GENERAL CRITERIA FOR RADIOACTIVE WASTE DISPOSAL

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Margaret N. Maxey, University of Detroit; Laurence I. Moss, Energy/Environment Consultant; Burdon C. Musgrave, Idaho National Engineering Laboratory, Goldie B. Watkins, New York State Department of Health.

There is underway, throughout the Department of Energy in house laboratories and externally funded efforts, a series of programs aimed at the development of technology for conversion of radioactive wastes to appropriate forms and placement of these materials into repositories in the earth's surface. To supplement these efforts, consensus criteria for disposal of radioactive waste materials are needed to assure protection of the biosphere from undue risks.

Several versions of criteria for waste disposal have been offered. Most of these have been limited by one or more problems: 1) lack of a defined objective, 2) difficulties with categories of waste, and 3) lack of a basis or reference by which to judge the success of the standard, that is to judge how much protection the standard provides. The lack of well defined objectives leads to uncertainties of the type: "Are we concerned about management or disposal?", and: "Are we to provide criteria or technical specifications?" A waste classification system provides the rationale for selecting the relative amount of protection from the potential hazards to be provided by the disposal system chosen. Decision on these first two points is necessary to allow elimination of the third problem, selection of a reference for judging the adequacy of the protection provided by a selected system.

A working group was gathered to develop a draft standard. Members were drawn from a variety of perspectives and disciplines; their personal values cover a wide spectrum. This membership draws from a variety of affiliations government (State or Federal), research, industry, academic, and private.

As a starting point, we reviewed several published or proposed criteria. The majority of principles and criteria contained in the literature examined can be more accurately defined as statements of concern than as criteria for performance. In out early discussion, special attention was afforded to provide assurances that the many concerns displayed by the various groups were understood and addressed. To incorporate these assurances, our criteria were written with the following conditions in mind:

> Significant quantities of radioactive materials currently designated as waste exist. These must be classified as to level of relative toxicity and be disposed of in a manner to assure that the biosphere is adequately protected with relation to its supply of food, water and air. The disposal site selected for each class of waste must be characterized adequately to permit prediction of the waste material behavior in that site, and to allow the impact on the environment to be established.
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> This standard will provide the criteria that shall be met for safe disposal and isolation of radioactive waste in the earth's crust until the relative toxicity of the waste is below that for which concern is no longer justified as herein defined. At all times the applicable radiation protection regulations including the ALARA principle will be met both during operations and throughout the period of concern for the respository's existence.

Review of those conditions was conducted repeatedly in the discussions of the specific criteria. Constant attention was paid to how the principle of ALARA was to be applied. ALARA is defined as: "as low as reasonably achievable taking into account the state of technology, and the economics of improvement in relation to benefits to the public health and safety, and other societal socioeconomic consideration:" (as defined in 10 CFR Section 50.34a). In this regard we decided that discounting radiation risk to the present generation can not be justified. We feel that the ALARA principle must and can be met during the operational period and throughout the ultimate period of concern.

The standard's scope was established to apply to the final disposal of radioactive waste materials in a manner assuring: the characteristics of the site, the method of disposal, and the properties of the waste form are jointly considered so as to meet all applicable safety and environmental protection regulations. This is intended to cover all types of radioactive wastes including transuranic wastes, mill tailings, low beta-gamma wastes, and the solidified high-level wastes. (These are to be general criteria with specific or dependent criteria to be developed for specific aspects of the waste disposal system.)

In consideration of conditions acceptable for long-term disposal of high-level radioactive wastes, the questions of institutional integrity and continuity is always raised. These questions, often irrespective of technical problems, require assurances not otherwise asked of societal decisions. While these assurances are technically predictive in nature, they can be answered only with technical experience plus projections into the future. To some who request this type of assurance, this carries far too great an uncertainty to be acceptable.

Because of the possible operation of "Murphy's Law", assurances are sought about all aspects of the system; these include, for example, assurance that:

I (a) The waste forms are stable
(b) The geology is stable

II (a) The operational requirements will be met
(b) The caretaker will continue to take care

Technically defensible answers can be provided for concerns of the first type. However, concerns of the second type are due to a misconception of the nature of the way the institution must function to provide the required control. Let us briefly evaluate some of the concerns voiced in this second category. With respect to the time span of need for waste management functions, the following phases can be defined:

<u>Phase I Operational</u>: This is the period of emplacement of wastes produced from relatively current nuclear energy operations. At most, this phase lasts approximately 50 years beyond the lifetime of nuclear power.

<u>Phase II Decay</u>: This period of approximately 600 years after removal from the reactor is a long time only if significant caretaker's responsibility is envisioned for an otherwise unused site.

Phase III Long Term: How long a time waste is to be a valid concern depends on the definition acceptable for zero concern. Acceptable model evaluation of pathways for transfer of hazardous components of the waste to the biosphere with engineered strengthening of specific limitations can eliminate extensive consideration of this third phase.

The question of institutional control is a question of continuity of important functions. Among these functions are the operation of energy conversion systems of which waste emplacement is a subtask. Successful waste emplacement after the period of beneficial use of nuclear energy does not in itself justify the extensive use of nuclear power; the cost of ultimate disposal is a small fraction of the value of the energy produced on any time scale.

Man is the most probable cause for the loss of functions necessary to operate energy conversion systems. The most probable loss would be caused by nuclear war which would create considerably more hazard than unattended nuclear waste ever could. However, as long as any form of society continues, adequate functions will exist to provide the control required for opration of the repository. After the repository is sealed in any reasonable geologic location, the only institutional function required is human intelligence to recognize the deposit if it is ever encountered.

The disposal of unreprocessed spent fuel significantly changes all of the above discussions. A repository filled with unreprocessed spent fuel is a greater threat to the biosphere than high-level waste due to the total transuranic inventory; in addition, it will be a plutonium mine and therefore, become more attractive for recovery -- deliberate intrusion -- as time passes. Therefore, unreprocessed spent fuel must be irretrievably disposed of or permanently guarded.

Another question often posited is how much protection is enough. This requires a judgement be made about when further risk reduction does and does not warrant significant expenditures. This is a difficult judgement to make and certainly is not one for which universal concurrence is likely to be attained. Intercomparison among different types of risks also requires some weighing of relative comprehension of risks. The intercomparison is eventually made, if at all, by a regulatory body, which may not act according to well-analyzed risk but may act in a political manner to reflect an impression of the public's collective apprehension about that risk. This leads to the absurd position that more effort per health effect should be spent to reduce risks from radiation from nuclear power than from medical uses of radiation. In this standard, we allow a probabilistic risk intercomparison as one approach to evaluation of a repository. We offer as well the alternative of comparison with risks of the same kind.

Concern is often expressed about the intergenerational problem of the "legacy" of hazardous wastes left for future generations without their consent. A different emphasis is as stated by William Mills, "I have no desire to provide extreme unwarranted protection against radiation risk and in doing so pass on to my offspring and future generations a legacy of foolish spending and unnecessary debt". Relative risk-benefit analysis can provide a basis for judgement. Similarly, as is often pointed out, people are willing to accept a much higher probability of harm from active (voluntary) risks than from passive (involuntary risks to which people are subjected but have no choice) risks.

Comparison with naturally occuring toxic materials, as used in the draft standard, accomodates both of these concerns. The net risk to future generations can be established when waste disposal repositories are compared with other very similar passive risks.

Radioactive waste materials shall be identified, classified, and disposed of into locations in the earth's surface in an environmentally acceptable manner. A waste categorization system is vital to the objective of matching the disposal method and location with the characteristics of the waste. Each class of waste demands specific methods and locations to assure that the biosphere is adequately protected with relation to its supply of food, water, and air, and that inadventent intrusion of humans or animals into the disposed waste is as unlikely as intrusion into comparably toxic elements in the earth's crust:

Class 1: Radioactive wastes under this classification include radioactive materials that clearly constitute a hazard if not disposed of with great care. Therefore, these shall be assigned to a deep, engineered geologic repository or disposed of in a manner such as to assure an equivalent degree of isolation.

Class 2: Radioactive wastes in this category are shown by material properties, specific radioactivity, and nuclide distribution, to be adequately contained in shallow geologic burial or disposed so as to assure an equivalent degree of isolation.

Class 3: Wastes in this classification contain radioactivity in quantities or concentrations so small that continued control or evaluation for radiation protection is unjustified.

Three approaches were developed for judging the adequacy of disposal concepts. The first alternative ("Acceptable Risk") reflects, in a conservative manner, society's implied willingness to expend resources to avoid the statistical occurrence of injury, early death, or adverse environmental impact. The risk of an occurrence is the consequences-times-the-probability; the variation in the willingness of members of society to allocate resources depends upon these perceived probabilities and consequences.

The second alternative ("Ore Body Comparison") provides high confidence that the hazards are at least as low as the risks from the reference natural uranium ore body.

To simplify the analytical problems, a third approach was developed in which a comparison with a reference natural uranium ore body would be made in each of three aspects: stability of the waste form/ore; integrity of the host medium; and isolation from the biosphere. The third alternative is similar to the second; however, a comparison is made of each of the three aspects rather than by way of comprehensive probabilistic models. If the proposed waste form and disposal site were judged to be safer than the reference natural uranium ore body in each of the three respects then a more comprehensive analysis would not be required. This third alternative ("Three-Stage Ore Body Comparison") provides high confidence that the contribution to the risk arising from: 1) dispersibility of the waste form in relation to its toxicity, 2) lack of integrity of the host medium, and 3) lack of integrity of surrounding media are each less than the contribution to the risk arising from the equivalent aspect of the natural uranium ore body.

Specific criteria were developed in the areas of protection criteria, waste forms, demonstration of site integrity, site suitability, retrievability, and monitoring and identification. A summary of the specific criteria follows.

Protection criteria require the assignment of properly classified waste to appropriate repositories consistent with the potential hazard. The significance of the potential hazard from the classes of waste requiring control can be established through comparison with other hazardous waste disposal-risk reduction actions society undertakes, and understanding of the relative hazard of naturally occurring materials in the environment.

When the mobility and the toxicity index (per unit mass) of the Class I waste disposed of in any deep geologic formation is comparable to, or less than, the mobility and the toxicity index of the reference ore body, then no further consideration of hazard from the waste shall be deemed necessary. When the access to aquifers, and the toxicity index of the Class II waste disposed in any shallow site becomes equal to that of naturally occurring toxic materials in the undisturbed earth's crust in the region (80 km radius) surrounding the site, the hazard from the site shall be considered negligible.

For Alternative 2, the Ore Body Comparison, the estimated hazard to mankind from any waste disposal site for any generation during the period of concern shall not be greater than that from the reference natural uranium ore body. The potential hazard to any individual member of the general public shall be no greater than ten times the hazard from the reference natural uranium ore body or restricted to the then current requirements, whichever is lower.

The chemical and physical form of the radioactive waste provide the waste with its barrier to dispersion and should be engineered to match the toxicity of the waste. Class 1 wastes should be constrained in a solid matrix, the waste form shall be selected so that it and its reaction products do not induce excessive stress through continued reaction in the host medium. In application of the third approach for wastes that are higher in toxicity than is a comparable mass of the reference natural uranium ore body, the waste's self containment parameters must be increased proportionately.

The integrity of the selected disposal site shall be assessed based on accepted predictive models which evaluate the potential release of hazardous material and the characteristics of the site host media. The computer codes used to describe these models and test the site characteristics shall employ realistic physical properties and material performance characteristics rather than applying factors of conservatism to these values. The repository site shall be shown to be free of significant viable faulting. Conservative factors should not be used in calculating expected values for ingestion and inhalations quantities, probabilities, or total populations exposed.

The model described by the codes shall be founded on physical principles accepted by consensus of experts in the appropriate fields. It is recognized that predictive models require estimation of certain parameters and the probability of deviations from the estimated values. Uncertainty in modeling and estimating values of parameters shall be treated explicitly and this quantification of uncertainty shall be carried through the calculations. The models should be designed if practical for field testing to verify the engineering margins of safety in the repository design.

During assessment of the potential repository site and disposal mode, evaluations of the existing natural containment features shall be made. Where applicable, potential radionuclide migration from waste disposal sites should be predicted and quantified. Engineered barriers may be used to reduce the probability of potential release of radionuclides from the repository sites. However, expenditures of effort to increase the integrity of the barriers shall be in proportion to the significance shown appropriate to them in the pathway evaluations.

The geologic medium shall be stable enough not to be significantly degraded by exploration, construction, emplacement of waste and post-emplacement sealing by the radiation, chemical, or thermal properties of the waste.

Suitable waste repository sites shall be selected to avoid use of valuable natural mineral resources or environmentally sensitive areas. The site shall be selected where the probability of inadvertent human intrusion in search of useful resource is low. The extremities of the repository shall be marked at the surface. Retrievability of the waste during the operational period for any repository should be maintained until safe repository performance is demonstrated. However, the long-term integrity of the repository and its contained waste shall not be significantly degraded by any consideration of retrievability. Therefore, the ease of retrievability must be weighed against the possible reduction in repository integrity. For Class 2 diposal sites, a barrier, which requires periodic maintenance may be constructed to meet the protection guidelines provided this is a cost effective alternative (evaluated at zero discount rate), and provided monitoring capability can be provided to test the barrier integrity at appropriate intervals.

The detailed criteria have not been offered here; rather the basis and method have been presented to show the approach and the rationale behind the criteria we have developed. Specific criteria and technical guides will be required for execution of a waste disposal approach and to achieve a balanced and technically valid approach to waste disposal criteria. Out criteria seek to avoid the pitfalls of other offered criteria and seek to achieve a balanced and technically valid approach by providing application of the nuclear safety defense-in-depth approach to a passive (that is not mechanically operating) system. Our criteria also seek to achieve this balance by ensuring requirements for performance of the engineering design are specified; sensitive or key parts of the system are strengthened; conservatism in the design is specified to avoid the consequences of major failures, and finally, an additional conservatism is provided for should it be needed to protect against the possible results of any failure.