage in the nuclear fuel cycle, including mining, milling, and enrichment of uranium and the fabrication of nuclear fuel, the principal wastes are created in the operation of nuclear plants.

The operation of these plants is based on a nuclear chain-reaction process, whereby fissile atoms, e.g., uranium-235, are split by neutron bombardment. The splitting in turn releases neutrons which bombard other fissile atoms, splitting them, thus continuing the chain reaction. Two broad categories of "high-level" wastes are produced by this process.

First, there are the fission products, which are the atomic fragments of the split uranium atoms. These fission product wastes are generally characterized by their very intense, penetrating radiation and their high heat generation rates. Two of the most troublesome fission products are strontium-90 and cesium-137. They each have half-lives[*] of approximately 30 years. Thus, it will take approximately 600 years before the content of these toxic materials in the waste is reduced through radioactive decay to one one-millionth of the original activity.

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*/ Half-life is the period it takes for any radioactive substance to be reduced by one-half. In a period of 10 half-lives, the number of original radioactive atoms is reduced by a factor of 1000; in 20 half-lives by a factor of a million.

The second category of high-level waste is the actinides. These are radioactive atoms that are heavier than actinium and include the transuranics, i.e., atoms that have atomic numbers greater than uranium. Transuranic isotopes are produced when large atoms, such as uranium-238 capture neutrons but do not fission. The actinides are produced as these large atoms undergo radioactive decay. Although actinides are less intensely radioactive, and thus generate less heat, than fission products, they generally are highly toxic and take far longer to decay radioactively than do the fission products. Plutonium-239 for instance -- a transuranic element produced by a series of nuclear reactors following neutron capture by uranium-238 -- has a half-life of 24,000 years. Thus, it will take 240,000 years before the plutonium-239 content in the waste is reduced to a factor of 1000; or 2.4 million years to be reduced by a factor of a million.

The high-level wastes, both fission products and actinides, are contained in the spent fuel elements which are removed from the nuclear reactor after having served their useful life. Either the wastes can be separated from plutonium and residual uranium by reprocessing the spent fuel or they can be retained in the spent fuel elements in the event that plutonium recovery is not desired. In military nuclear programs, where plutonium recovery is desired for the production of nuclear weapons, reprocessing is an essential step. In the U.S. civilian nuclear program, reprocessing of spent fuel has been indefinitely deferred in an effort to slow the proliferation of nuclear weapons.

About nine million cubic feet of high-level waste has been produced by the U.S. defense program. This waste is presently being stored in solid or liquid form in steel tanks at three federal sites. About 4500 tons of spent fuel from U.S. commercial reactors has accumulated at the reactor sites. While the quantity of defense waste is expected to increase slowly, this is not the case with the civilian waste. Under current projections, some 70,000 to 90,000 tons of U.S. commercial spent fuel, containing 25 to 30 billion curies of activity, will have accumulated by the year 2000.

As a crude measure of the toxicity of these materials, to meet existing federal drinking water standards it would take over 60 million billion gallons of water to dilute the fission product wastes accumulated in the U.S. by the year 2000.

While some technologies exist in preliminary form for immobilizing high-level waste, identification of suitable geologic media and sites and disposal of the waste in mined repositories, some new and hitherto untried technology is required to demonstrate the feasibility of geologic disposal. Any assessment that disposal of the wastes meets acceptable levels of risk must ultimately depend on a judgment of the disposal appraoch against some criteria defining what is acceptable.

To date high-level radioactive waste disposal licensing criteria do not exist in final form although there are programs underway to develop these criteria. Additional design criteria are also yet to be developed. Techniques are not yet available to determine whether a specific disposal approach satisfies a set of criteria, and adequate programs are not in place to develop such techniques. Consequently, isolation of high-level radioactive waste acceptable for licensing is yet to be demonstrated.

III. Equal Opportunity: The Criterion for Intergenerational Equity

Criteria for nuclear waste management should involve formal notions of decision-making and social choice. The following discussion examines how nuclear waste management criteria can be deduced from such notions. Arguments center not on maximizing the efficiency of power production for the present, but on questions of social choice between allocations of benefits and hazards over time. If the economic aspects of the issue were those treated in calssical theories of micro-economics, there would be no issue at all: hazards from nuclear wastes dumped into the environment and left for future generations would be externalities and would be ignored by behavioral units such as firms and consumers.

Modern decision analytic science tries to "prescribe how an individual who is faced with a problem of choice under uncertainty should go about choosing a course of action that is consistent with his personal basic judgments and preferences." In order to use the procedures and techniques developed by decision analysts, the individual need only be rational, and satisfy a few consistency conditions. The essence of the rationality standard is that if the individual is presented with a number of possible outcomes of his decision, he must be able tó express his preferences by making statements like "I prefer outcome A to outcome B," or "I am indifferent between outcome A and outcome B." The essential consistency condition is that the individual must be transitive in his preferences. If he prefers outcome A to outcome B, and prefers outcome B to outcome C, then he should prefer outcome A to outcome C.

The rationality and consistence constraints are imposed not to produce an analysis which suggests action along a recommended ideal but to allow an analysis to occur. They state merely that the individual can express how he feels about outcomes and would like to be consistent with those feelings. When these standards apply, formal deicsion analysis can be used to analyze a problem, and, via a long interactive process between analyst and decision-maker, "solve" it in a way that is perfectly consistent with the decision-maker's feelings.

If possible, it would be desirable to produce some sort of procedure by which a society can go about making decisions which are rational and consistent in a way analogous to the standards of individual decision-making. The study of such procedures is the domain of distributive economics. In particular, this sicence tries to develop procedures for societal decision-making which promote fairness and justice. Defining exactly what constitutes justice is part of the problem before distributive economists.

One measure of how just is a societal decision-making process is how accurately the process aggregates individual preferences into an overall expression, called a societal preference function. Decisions produced by society as a whole might relate to allocations of benefits and costs (such as wealth and hours spent working at a particular job) among members, or could relate to other societal actions conferring intangible benefits like budget allocations for research which might save lives in the future.

Procedures which society might use to make decisions could be various market mechanisms, government controls wielded by administrators, voting procedures, or any other processes which result, implicitly or explicitly, in a decision being made. Distributive economists approach the problem in a general way, and try to infer general principles. Much theoretical work has been done to see if individuals' preferences can be aggregated to form an overall societal preference expression.[2-6]

This work has shown that interpersonal comparison of preferences requires some means of going to each individual in the society and quantifying his feelings about possible outcomes of society's decision in an expression which allows comparison with other people's feelings. These general results imply that if you want a decision to be fair to all affected by it, you must at a minimum have access to everyone's feelings about the outcomes. A fair allocation of risks and benefits between present and future generations would be one which would be picked by a group preference function which consistently reflected the preferences of all the members of the group, in this case composed of people living in the present and in the future.

The theoretical conclusions apply to any methodology used to make decisions, including cost/benefit analysis, voting by individuals, market mechanisms, and so on. Their implication is that there is no way through which formal analysis or decision-making processes of any sort can certify that any course of action allocating hazards to the future will be seen as fair or agreeable by future generations. Fundamentally, this is because there is no way to consult anyone from future generations about his feelings on preferences of outcomes and risks.

Page[5,6] argues that the most sensible approach to this problem of intertemporal justice is to use <u>equal</u> <u>opportunity</u> as the criterion of intergenerational equity.

Barry[7,8] converges on the same equal opportunity criterion through his analyses of intergenerational justice. Barry notes that justice responds to the question of the proper division of resources, rights, opportunities, etc. In its simplest terms it means we give a person his due. In "Circumstances of Justice and Future Generations," Barry refutes Hume's theory of the circumstances of justice and argues instead that claims of future generations fall properly within the scope of the theory of justice, and proposes that the relevant concept of justice is justice as equal opportunity. This latter proposition is developed by Barry in "As much and as good . . .", when he also rejects alternative criteria, for example those based on utilitarianism.

The conclusions thus far reached are essential to understanding why some representations made by public officials on the acceptability of nuclear waste risks are incorrect. For example, the Environmental Protection Agency (EPA) has suggested that levels of danger which may be imposed on future generations can be defined by referring to the acceptability of risks exclusively among the present generation.[6] The EPA tried to justify this recommendation as fair by referring to social choice concepts, yet the EPA conclusion is obviously wrong if one accepts the premise that fundamental precepts of rationality and consistence require the incorp oration of every involved individual's feelings into a group's decision if that decision is to be fair. Similarly, while the Nuclear Regulatory Commission (NRC) uses $1,000/man-rem as a value placed on human life and offers a rationale for this choice, this in no way can be represented as a fair and reasonable measure of our society's group opinion. This figure's use in government programming demonstrates the government's willingness to use expedient value judgment, regardless of society's opinion of its morality, if it may be related to implicit decision-making assumptions.

The conclusions of economists like Page and philosophers like Barry give us an ideal goal for our radioactive waste programming: an equal opportunity criterion -- through a neutral allocation of benefits and risks to future generations. This ideal result finds practical application in refuting the arguments that a present commitment to nuclear power is fair because investments in a technological society now via nuclear power will benefit the future as a result of an enhanced society more than they hurt as a result of waste hazards. From the results of formal reasoning, it can be seen that this argument requires weighing benefits now versus costs later to make an allocation which is known to be unfair. The ideal may be unattainable, but it is essential to minimize unfairness by the closest possible approach to neutrality with the future.

The practical result of distributive economists' impossibility conclusions and the equal opportunity criterion proposed by Page and Barry is that society should strive toward making nuclear waste disposal neutral to future generations, in order to be as fair as possible. This is a necessary, if not sufficient, condition for "safe" disposal of waste.

It would appear that we have gone through much theoretical discussion to reach a common sense conclusion. Everything the present generation does has its impact on an unconsulted future and so is in some measure unfair to future generations; even more unfair, however, are those actions consciously promoting a policy which involves the distribution of benefits now and hazards later. The least unfair mode is one which tries to keep deliberate allocations of benefits and costs confined to a single generation, where those imposed upon by hazards are at least available for comment. The least unfair way of managing intertemporal relationships is for each generation to try to leave the earth as it was when they arrived. As a goal, a necessary condition for acceptable distribution of hazards and benefits is the neutral allocation, where no pattern of benefits and hazards is imposed. Decisions striving for a neutral allocation are, therefore, the most acceptable.

IV. The Waste Management Criterion

These considerations lead to a fundamental criterion that should be applied to the disposal of radioactive wastes:

> Nuclear operation of all types (such as mining, milling, fuel processing, decommissioning, and waste isolation or disposal) should be conducted ao the overall hazards to future generations are the same as those which would be presented by the original unmined ore bodies utilized in those operations. There should be high confidence that the risk to all future generations from radioactive waste should be less than, or (considering uncertainties in the calculation) comparable to, the risk to all future generations from the original uranium resources from which the radioactive wastes were derived, assuming these uranium resources were unmined.

The attempt here is to choose a criterion based on a theory of justice and equity. Waste criteria must be fair to future generations independent of the benefits this general reaps from the use of nuclear power. The criterion above simply ignores the net benefits of using nuclear energy. Instead, it considers only the risks to future generations. In simple terms, the criterion above requires that a disposal system produce no more risks to the future than would have been produced by original uranium ore bodies utilized in nuclear power, assuming they had remained unmined.

Can The Criterion Be Met?

To address the question of whether this criterion can be met, it is useful to begin with a simple thought experiment to conceptualize the problem. Suppose it were possible to take radioactive wastes, to instantaneously convert them into an exact duplicate of the original uranium ore from whence they came, and to emplace the resultant ore underground in a duplicate of the original ore's geologic environment.

The risks to future generations from waste emplaced in this way would be identical to those posed by the original uranium ore , because the emplaced wastes would be identical to the original ore. In these circumstances, elaborate modelling exercises that estimate risks to future generations would be needless and possibly misleading, because two identical arrangements would be expected to perform identically over time. This expection is adopted as a basic postulate: identical waste disposal mechanisms, in identical geologic environments, will produce an identical field of risks to future generations.

Under this postulate, the proposed criterion would be satisfied by emplacing wastes in an artificial "ore body" whose characteristics are identical to unmined ore bodies. The process employed here in principal, and to a large degree in practice as well, requires only comparisons between measureable attributes of reference ore bodies and waste disposal plans.

Admittedly, the ideal state of perfect equivalency to a reference ore body is unattainable. Any solutions aiming at equivalency will to a greater or lesser degree suffer some shortcomings as a result of the basic differences in radionuclide composition between wastes and source ore.

Source ore contains primarily uranium-238, a very long-lived isotope of uranium, and its decay products, such as thorium, radium, and radon. Because of the uranium isotope's long half-life, source ore radiotoxicity changes little over spans of tens of millions of years and so can be viewed as a steady-state variable over extremely long time periods. Radioactive waste, on the other hand, is a highly complex mixture of artificial and natural radionuclides, most of which undergo some decay activity and produce daughter products which may also be radioactive. The exact mixture at any point in time depends on details of initial fuel composition, irradiation variables, post-irradiation processing, and time elapsed since irradiation.

Figure 1[9] is a comparison of an ingestion hazards index of radioactive waste over time to that of source ore expressed in terms of the amount of water necessary to dilute a unit of waste, or ore, in order to meet current Federal radiation protection standards.* This fugure shows how the toxicity of radioactive waste resulting from various fuel utilization programs changes over time. Since the goal is to mimic the reference ore hazard over time, the waste disposal plan, in terms of its capability to prevent movement of the activity to the biosphere, must have higher performance standards applied over the first 2000 years or so than in later years.

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*/ The data used to derive this figure have large uncertainties and in some cases are obsolete. The figure, therefore, is displayed only for its qualitative value.

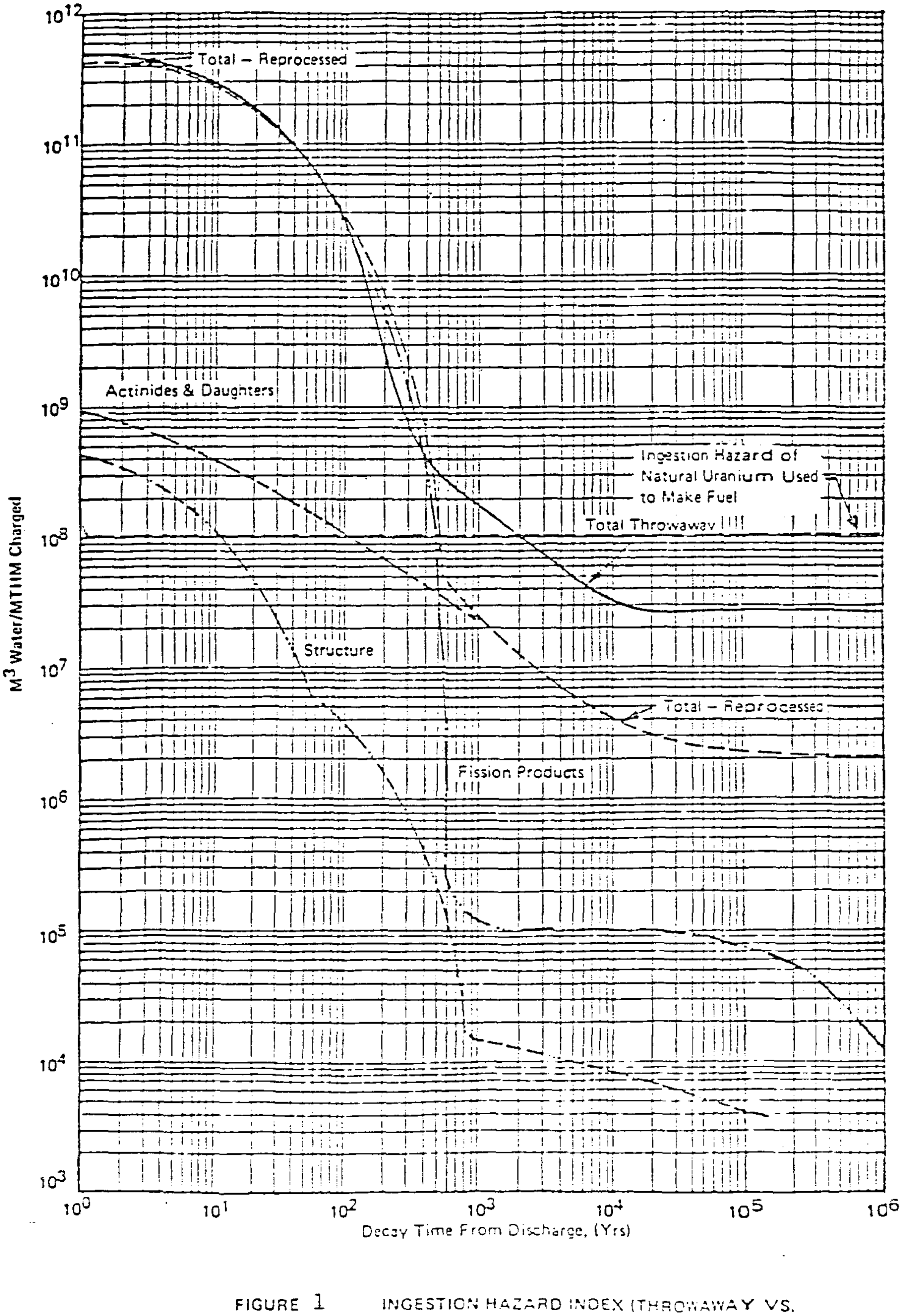

FIGURE 1 INGESTION HAZARD INDEX (THROWAWAY VS. REPROCESSED AND RECYCLED LWR FUEL)

Exactly how characteristics of waste plans may be compared and judged identical to those of natural ore bodies is a complex matter when viewed in detail. Further, it should be clear that although perfect equivalency with ore bodies is a worthy goal, it is impossible to obtain with absolute certainty. Differences between radioactive waste and source ore combine with other incommensurables to inject some doubt as to the future performance of disposal plans, no matter how closely the presently measurable characteristics of the plan match those of natural ore bodies. The important point here, however, is not that the criterion is faulty, but that one is still faced with the basic uncertainties common to all predictions of what will occur in the future, and these uncertainties are bound to infect any effort aimed at judging any waste disposal plan against criteria defining acceptability.

There are two very different alternative approaches for managing this problem. The first is an application of the defense-in-depth philosophy utilized in the licensing of nuclear power plants, and the second is based on extensive use of risk-consequence modelling. This author believes the latter is likely to increase the doubt that a waste plan will meet desired goals, while the former diminishes uncertainty. In either case, again the question here is not with whether the criterion is appropriate but how one manages uncertainties and whether one is satisfied with the regulatory approach taken in judging whether the criterion is met.

The defense-in-depth design philosophy embodied in nuclear reactor licensing procedures of the U.S. Nuclear Regulatory Commission (NRC) implicitly acknowledges that things rarely go as one would like, especially with complex plans. To manage uncertainty, it uses the ideas of independence and redundancy to assure that the plan will meet its goals. Under this philosophy, the plan will be designed around multiple independent components, the operation of any one of which is sufficient to meet the basic goals even if the other parts are arbitrarily assumed to have failed. In other words, under this philosophy, failure of <u>all</u> the components must occur for the overall plan to fail.

Uncertainty still occurs, of course, as a result of possible common mode failure, and as a result of residual uncertainties that each component, on its own, really is sufficient if the others are arbitrarily assumed to have failed. Nonetheless, the application of defense-in-depth as a design philosophy can diminish the uncertainty of reaching one's goals.

The second approach -- one favored by some people within Government agencies but which this author believes is unacceptable -- might best be described as systems analysis using risk-consequence modelling. To judge whether a given waste disposal plan is acceptable under this philosophy, the entire plan, as a unit, from waste form to general site, is plugged into a mathematical model purported to function as an analog to the real world. The model yields what is taken to be an accurate or a conservative (in terms of safety) simulation of the behavior of the waste disposal plan over time. If the predicted behavior is within limits, the waste plan passes; if not, it fails.

This approach can lead to increased uncertainty: first, because failure of a single key component could jeopardize the entire plan, and, second, because, in addition to the probabilistic output of the model, one is faced with the very real uncertainty of whether or not the model accurately represents all of the many things which might occur over hundreds of thousands of years -- that is, whether the model represents the real world or simply represents what its author thinks the real world is.