# THE STATE OF THE TECHNOLOGY OF WASTE MANAGEMENT

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Nuclear waste management has now become a major--if not the most critical--issue relating to the future of nuclear power in this country. The draft IRG report's "neutrality" with respect to this linkage seems to typify the Federal government's inability or unwillingness, at least up to this point, to arrive at timely national policy decisions regarding the role of nuclear power in our energy mix, or, in the context of this symposium, to define and implement a waste management program to resolve the issue.

The subject of this symposium is central to consideration of this state of affairs. Do we or don't we know how to manage these wastes? If we don't know enough now, will we know enough later? When? And with what degree of assurance? Do we establish a moratorium and/or deny the choice of the nuclear option? And what about the wastes we already have? Depending on one's persuasion or field of discipline other related questions have been and, indeed, are being, raised.

Although my views with respect to the state of waste management technology are at least implicit in the program--I am to be followed first by a critic and then by a skeptic--I will state my views in summary fashion at the outset. In that way, to the extent it might be helpful, I will give my fellow panelists a clear target to shoot at.

In my view we know enough <u>now</u>, that is, the technology exists, to enable us to mount safe and environmentally acceptable waste management programs. More specifically, since I propose to focus on high level wastes in my remarks--with respect to HLW, technology exists to enable us, on a conservative basis, to locate, design, construct and initiate operation of a waste management system involving a deep geologic repository in salt and a vitrified (borosilicate glass) solidified waste form that would be safe and environmentally acceptable. I include retrievability for performance check-out as a feature of this system. Other HLW management systems involving other geologic media and waste forms are also highly likely to be suitable for later application.

I believe the over-all validity of this view has, in general, been supported by conclusions in the draft IRG report and other independent reviews such as the APS, Ford/Mitre and the NAS. For example, an NAS panel on waste solidification in the pre-publication version of its report has noted that "many solid forms are likely to be satisfactory for use in an appropriately design system" and "Furthermore, at least one form--glass--because of an extensive development effort is currently adequate for use in a first demonstration system consisting of solidification, transportation and disposal." It also notes that "For the implementation of a large scale solidification program, glass may also be adequate, but on the basis of our analysis it cannot be recommended as the <u>best</u> choice, especially for the older DOE wastes." (emphasis added) The panel also concluded that "Because the difference in potential health hazards to the public resulting from the use of various solid form and disposal options are likely to be small; cost, reliability and health hazards to operating personnel will be major considerations in choosing among the options that can meet safety requirement."

Nevertheless, it is apparent that concerns expressed by some regarding what is characterized as "gaps in knowledge" and "uncertainties" are being used as a basis for questioning the viability of the glass-salt system or at least the timing of its application, without adequate consideration of their significance or relevance.

I propose to address briefly some of these so-called "uncertainties" or "gaps" as the basis for the view I have expressed regarding the status of technology for that system, and also hopefully as a prelude to more detailed discussion in other presentations at this meeting and in other forthcoming documentation, including the DOE GEIS and the WIPP EIS.

First of all, in considering the state of knowledge regarding geologic disposal of nuclear waste, I believe it is important, as I have just indicated, to evaluate the alleged uncertainties and gaps in terms of their relevance and significance to overall system performance, that is, radiation exposure to individuals and populations over time. This relevance or significance is related to several factors:

1. First, the time frame of interest or concern, for example, the risk of HLW contaminating public water supplies is comparable to that of a natural U ore body after several hundred years. Accordingly, uncertainties in being able, as an example, to characterize geologic faulting over very long time periods is less relevant or may even be insignificant to the extent conservation failure/consequence mechanisms do not lead to meaningful consequences. In addition, because of the substantial reduction of potential risk after several hundred years (for HLW) there is less need for precise information about possible events in the distant future, i.e. we can be more confident of natural, engineering and even institutional solutions during the period of relatively higher risk.

2. A second factor is the ability to accommodate gaps in knowledge or uncertainties by conservative design, engineering and operation.

   The practice of engineering involves the making of bounding analyses based on available knowledge and information, and determining if these results provide the bases for practicable solutions to technological problems. Such analyses also help to define information and data required to enable practicable engineering solutions and, commonly, to improve the efficiency and economy of the solution, i.e., to reduce conservatism. I might mention in this connection the heat load and its amenability to control by dilution, aging, spacing, ventilation, etc.

3. Another factor that relates to the relevance or significance of so-called gaps or uncertainties is the availability of site-specific data and information which may serve to reduce the range of uncertainty in specific areas, e.g. bulk properties of host rock, brine content and site-specific geohydrologic features.

4. The iterative process of system sensitivity and design analysis is also important in assessing significance or relevance of uncertainties or gaps. While better, more realistic, more sophisticated models for safety analyses and risk assessments are clearly desirable, conservative application of existing models can provide a reasonable basis for evaluation of the sensitivity of repository performance to (conservative) variation of specific factors.

Although the importance of a "systems approach" (which, I might suggest, is not a recent discovery with respect to geologic repositories) has been emphasized, unfortunately the results of a systematic approach to evaluation of the relative importance of specific factors to the over-all performance of the repository system has not been as readily available to the public, or from all outward appearances, to the IRG, as they should be. Hopefully, this meeting may begin to improve this situation.

Now, let's take a brief look at some of the more important technical issues that have been cited by some to be the basis for questioning the viability of the geologic repository system involving salt and glass, presumably because of excessive uncertainty and gaps in knowledge. They include:

1. Thermal effects
2. Brine migration
3. Waste form and waste-rock interaction
4. Bore hole and shaft sealing

These are not listed in any particular order and obviously are inter-related.

Central to any consideration of thermal effects, whether they be in the very near-field (canister dimension scale), near-field (repository room dimension scale) or far-field (1-2 times overall repository dimension scale and up to the earth's surface) and whether these possible effects relate to rock mechanics, heat transfer or thermo-chemical effects, is characterization of the heat source term. This heat source term is dependent on first, the type of waste and therefore its decay or heat generation vs. time patterns, second, the age and configuration of the waste at time of emplacement and third, the areal thermal loading density or spacing in the repository medium. All of these factors can be specifically quantified and, more importantly, are subject to direct control. Also, the amount of temperature increase and its distribution can be further modified by specific repository operations, such as mechanical ventilation.

Since salt has been mined underground for centuries at various locations there is a substantial experience and knowledge base for salt mine design. While experience with the effects of thermal loading is of fairly recent origin, a substantial knowledge base regarding thermal properties of salt has been developed from both field and laboratory tests. Project Salt Vault (PSV)[1] provided one of the first demonstrations of the effects of thermal loading imposed on a salt mine. It is of interest to note that the PSV results have been reproduced analytically through specific independent computer simulations by Ratigan and Callahan (finite element method)[2] and by Wahi et. al. (finite difference method).[3] Data and information exist to provide the necessary input parameters required for a rigorous, conservative analysis of thermal effects. Quantification of these parameters including heat sources, decay rates, and physical properties of salt, such as thermal conductivity and heat capacity, has been done by Llewellyn,[4] Birch & Clarke,[5] Cheverton & Turner,[6] Smith[7] and others. Rigorous analytical methods and techniques and programs and models for solving the heat transfer problems and rock mechanics problems are also available. An example of the conservation associated with a very near-field design consideration is that related to salt decrepitation, or fracture temperature of salt due to the differential thermal expansion of brine inclusions that may be found in the salt and the salt crystals themselves. McLain & Bradshaw noted that the temperature at which decrepitation was detected in some 48 samples of bedded salt from seven different locations averaged about 280 C with none being less than about 250 C. Several samples showed no signs of decrepitation at the maximum text temperature of 400 C. None of a number of samples of domal salt decrepitated. Cheverton and Turner showed that with thermal loadings of 150 kw/acre and 5.1 kw/canister no more than 1% of the salt volume in a unit cell surrounding the canister would exceed 250 C and no more than 25% of the salt volume would exceed 200 C. However, as has been noted by Llewellyn and others the thermal source strength of a 10-yr old HLW canister is only about 2.1 kw. Clearly, then, very near-field design temperature constraints are not limiting. I would also emphasize again that a) this particular factor is of a site-specific nature that is subject to specific determination as a basis for specific repository design requirements, and b) the thermal strength of the source is subject to direct control.

Similar statements can be made with respect to thermal effects in the near-field, e.g. structural stability of room openings and pillars and relation to extraction ratios, and to far-field considerations such as up-lift and the potential effect on the integrity or permeability of overlying stratigraphy and surface or aquifer temperature increases.

All of this leads to the conclusion, in my view, that thermal effects are amenable to rigorous analysis and design accountability, and do not represent any real obstacle to practicable repository design, construction or operation.

I would also reiterate that the fundamental principle of using conservative engineering approaches to the design of a repository does not obviate the need for laboratory and field testing and continuing up-grading of analytical design methods. Essentially all engineering undertakings require these as an integral part of the design process.

The subject of brine migration has been discussed mostly on a theoretical basis, which is fine, but perhaps not enough on a pragmatic, empirical basis. As a result there exists, I believe, a lack of perspective regarding the importance of this phenomenon to repository performance.

For example, estimates of brine inflow of up to a few tens of liters into an emplacement hole in bedded salt containing 0.5 vol % brine inclusions have been made by Jenks and others on a conservative basis, i.e. migration at maximum rates (initially about 0.7 l/yr) and that grain boundaries or stress field had no effects on migration, and a 150 kw/acre heat loading with an 8 ft canister pitch in the center of an 18 ft open room. With a canister which was 3 m high and 0.3 m in diameter this inflow would represent about 1 cc of brine per $cm^2$ of canister surface area. On a volumetric basis the canister volume would be about 7 times that of the brine. This would suggest that any dissolution would be limited to a small fraction of the canister volume, and further that the liquid volumes would hardly be enough to result in the creation of hydraulic pathways to the biosphere.

However, in PSV the actual migration occurred only after electrical heater failure or sudden removal of the heat source, and resulting relaxation of the thermal stresses surrounding the emplacement hole. There is empirical evidence that the migrating brine does not cross the crystal grain boundaries and that in PSV the brine was trapped on grain boundaries, and that relief of the tangential compressive stress following heater shut-down allowed the grain boundaries to open enough to permit the brine to escape to the air gap space.

So we have a situation where it appears that there is at least some basis for suggesting that brine inclusions in salt will not migrate to waste emplacement holes in the salt, and that if they did the volumes involved would not likely be of major concern. Furthermore, when one considers the ability to modify the thermal gradient by control of the thermal source as indicated earlier, plus the possibility of getter or adsorbent backfills as part of the repository design, then it seems reasonable to suggest that the brine migration issue is not a determinant of the viability of salt as a repository medium.

Once again, I would cite data on brine migration as something that is amenable to site-specific testing which can, and should be carried out as part of the repository design process.

Recently there has been a spate of questioning regarding the validity of borosilicate glass as an acceptable waste form. This despite the conclusion of the NAS panel I noted earlier. According to some critics and/or skeptics--we'll hear from them directly in a little bit--heat generating borosilicate glass under the hydrothermal conditions in a salt repository will deteriorate very rapidly and essentially no benefit would be derived from the insolubility of the glass. First, I believe one has to question whether the hydrothermal conditions that have been cited as producing this rapid deterioration are realistic. For example, temperatures of 200 C to 800 C near the waste canisters are talked about but it is not clear to me at all how such high temperatures would be reached, especially if water were (somehow) present. A much more realistic temperature range for a dry medium is probably from 50 to 200 C. Further, once again, temperature limitations are subject to control by such things as dilution, ventilation, etc. Other participants in this meeting who have been directly involved in comprehensive investigations of various waste forms, including borosilicate glass, can address the details but based on work by PNL and others on effects of radiation, stored energy, stability under reasonable (and conservative) hydrothermal conditions I believe one can indeed conclude, as apparently the NAS group did, that borosilicate glass is an acceptable waste form in a salt repository. It may not turn out to be the <u>best</u> in all systems but we must beware of the <u>best</u> becoming the enemy of the <u>good</u>, or maybe even already <u>too</u> <u>good</u>!

Concern with borehole and shaft sealing is related to the potential for man-made openings to provide a pathway for ingress of water and resulting in repository flooding, medium and waste dissolution, and a hydraulic pathway from the repository to the biosphere. The idea that salt is, for all practical purposes, impermeable to water is generally accepted and is supported by various independent observations, including those of Baar describing the existence of pressurized inclusions or pockets of gas and fluid in salt formations, and the work of Gloyna and Reynolds and Aufricht and Howard, among others, in the early '60s. Accordingly, it is suggested that the only important way in which significant quantities of water might enter a repository could be through boreholes or shafts that are not effectively sealed. It is my view that the experience of the petroleum industry in effectively sealing boreholes provides sufficient confidence in our ability to be able to meet the requirements for barriers to water flow through such openings. A demonstration of such sealing was carried out by Oak Ridge through a major well servicing organization. As I recall this was done 4 or 5 years ago but, unfortunately, I am not aware of what, if any, follow-up observations were made or what the results were. In addition, on-going work to develop special sealing materials should provide added confidence in our ability to effectively seal boreholes and shafts. For example, Olsen and Martin have described seals of compacted clays or shales that can have a permeability to water as low as $10^{-10}$ cm/sec and because of their chemical and mineralogic composition would be effective for long periods of time. One might also point out that to the extent it is deemed necessary or desirable, consideration can be given to locating shafts away from the central repository area to minimize possible potential complications of thermal effects on shaft seals.

There have also been raised other issues which are argued to cast doubt on the salt-glass system. These include questions regarding salt dissolution, so-called breccia pipe formation and its potential for providing a pathway to the biosphere, and others. I am reminded here of Aaron Wildavsky in his recent article in American Scientist entitled No Risk Is the Greatest Risk of All where he notes that "chicken little is alive and well in America." It is my firm belief that conservative systematic analysis of these questions, in the context of repository performance requirements, will show that they do not compromise the viability of the deep geologic repository system in salt using glass as a waste form.

I would make a further closing observation that is technologically related but also has, I believe, serious socio-political implications. It can be argued, on rational technical grounds, that early implementation of a geologic repository program is not essential. Proven technology exists for extended interim storage of wastes and/or spent fuel, and further decay results in some advantages from a thermal-effects and radiation standpoint. Further, it is quite conceivable that continuing development effort will produce improved second generation systems. However, if the perception of the reasons for delay is that we don't know how to do the job, and further work is required to see if we can find a solution, and this perception is the basis for denying the choice of the nuclear option, then I firmly believe we are confronted with a situation that is neither soundly based technically nor in the public interest.

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