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Nuclear Waste: Increasing Scale and Sociopolitical Impacts

The shorter-term impacts of large-scale nuclear waste operations should be examined.

Todd R. La Porte

Summary. The article argues that insufficient attention has been paid to the operational aspects of the U.S. radioactive waste management system when it grows to the scale necessary to handle wastes produced by a fully deployed plutonium economy. Without such information, many of the unsettling speculations which have become part of the public debate and are summarized herein cannot be clearly addressed. The article then outlines the types of information necessary to begin estimating the costs and consequences of radioactive waste management. Finally, an index of social exposure to radioactive hazard is proposed to improve the basis for policy decisions in this area.

Planning for radioactive waste management has been criticized primarily because estimates of potential environmental damage have been inadequate (*1*) and, secondarily, because the impact of radioactive waste management systems on social and political development has been ignored (*2*). Here I address the latter consideration and begin by noting several speculations that have colored the public debate about the social and political consequences of radioactive waste management. Implicit in each speculation is the expectation of a large-scale waste management system. I then propose some first steps toward providing a firmer basis for estimating social, economic, and political, as well as environmental, impacts of managing increasingly large volumes of radioactive wastes. The argument calls, first, for developing reasonably detailed descriptions of each of the waste management systems that might be used and, second, for estimating the organizational requirements for each of these systems when they are faced with increasingly large volumes of waste. In addition I suggest that for each potential waste management and organizational system, estimates be made of the chances that human beings would be exposed to radioactive hazards.

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Speculations on Sociopolitical Consequences

Most frequently, questions about the management of radioactive wastes are associated with what might be called the "1000-year problem." That is, how can we develop highly reliable, socially acceptable technical systems that are so effective that they will nearly eliminate for at least 1000 years the long-term risks to those generations who will not benefit from the processes that produced the risk (*3*). These are, of course, very important problems, but there are a number of equally important, more immediate matters. These are, in a sense, the "10-year problems"—those associated with the handling of spent fuel, especially if reprocessing is involved, during the 10 years or so before wastes can be safely stowed away in permanent repositories—and they involve the shorter-term social, economic, and political consequences likely to result from actually developing the organizational systems required as the scale of radioactive waste production and management greatly increases.

Discussions about the shorter-term consequences of radioactive waste management have stimulated some unsettling speculations about the various effects on social, economic, and political aspects of life were a "plutonium economy" or any large nuclear economy actually to be developed (*4, 5*). A notable characteristic of these speculations is the anxiety seemingly related to the effects of increasing scale in the operations of radioactive waste management systems. Below I summarize these speculations in a form often used in the debate. I do not argue for their accuracy in fact, rather that they derive mainly from what information is readily available.

Speculation 1. The extraordinary toxic and long-lived properties of radioactive wastes require a nearly fail-safe performance not only from the facilities in which they are processed and ultimately stored, but also from all of the people involved in the processing. As the volume of wastes increases, the most crucial scarce resource may well become the people who are highly skilled and who can be motivated sufficiently to perform continuously at extraordinarily high levels of reliability, even though it is likely that the jobs will generally be routine and boring on a day-to-day basis. Monetary reward may not of itself be sufficient, after a certain level, to assure the contribution of the very capable people likely to be needed. Therefore, special measures will probably be necessary to gain their wholehearted and enthusiastic performance. This may mean quite special and probably costly recruiting and training programs; programs that could result in a kind of paramilitary force with great élan and dedication which by virtue of its elite character could bestow considerable social prestige to the "U.S. Radioactive Waste Disposal Service." It is not too much to imagine a growing cadre of "sanctified garbage watchers" concerned primarily with security and the maintenance of order.

How large a cadre of people would be necessary to operate the various technologies of waste management is uncertain. As the volume of waste grew, its size might become considerable. The prospects of such a situation stimulates concern about the effects of a large paramilitary force on democratic institutions and indicates that both the financial and the sociopolitical costs should be seen as part of the total costs to society of achieving a mature plutonium economy.

Speculation 2. The construction and operation of a large-scale system of radioactive waste-processing and storage facilities is likely to effect unsettling changes in the communities and regions involved. By virtue of the size and the special transportation and security requirements of these facilities, the communities and regions adjacent to them might have to place extraordinary demands on their public services. Rapid development often requires equally rapidly increased public services to meet the needs of the new residents, often disrupts the orderly development of the community, and greatly affects the character of community life. This is especially germane to the impact of radioactive waste-processing and storage facilities because they are almost certainly to be located in areas of limited, dispersed populations. In an era of increasing skepticism, especially in smaller communities, about the values of economic and population growth, the imagined effects of rapid growth raise considerable anxiety.

Speculation 3. The economic benefits of increasingly large-scale waste-processing programs are not obvious and have been questioned (*6*). In an economic sense, local communities often gain a measure of benefit if the new facilities actually increase the number of jobs available to those already residing in the affected communities. But it is not clear that radioactive waste-processing and storage operations automatically provide employment of this kind. Most of the new jobs may well require people with special training in waste processing who must be brought into the community. The economic benefits to the affected communities may thus be reduced.

At the national level, the costs for the total radioactive waste-processing system have not yet been estimated. The capital investment for reprocessing and waste solidification facilities, transportation systems, storage mines, or ocean disposal operations will probably be substantial. When combined with the investments necessary to construct and operate the nuclear plants, the cost to the nation as a whole may be unacceptable. It has been estimated, for example, that it may cost from \$2 billion to \$10 billion or more to dispose of the wastes already produced by the military (*7*). These moneys will come from the tax rolls. Furthermore, on the basis of the nuclear waste industries' performance to date, it is conceivable that, even though there are no plans for such a subsidy, a sustained public subsidy of the management of commercially generated waste could become necessary. Again, these costs should be added to the tally in determining the total costs of nuclear energy.

Speculation 4. Continued expansion of waste-processing facilities is likely to stimulate increased conflicts between environmentalists and the federal government and between the states and federal agencies. If nuclear facilities became widely distributed, opposition from those communities near the areas of greatest hazard—the facilities, transportation routes, and the ultimate disposal sites—might spread and coalitions of communities-in-opposition might result (*8*).

Dilemmas in the relation between government and the public are also evident (*4*). Any disclosure that radioactive materials have escaped from the system, or the report of any event that could be interpreted as leading to a potential escape, is likely to prompt strong reactions from people living in the areas of waste-processing or storage facilities. Yet the failure immediately to disclose such an incident increases the public's distrust, and raises questions about the veracity of the governmental agencies or private firms involved. This poses a nearly "no-win" situation for both the operators and regulators of waste facilities.

At the international level the United States might have to confront both the problems of nuclear proliferation and the opposition of some other countries if plans for waste disposal came to include the seabed or outer space. Recent presidential decisions regarding the limitation of breeder reactor development and indefinite delay in construction of reprocessing facilities is indicative of the first problem (*9*). When and to what degree spent fuel will be reprocessed, thus changing the character of the wastes, is uncertain. It seems reasonable to expect that continued efforts will be made to perfect both these technologies and that the logistics of the waste management processes will thereby become more complicated. Furthermore, disposal of radioactive wastes outside the limits of the United States could open the government, at least in the short term, to propaganda attack from countries antagonistic to U.S. interests. International reactions to U.S. waste disposal policy will certainly depend on whether international waters or outer space are involved (*10*).

Speculation 5. Many of the suspected longer-term social and economic consequences of a radioactive waste management system that has become a part of a plutonium economy, or any other highly expanded nuclear economy, cause deep fears in the public, even though such consequences are so difficult to estimate with much confidence (*11*). The wastes generated by the military have already created significant management problems (*12*) and the development of fast breeder reactors as well as the use of light-water reactors (LWR's) would compound this situation. Because of the greatly increased scale of the system and increased volumes of the wastes generated, significant changes in social attitudes could result (*4, 11*). The growing awareness of the legacy we are leaving to future generations could arouse in the public an increasingly high level of anxiety, and perhaps guilt, and this could lead to an increasing emphasis on security and monitoring systems designed to detect, limit, or prevent any inadvertent or intentional release of radioactive materials. But even with great concentration of effort, it seems reasonable to expect a significant escape of radioactive waste sometime in the next quarter century. As this possibility increases with the scale of operation, major changes in our thinking about civil liberties may take place. In a fully developed plutonium economy, the institutions responsible for nuclear energy production and waste management may assume a degree of importance equal to most of the other agencies within the government. During the next decade, more information will become available on the long-term genetic effects of radiation and the migration of radioactive materials through the food chain. If developments in this area proceed like those in other areas of ecological and health studies, this information may reveal a more complex and dangerous situation than is now apparent, and may lead to greatly increased public pressure for governmental regulation and surveillance and complicate the processes of governance.

Clearly, high levels of uncertainty shape the character of each of the above speculations; uncertainties stemming in part from lack of systematic information about the actual operational requirements of radioactive waste management as the volume of wastes increases in proportion to the spread of nuclear power plants themselves. At present, environmental impact statements (*13*) provide only limited technical engineering information about the production and disposal of radioactive wastes. Feasibility studies, limited again to engineering considerations, implicitly deal with a relatively small volume of wastes. There is no explicit consideration available to the public of the operational or managerial requirements as the number of nuclear reactors increases. Nor are there any credible economic and social estimates that take into account large-scale increases in nuclear energy production.

Citizens who are drawn into considering public policy issues surrounding radioactive waste management are left to infer information on the basis of individual experience and intuitive projection. But neither those opposed to nor those supporting current plans for radioactive waste disposal have made explicit their assumptions about these operational requirements and impact projections. The assumptions remain inchoate, the product, one could suspect, of perhaps unconscious resolution of the deep uncertainties involved; resolution, indeed "over corrections," in terms of the particular fears and value preferences of the contestants.

I will now outline the types of information that must be provided if the uncertainties now plaguing the debate on radioactive waste management are to be reduced. The scale of proposed operations is central to this exercise, and a way of ordering the ranges in scale is suggested. I will also discuss the operational information that is necessary for assessing the social impact of radioactive waste management and will propose the development of an index of social exposure to radioactive hazards.

Assumptions in Estimating the Effects of Increasing Scale

The challenge of radioactive waste management is directly related to the amount of wastes produced in various forms by commercial reactors and by military activities. To provide a frame of reference for this discussion, I will describe three stages in the development of a plutonium economy; these stages will serve to bracket the extremes of operational data that are needed for more comprehensive analysis of various waste management options (*14*). The numbers used, especially for stage 3, may include unrealistic estimates and are presented for illustrative purposes only.

Stage 1. Problems of the 1980's. Regardless of what the future brings for nuclear energy developments, there is already a very significant radioactive waste management problem. By the end of 1977, the inventory of curies of important nuclides generated from military and from commercial operations was almost equivalent (*15*). That is, the wastes from these two sectors, even though the volume of wastes from the commercial sector is now only a fraction of that resulting from military development, are roughly equal in the degree of radiation hazard they represent. It is estimated that by the 1980's there will be some 450,000 tons of high-level wastes in solid form produced by the military. The volume of commercial waste will begin to rival the military wastes by the end of the century (*16*). Thus, at a minimum, it will be necessary to manage the high-level and low-level wastes already produced from both military and commercial activities as well as the wastes to be produced by those LWR's likely to be put into operation within the next few years. Plants under construction or well through the licensing process will probably be completed in the 1980's. The resources already invested in construction and the commitments made concerning those reactors that are near the end of the licensing process are so great that termination of their construction and operation is unlikely. The economic losses would be too high and the political penalties too great.

To the domestically produced wastes should be added the wastes that the United States may import in the future through "buy-back" agreements with nations whose nuclear developments this country has encouraged. I will assume here that the United States will continue to seek a reduction in the risk of plutonium diversion and of further nuclear proliferation as well as to limit environmental damage, especially to the sea. Thus, the 1980's stage will have to allow for the federal government risking considerable political damage at home and importing the wastes produced by nuclear plants built and fueled by U.S. companies for foreign powers.

In sum, the problems facing the 1980's depend on the amounts of waste: (i) already on hand from military and commercial operations, (ii) to be produced by the some 58 nuclear-fueled power plants already in operation at the end of 30 June 1976, (iii) to be produced by the some 80 plants now under construction and the 20 plants with stated construction starting dates (*12*), and (iv) the wastes to be bought back from the up to 50 plants either on-line or on order in other nations that have been or will be supplied with fuel from U.S. firms (*17*). Even if there is no further expansion of nuclear power and the plants producing wastes are not replaced after their expected 30-year lifetimes, the management of waste will have to continue for at least the next 40 to 50 years, that is, the lifetime of plants to be built in the near future plus the "10-year" handling time.

Stage 2. Problems of intermediate expansion. Here I assume an expansion of LWR's considerably above the level in stage 1 but still well below the stage of maximum foreseeable expansion. Stage 2 includes the waste from the some 250 reactors that could be built in the United States if a rate of growth of about 5 percent per year were realized through the year 2010. To this number of reactors should be added those, say, 75 reactors that might have been built, with fuel provided, for foreign powers through the year 2010 from which the United States would import radioactive wastes. Military-produced wastes must also be included in the total for each stage.

The estimate of 250 total reactor units in the United States by 2010 is based on the assumption that environmental and other regulatory objectives are met. I also assume that the operational problems in constructing and operating these plants are solved and that the major difficulty is that of obtaining sufficient capital resources actually to construct the facilities.

One important source of anxiety concerning nuclear energy production is the social and economic consequences of rapid as compared to more moderate growth. Here I assume a growth rate of about 5 percent per year, but a significant addition to the analysis would be a comparison of the differences in operational requirements, and hence social and economic impact, were the growth rate to be markedly less—say, about half the maximum feasible rate. I would then have to assume that the level of 250 reactor units within the United States and 75 reactors abroad would be reached 30 years later, in 2040.

Stage 3. The problems of maximum foreseeable expansion. Here I assume that within the United States a *plutonium* economy, based in part on the fast breeder reactor, has been developed nearly to its maximum extent and that the technical, as well as regulatory and political, problems involved with the fast breeder reactor have been solved. Because of the somewhat different processing methods required for the wastes from breeder reactors, additional and perhaps complicating operational requirements will have to be met. I assume then that some 600 reactors—300 LWR's and 300 fast breeder reactors—have been built and that the United States has agreements to buy back wastes produced by some 150 LWR's fueled by this country and operated by foreign powers. As with stage 2, the matter of growth rate is crucial. One analysis should be based on the assumption that the 600 domestic and 150 foreign reactors are in operation relatively rapidly, say by 2050, and a second analysis should be based on the assumption that this level will be reached more slowly, say by the year 2100. These numbers of waste-producing reactors could be too low (there have been much higher estimates in some projections) or too high, given President Carter's recent policy announcements regarding the fast breeder. But for my purposes these figures illustrate the dimensions of the analytical problem and could easily be adjusted in further calculations.

Table 1. Steps in the management of radioactive wastes (*26*).

1. Collection of the various waste forms
   (i) spent fuel (if designated as waste)
   (ii) mine tailings, fabrication plant wastes
   (iii) decommissioned plants and other irradiated equipment
   (iv) low-level wastes from reactors
2. Initial handling prior to reprocessing
   (i) onsite storage and packaging
3. Reprocessing of spent fuel (with variations for military and commercially produced wastes)*
4. Interim storage
5. Solidification
6. Long-term to ultimate disposal

*This phase should include partitioning of actinides if space disposal option is analyzed.

Analysis of the stage 3 problems will necessarily be highly subjective in many respects because it is impossible to make accurate predictions of future conditions. Nevertheless, such an analysis must be conducted in order to provide a broad spectrum of information on which policy-makers and the public can base their decisions. Analyses in terms of the three stages I am suggesting, within the context of the optimistic assumptions of a benign political environment, will provide "base-line" data; any upward deviation from the assumptions noted above will work to increase the resources necessary for radioactive waste management programs in the future.

Outline for the Development of Operational Estimates

The complex character of radioactive wastes from military activities and commercial nuclear energy plants (including LWR's and fast breeder reactors) confounds the problems of providing the information necessary to estimate the impacts of actually carrying out measures to dispose safely of these wastes. To limit this discussion, I will use the following brief description of radioactive waste management processes as a template for a more detailed discussion of the operational information.

Phases of radioactive waste management. Regardless of the specific methods used in managing radioactive wastes, some variation of the sequence of steps or phases outlined in Table 1 is followed. It should be possible to develop for each particular combination of technical possibilities in the waste management process, operational estimates of what level of effort is required for each phase. While the decision to reprocess wastes may be deferred or never made, inclusion of the reprocessing and partitioning of wastes is useful for analytical purposes. For completeness, analysis involving a nonreprocessing option should be conducted in which the waste must be disposed of in the form of spent fuel.

Here I will not attempt to summarize the great amount of work that has been done on exploring the various combinations of technical processes that might be used in converting spent fuel and irradiated equipment associated with fuel fabrication, reprocessing, and solidification of waste materials into a form that could be safely stored for thousands of years; suffice it to say that careful description of the technical alternatives is necessary to proceed to the next step.

Essential operational information. Two types of operational data are essential: first, functional analyses of the activities necessary to carry out a particular phase and, second, analyses of level of resources (personnel, funds, support facilities, for example) necessary to realize each function. Again, to reduce the complexity of this discussion, I will reduce both types of information to a relatively short list of activities and resources. Other items can be added as refinements become appropriate.

In order to develop any radioactive waste management system, four functions have to be satisfied: construction of the facilities, operation of these facilities once construction is completed, transportation of wastes to and from various facilities, and finally, monitoring and surveillance of internal systems and external approaches to ensure security against accidental and intentional releases of radioactive wastes. It is clear from the different engineering requirements of various waste processing alternatives that these four functions would be implemented in quite different ways depending on the alternative employed. Choices among the various types of ultimate disposal and the number and location of disposal sites would have a particularly significant effect on variations in the transportation and surveillance requirements. For example, disposal of either high-level or transuranic wastes in geological formations, say in salt domes, implies a much different network of transportation than would disposal of such wastes in deep-sea burial sites in the mid-Atlantic. Different regions would be affected, different security problems would require solution, and different regulatory requirements would be necessary. Similarly, the choice to dispose of high-level wastes in outer space would have much more dramatic consequences for particular functional activities because the partitioning of high-level, reprocessed wastes would be necessary. There are many more examples, of course, but those I have given are sufficient to show that alternative methods of waste processing and of waste disposal cannot be compared without more detailed information about the particular activities necessary to construct and operate facilities, to transport wastes around in various forms within the system, and to provide security for often quite different situations. The information that is obtained should include, at minimum, estimates of the time periods involved, the likely geographical dispersion of activities, the type of skills needed for successfully carrying out each function, and the complexity of the internal coordination required. There are also a number of administrative functions which should be added to these more operational activities but, for sake of simplicity, I will not include them here.

Once there has been a reasonably clear explication of these functions, it will be necessary to provide, for each phase of whatever technical options are under consideration, estimates of the resources—manpower, financial, and logistical—necessary to carry out each function at desired levels of reliability. This is the most important step in arriving at information from which inferences about the social, economic, and political impacts of different radioactive waste management systems can be drawn.

First, manpower requirements should be calculated in terms of the number of employees necessary, and the variety of occupational specialties and their number in terms of skilled, semiskilled, and unskilled personnel. Several other types of data concerning manpower questions are also important, but they are more difficult to provide in the absence of information about the actual locations of radioactive waste-processing and storage facilities. These are estimates of the likely dispersion of housing for workers over the areas adjacent to the facilities and the proportion of workers who would be employed locally and those that would be "imported" from outside the region either from within the United States, or, as is the case abroad, from foreign countries.

Second, financial resources should be estimated, including the amounts of capital investment needed; the amounts and proportions of payroll that would be disbursed through local facilities as opposed to facilities elsewhere in the country; the money likely to be spent for purchasing equipment and services locally compared with those purchased outside the region; and, finally, the likely proportions of income received from taxes, on the one hand, and from private sources or users, on the other. Though more problematical, some estimation of the industrial groups or government agencies that would be likely to participate in the construction and operation of expanding radioactive waste facilities would be significant. Since such involvement will perforce increase the economic and social influence of these groups or agencies, information about the likely participants and the magnitudes of financial resources allocated to them for these developments would help to clarify the public debate.

Table 2. A matrix of resources and functions for six phases in radioactive waste management shown in Table 1.

Operational requirements	Functional activities			
	Construction	Operation	Transport	Security
	(1)	(2)	(3)	(4)
Manpower (1)	A_{11}	A_{21}	A_{31}	A_{41}
Financial (2)	A_{12}	A_{22}	A_{32}	A_{42}
Logistics (3)	A_{13}	A_{23}	A_{33}	A_{43}

Finally, an estimate of the logistical requirements and material needs for each phase of technical application is also necessary. This is important for the special equipment or rare natural resources that will be required as well as for the more plentiful materials such as steel, concrete, and water.

If one combines the functions and the resource elements into a matrix as shown in Table 2, one can see that for each function a series of estimates can be worked out for the resources necessary to carry out that function. These should be combined for each waste management alternative as it would be implemented for each of the three stages of waste production, that is, from stage 1, the 1980's, to stage 3, the maximum foreseeable expansion. If one now estimates such a matrix of resources and functions for each of the six steps in radioactive waste management (see Table 1), one begins to build up a body of data that can be used in the social comparison of various technical alternatives. Much more useful comparisons than are now possible could be made between the radioactive waste management systems involving, say, disposal in a geological medium contrasted with entombing wastes in mid-ocean. Of course, more refined analyses should be done of the differences within a particular mode of various numbers of specific sites.

These kinds of operational data can usefully be divided into those dealing with the requirements likely to be necessary for implementing the development of local facilities and those associated with the relations among local facilities. One of the most important segments of these analyses is the determination of the differences in local impact compared to the impact of increasingly widespread and intensified networks of waste producers and processors as the volume of wastes grows. It may well be that as the size of the network grows, problems associated with transportation coordination and regulation will increase more rapidly than problems of local impacts.

Even at this subjective level, comparisons between various radioactive waste management options suggest considerable variations in social, economic, and political impact. And there is great uncertainty about the particular character of changes in these areas. Information of the types proposed above would provide an improved basis for comparison, but additional data are necessary for meaningful social assessments to be made: namely, data on the risks of humans and other organisms being exposed to radioactivity as the scale of nuclear energy production increases.

On Developing Indices of Social Exposure to Radioactive Hazards

The very long-term toxicity of radioactive materials is at the root of the public's concern about the present and future use of nuclear energy (*18*). Thus the controversy over radioactive waste management centers on which method of disposal will most nearly eliminate the possibility of ever exposing human beings to these radioactive materials. Although some information is available on the potential biological insult from actinides, including the potential genetic effects of exposure and the possibility of migration of radioactive materials through the food chain, there is little information on which to base discussions of the advantages and disadvantages of the different organizational strategies for waste management. The larger the volume of waste materials and the more varied its composition, the larger and more complicated the total system is likely to be; and the more complicated the system, the more we are prone to imagine that, if anything can go wrong, invariablly it will at some time or other. This bit of organizational folklore—Murphy's Law—is a belief shared by many Americans (*19*). If the consequences of error may be very damaging, as in the case in point, the force of the implication of Murphy's Law is greatly magnified.

Since different waste management systems have different levels of complexity and, therefore, different probabilities of potential breakdown, more information should be available on the operational reliability of sociotechnical systems as their scale and internal complexity increases (*20*). Thus, for each alternative waste management system, and for each phase and scale of each alternative, indices of social exposure to radioactive hazards are needed. Index building across various technical options for various organizational designs would, along with cost estimates, provide a much better basis for comparing alternatives.

Such indices would combine two probabilities: first, that a system might fail sufficiently to allow the escape of radioactive materials and, second, that if there were an escape of materials, human beings might be exposed to both short-term and long-term radiation (*21*). There has been some analysis relevant to these concerns, but it deals mainly with the ultimate disposal segment of the radioactive waste management sequence (*22*). While this is, of course, crucial for long-term risks of exposure, it does not address the very complex and often lengthy processes involved in the intermediate steps required in various processing alternatives before final entombment is accomplished. In terms of the public's concerns about radioactive wastes, the shorter-term organizationally related problems must also be addressed. Such indices could perhaps be developed from materials already included in various safety analysis reports and environmental impact statements, in which case the task would be considerably eased.

In proposing such index building, the problems of accuracy in forecasting must be kept in mind. These entail the difficulties of translating probability estimates into sensible meanings for those who might use them (*23*). Analysis of the relations between technical and human performance would need to be quite explicit. These analyses would aid greatly in uncovering the unconscious assumptions about human performance of both technical and social analysts and would improve not only the quality of research but also the development of and debates on policy. Such an analysis of exposure risks might also reveal segments of the process which could be redesigned in order to decrease the possibility of exposure of radioactive hazards to humans (*24*) and permit both error-identifying and error-containing processes to be designed into the waste management system at the outset (*20, 21*). In this technological area, perfecting the system through trial-and-error learning has very limited utility.

Estimating Social Consequences

In this article I suggest that information of a type not now available or perhaps not yet assembled for public use should be provided both to improve the quality of policy development in selecting an acceptable radioactive waste management system and to inform the public debate concerning such systems. The type of information and analyses described herein should be sought from industry, the Department of Energy, and the Nuclear Regulatory Commission by citizens and policy-makers alike. But I hasten to say that information is not of itself sufficient to assure greatly increased predictive capacity. Improved social, economic, and political prediction requires a reasonably well formulated and tested theory of social, economic, and political dynamics that could be used to interpret data, much as engineering data can often be interpreted on the basis of well formulated scientific laws to predict the technical dynamics of a complex engineering system. But a review of current developments in the social sciences would not reveal well-formulated conceptions of technology and social or political change. Rather, this is a relatively underdeveloped area and there seems to be little if any recognition within policy analysis circles of the significance of this limitation. Little has been done, for example, by the National Science Foundation, the Office of Technology Assessment, or the various technology-based government agencies to encourage research on these problems (*25*) and it has been in the interest of industry, at least until recently, to ignore what little can be said about such matters.

More complete information concerning the operational requirements for large-scale, complex developments of different radioactive waste management systems could be a strong stimulus to achieving a better understanding of the relations between technological development and social and economic change. With such information, for example, it would be possible to begin the following analyses. First, for any level of likely technological development, say to result in the scale of operations described in the problems of intermediate expansion, what changes in existing financial and legal arrangements and public attitudes would be required to put such a technical system into operation. This centers attention on the required changes in political authorization and in the regulatory situation which would be necessary to achieve the technical results. It also provides at least one basis for judging the opportunity costs incurred and the expenditure of "political energy" which might be needed. Second, with the foregoing estimates being used as a basis, questions could be asked about the social and political consequences of having reached the level of technical performance expected with the attendant changes in economic and legal institutions discussed above. This two-step process seems to be within the capacity of today's social scientists and would add greatly to the clarity of debate and policy analysis.

More complete information about operational requirements concerning radioactive waste management will not necessarily result in a quick judgment that nuclear energy is preferable to other energy sources, nor will it necessarily result in ready public acceptance of nuclear energy. Critics or proponents of nuclear energy development may demand that the same types of information suggested herein for radioactive waste storage problems should be made available about the energy production end of the nuclear energy cycle. Likewise, more data on the operational requirements of coal production and other energy alternatives would be necessary to provide a fair comparison with nuclear energy economics. The crucial aspects of these studies would be the consequences of increasing the scale of operations necessary to achieve the production of energy (with the consequent production of wastes) at levels anticipated for the future. Such information would reduce some of the confusion based on intuitive and unspoken assumptions underlying the speculations about the changes that will be necessary to carry out particular nuclear energy and waste management options and the consequences of such changes. Such information would base the contest between the energy alternatives more nearly on judgments about who should benefit and who should be disadvantaged in the process of technological development.

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Year	Military	Commercial
	High-level	
1975	85 million gallons[a]	0.6 million gallons[b]; 0.07 million cubic feet[c] (spent fuel)
1985	65 million gallons[a] (450,000 tons in solids)	0.6 million gallons[b]; 0.25 million cubic feet[c] (spent fuel)
2000	70 million gallons[a] (485,000 tons in solids)	0.08 million cubic feet (HL solid waste); 2.0 million cubic feet[c] (spent fuel)
	Transuranic and low-level	
1974	42 million cubic feet	9 million cubic feet
1985	55 million cubic feet[d]	15 million cubic feet
2000	75 million cubic feet[d]	51 million cubic feet

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27. This article, a revision of a discussion paper to the Committee on Radioactive Waste Management, Commission on Natural Resources of the National Research Council, September 1976, was done independently of the Committee and was not commissioned by it. Ames Research Center, NASA under grants (NGR 05-00300421) and (NGE 05-003-471), supported work underlying this article. I thank G. Rochlin, P. Bishop, P. Craig, D. Metlay, H. Feiveson, J. Bartlett, K. N. Lee, R. Schuller, and S. Zwerling for helpful comments and N. Michelsen and C. Winter for assistance.

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