Management of Radioactive Wastes

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NUCLEAR FUEL CYCLE

Safe operation of a nuclear reactor is not the end of nuclear responsibilities. Nuclear fission breeds responsibilities, some with long half-lives. Nuclear power programmes require consideration not only of the power plants, their siting and operation, and planning for the nuclear fuel supply but also of what is to be done with the irradiated fuels and the nuclear waste in them. There have to be decisions on spent fuel management, whether the fuel is to be stored and/or reprocessed (when and where), on having the appropriate facilities and technical competence available when needed, on the management and disposition of the radioactive wastes resulting from any fuel reprocessing, and on the safeguarding and utilization of the nuclear materials recovered from reprocessed fuels. Fig. 1 is one way of schematically illustrating the nuclear fuel cycle. Irradiated fuel storage normally has not been included as part of the cycle but it has been included here because, today, fuel storage may become a viable option prior to reprocessing the fuel at some later time. The shaded areas of Fig. 1A indicate where we believe there are immediate and future areas of concern in the nuclear fuel cycle operations, essentially all involving radioactive waste management. In addition, there is decommissioning which applies to all fuel cycle facilities.

MILL TAILINGS

The residual activity in mill trailings is due chiefly to naturally occurring radium-226. Although its concentration in mill tailings is very low, about 800 picocuries per gram, it is of concern because of its long half-life (1,620 years) and associated decay products. Radon gas from the decay of radium-226 can diffuse outwardly from those tailings. Consequently, there is general agreement that such tailings should not be used either in structural materials or in backfill material in connection with buildings for human occupancy. Thus, there is a need for long-term control and surveillance of uranium mill tailings.

The radiation from uranium mill tailings does not present a serious health hazard in open, well-ventilated areas or outside. Nevertheless, the hazard will persist for thousands of years. Consequently, location and disposal of tailings must be planned and engineered with the foregoing and permanence in mind. When use of a particular tailings disposal area ceases, it should be stabilized and revegetated to the extent feasible with protection from water and wind erosion. Its location should be well marked as permanently as possible and registered with local land authorities and with appropriate restrictions in perpetuity being placed on use of the area.

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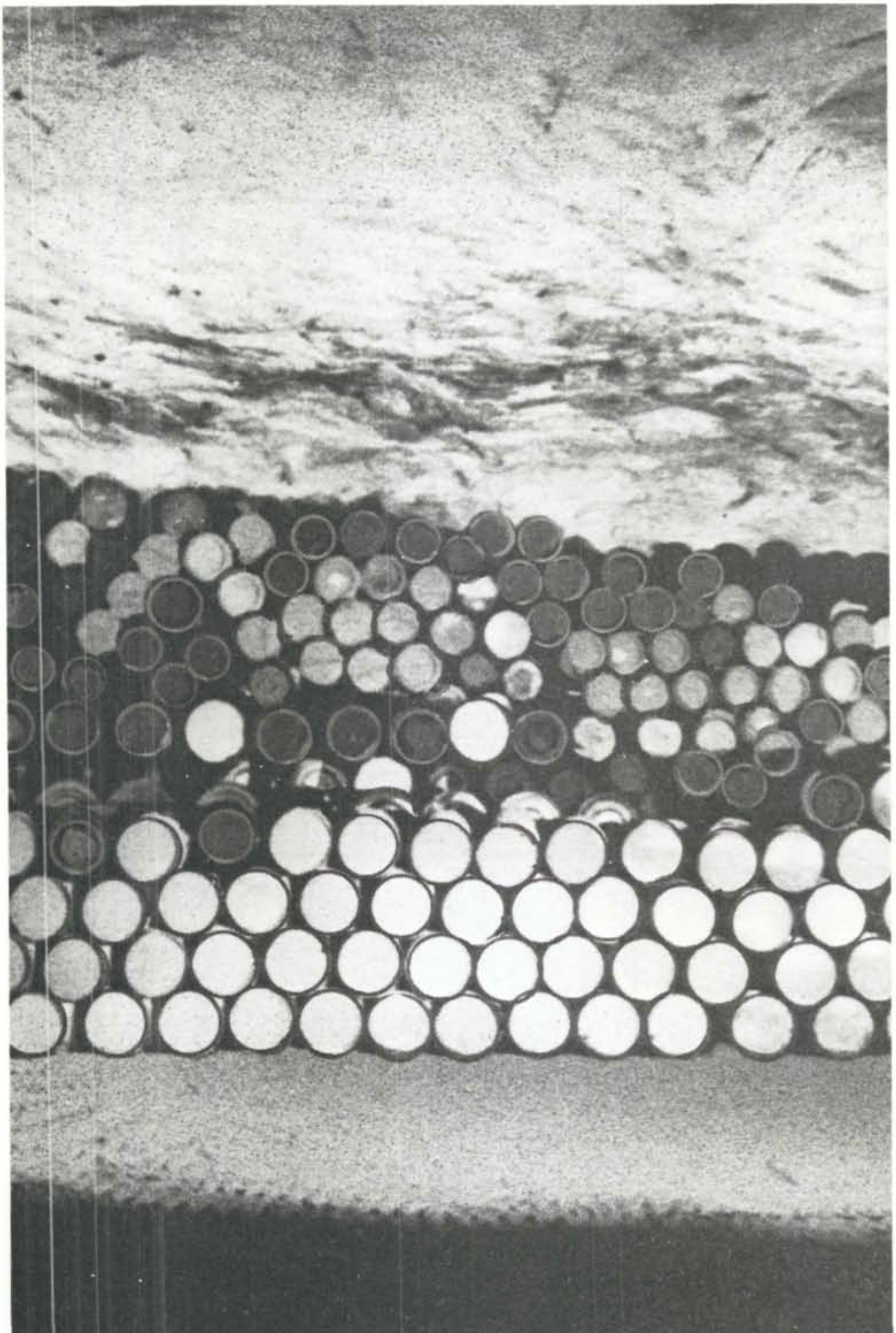
Drums of radioactive waste are being stored in the abandoned Asse salt mine in the Fed. Rep. of Germany. ▶
Photo: G.S.F.



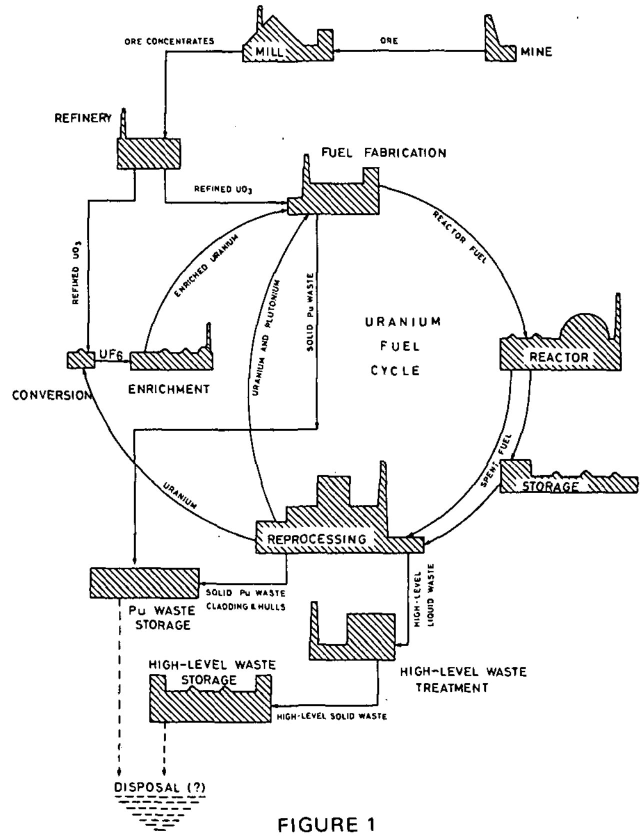


FIGURE 1

FUEL STORAGE

A tacit assumption seems to have been that when the spent fuel is discharged from a reactor, fuel reprocessing and waste management services will be, or soon will become, available at charges which would be compensated for by the value of the recovered fissile material. Furthermore, there has been the assumption that the reprocessor of the fuels would provide all of the necessary waste management services arising from the reprocessing to the extent that those concerned with reactor operations no longer would be involved with responsibilities for managing these wastes. The charges for the waste management services would be included in the fuel reprocessing charge. Except for the heavy water reactors using natural uranium fuels, there seems to have been little thought given to situations where fuel reprocessing services either may not be available or are economically unattractive. Consequently, for either one of these two reasons, there are indications that a shortage of fuel storage space is becoming a pressing problem requiring immediate attention.

While irradiated or spent fuel is not regarded in most nuclear economies today as a waste,

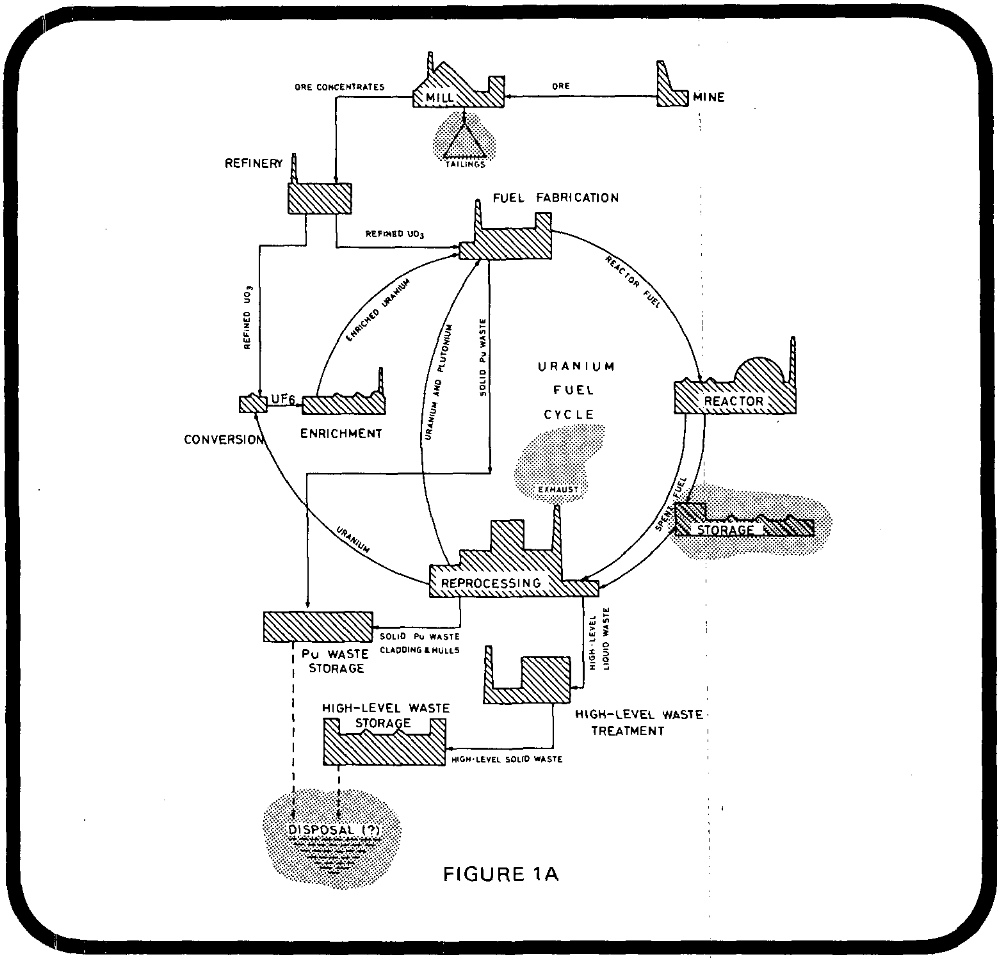


FIGURE 1A

the management of it while in interim storage is not unlike the management of solidified high-level waste. All the heat generating fission products are there, even more plutonium, and, in addition, the gaseous nuclides, tritium, iodine and krypton. While the container and the fuel form may not meet the waste manager's goals for solidified high-level waste, they have withstood rather brutal treatment in the reactor. The problems attendant on such storage are not a lack of technology but the provision of facilities and practices to assure continued cooling, adequate monitoring and surveillance to detect release of activity from the containers, adequate treatment of effluents, no unauthorized entry or removal and that faulty or failed containers can be replaced or overpacked.

However, if the fuel is to be considered as waste – that is, not to be processed – then one is faced with all the normal high-level waste problems plus the questions of how to handle the gaseous wastes and should the oxide material be converted to another form or can it be overpacked and stored or disposed of in its present form, with or without outgassing? Furthermore, unless there is a disposal method available for these alpha-bearing wastes, then one is faced with their continuing storage or reprocessing these fuels as a way of disposal.

DECOMMISSIONING

The decommissioning of facilities associated with nuclear power generation will not become a widespread problem for twenty or thirty years. However, what is done each day in designing, constructing, operating and maintaining these facilities determines the magnitude of that problem. A group of consultants for the IAEA has defined three stages of decommissioning as follows:

Stage 1: Lock up with surveillance

"This can generally be regarded as a temporary expedient prior to future work, but in many cases it may be all that is justifiable."

Stage 2: Conversion and restricted site release

"This stage can take many forms but means essentially that some or all of the plant is converted to other uses."

Stage 3: Unrestricted site release

"For this stage removal of all significantly radioactive equipment and structural material is required to allow unrestricted access and unrestricted land use."

Anyone who has dismantled a contaminated hood or glove box, or closely observed such an operation, can begin to appreciate the problems of decommissioning a reactor to Stage 3. But, can anyone really appreciate the problems of decommissioning a plutonium fuel fabrication plant or a fuel reprocessing plant to Stage 3? The costs of such a decommissioning effort, including the management of the resulting wastes, have been estimated to equal or exceed the original facility cost. Although no one has tried to design a facility for ease of decommissioning, the studies and actual decommissioning work done to date indicate that many of the design alternatives that are most attractive from the construction and operations viewpoint may make decommissioning much more difficult.

If one objects to passing a nuclear liability to future generations, this decommissioning problem already may have gotten out of hand. But that does not mean it should continue to be. Governments, regulatory authorities, utilities and industry need to face the questions – who is going to "clean up" and "how much" when operations at a nuclear facility cease? If a government is going to do it, criteria need to be established for the condition of the facility at the time of its transfer for decommissioning. If a public utility is to do it, the anticipated cost should be taken into account in the charges for electric power. If industry is going to be liable for decommissioning its nuclear facilities, then their charges also must take into account the costs of decommissioning. At this time, criteria for decommissioning and arrangements for the funding to do this are not being taken into account. No matter who will do the decommissioning, the public should insist that total cost be minimized since in the end the public will pay for it. This means that criteria for the decommissioned site and facility should be established, then decommissioning plans should be factored into plant design and into operating and maintenance procedures. This planning for decommissioning is a drastic departure from present practice but until it is done, how can the public and those opposed to nuclear power be convinced that nuclear monuments are not being built?

KRYPTON-85 AND TRITIUM

In gaseous radioactive wastes, the nuclide of concern to date has been iodine-131. However, with its 8-day half-life, it is controlled rather simply either by sorption in an appropriate media and allowed to decay or by allowing sufficient decay time prior to reprocessing the fuel.

Gaseous radionuclides which may become a problem in the future are tritium, krypton-85 and possibly iodine-129. Xenon-133 with its relatively short (5.3 day) half-life is not expected to become a problem. On the other hand, there is some concern being expressed regarding a build-up of carbon-14 in the atmosphere and biosphere as a source of population exposure from nuclear power.[1] While the capacity of the environment with respect to tritium, krypton-85 and iodine-129 is not well established, it has been estimated that the global concentrations of tritium and krypton-85 may approach acceptable limits during the first half of the next century. The principal releases of krypton and tritium occur during fuel reprocessing.

Some regulatory groups and critics maintain that the technology which is available today should be applied and recovery of the gaseous radionuclides be initiated immediately. Apparently, they have been misled by work reported on pure gases into believing such technology is ready and available for the conditions actually encountered in real plant operations. Actually, the principal technology to resolve in all processes for removal of gaseous radionuclides is clean-up and pre-treatment of the gas to produce a suitable feed for the removal processes.

One cannot say that removal of tritium and krypton from gaseous waste is an immediate waste management requirement but it may become one in the future. Consequently, within the next ten years processes for removal and confinement of these two gaseous radioisotopes should have been demonstrated and available. To do this, it seems that there is going to have to be a greater level of effort in developing the appropriate technology than there exists at present. In addition to developing technology for handling tritium and krypton-85, the waste management ramifications regarding carbon-14 also should be investigated.

STORAGE AND DISPOSAL OF HIGH-LEVEL AND ALPHA-BEARING WASTES

Satisfactory technology is either being used on a routine operating basis or being demonstrated for every sector of the nuclear fuel cycle except for high-level waste disposal, which is disposal in the sense that the hazardous concentrations of radionuclides are effectively isolated from the biosphere in a final resting place where control and surveillance eventually can be relinquished. After over 20 years of nuclear power programmes in several of the major developed countries, technology for the solidification and storage of high-level wastes from reprocessing power reactor fuels still remains to be employed on a continuing full scale operating basis, while methods for the disposal of high-level and alpha-contaminated wastes have progressed no further than studies. Although use of several possible alternatives can be projected broadly, reactor operators and authorities responsible for a nuclear power programme do not have adequate knowledge today of what the responsibilities and charges will be with respect to the reprocessing of the fuel and the disposal of the resultant radioactive wastes.

Because of the extremely long half-life of the alpha-emitters and the realization that effective containment has to exist for hundreds of thousands of years, elimination of the alpha-emitters from the bulk of the waste, especially the high-level waste, is an attractive idea. The success of this scheme, removal of the alpha-emitters, would depend essentially upon a quantitative removal of these nuclides from the fission and activation products found in the reprocessing plant waste stream. Processes are available to achieve a reasonably complete separation of the alpha-emitters from the fission products but the problems are the cost and maintaining the operational controls necessary to achieve such a separation in practice. Then, of course, there is a proliferation of additional radioactive waste effluents and contaminated facilities and equipment which have to be handled and which could be a bigger problem than the original alpha contamination.

If separation of the alpha-emitters can be made applicable for a production operation, one faces such questions as: Are the benefits of having an alpha-free fission product waste worth the cost plus the risks of extra handling and processing and the additional contaminated materials that are generated, and what is to be done with the alpha-emitters?

The radioactive waste disposal question is a challenging one and the sooner an acceptable disposal method for these wastes can be demonstrated the better. Until this question is resolved satisfactorily, nuclear power programmes can expect increasing opposition, particularly for the construction of fuel reprocessing plants as well as for nuclear power itself. Opponents of nuclear power are becoming aware that nuclear power reactors in themselves release relatively small amounts of radioactivity when compared with fuel reprocessing plants. However, with the exception of the volatiles, essentially all of the nuclear wastes accumulate in storage areas. But the construction of facilities which are to be used for storing the radioactive waste forms during some unspecified interim period while alternative methods for the disposal of their contents are being studied and developed, does not encourage the public confidence regarding the benefits of nuclear power and certainly provides arguments for those opposed to nuclear power.

It is understandable that few, if any, localities feel inclined to accept fuel reprocessing plants and/or waste storage sites with the prospect of becoming what is popularly called "a dumping ground for nuclear waste" regardless of all technological assurances for safe storage of such material. However, localities would, we believe, be more ready to accept suitably located fuel reprocessing facilities provided there is an acceptable disposal method being demonstrated.

At present, there appear to be four general concepts for the ultimate storage location or disposal of those radioactive wastes which require many centuries of isolation, namely:

1. by sending into space;
2. by transmutation, for example, by bombardment with atomic particles into stable elements or short half-life radioisotopes;
3. using the surface of the earth, which includes the concepts of using engineered facilities on ground surface or placement on the ocean floor;
4. using geologic formations within land masses or beneath the sea bed.

While the foregoing concepts have all been studied conceptually, the only promising ones available for application during this century appear to be the last two, using the surface of the earth or geologic formations. If one applies the criterion of retrievability, which could be needed in case of an unforeseen development, then this virtually eliminates the oceans and leaves but two alternatives, use of engineered surface facilities or use of geologic formations within land masses.

At this time then, one can consider two approaches as being currently applicable for isolating waste from the biosphere for long periods of time: a surface storage facility with continuous monitoring and surveillance versus a disposal technique that presumably would leave no burden to future generations. While one must admit there can be no absolute guarantee of radionuclides not escaping from a geologic site, one also has to consider that there can be no absolute guarantee on the continuous maintenance and monitoring of a surface storage facility. Maybe it boils down to whom one trusts the most, man or nature.

In any comparative hazards evaluation between surface and geologic storage one cannot overlook the fact that waste stored or disposed of in a geologic formation, say at least several hundred meters deep, is far better protected from catastrophic acts of nature and man, including the human tendencies for procrastination and neglect, than is waste being stored in facilities on the surface of the ground. So, storage in geologic formations might be considered as the best compromise between safety and responsibility. And here, the term storage in geologic formations is used because until the safety of using a geologic location for the disposal of radioactive waste has been reasonably assured, the waste first will have to be stored there. Surveillance and retrievability are relative things. While surveillance and retrievability would be less complicated using a surface storage facility, surveillance and retrievability from a geologic storage site could be accomplished quite readily with proper design and management.

The only credible pathway by which radionuclides confined in a geologic formation can reach the biosphere and become a hazard to man are their movement through ground water action. Consequently, the principal criterion for geologic disposal is to use either a dry formation or one where there is little or no movement of ground water with geologic indications that this condition will remain relatively stable for hundreds of thousands of years. Another approach might be to protect the waste and/or radionuclides in it from ground water movement and, for redundancy, both measures might be taken. Besides the natural barriers afforded by a geologic disposal site to the movement of radionuclides, the form of the waste and its packaging or containment are two other important aspects which can provide additional elements of safety and confinement for placing waste in a geologic formation. Combinations of the three can provide considerable latitude for assuring perpetual isolation of the radionuclides from the biosphere.

Geologic formations such as salt, granites, shales and clays have been in existence and relatively stable for millions or hundreds of millions of years. By thorough investigation of formations and their surrounding formations, the historical stability of the formation can be determined as well as the presence, absence, or type of connate or nearby water that might form a pathway to the biosphere and man. Regardless of whether the geologic formations are salt deposits, limestones, shales, granites, etc. most of the locations and deposits probably will be unique and will have to be examined and evaluated as to their respective structure and the particular hydrological situation. Some formations and their situation may be considered "less safe" than others but that does not necessarily mean they would be "unacceptable."

All evidence indicates that high-level and alpha-bearing wastes have been managed safely to date but the questions that nag the public and cannot be answered with evidence today are, "What are you eventually going to do with it?" "How are you going to isolate it from the environment for the thousands or millions of years that a potential hazard exists?" "How can you be sure it will not contaminate the biosphere?" "What assurance do we have that you can dispose of it safely?" "Where?" and so on. Therefore, it seems imperative that the necessary investigations move ahead to select potential disposal sites in geologic formations and embark upon demonstration projects at these sites without further delay. As mentioned earlier, any demonstration of disposal in a given geologic formation should be conducted initially as a storage operation. When the safety of the site and the operation has been demonstrated and proven beyond reasonable doubt, the intent to retrieve can be abandoned, the degree of surveillance reduced and the operation continued as disposal.

In general, resolution of the high-level and alpha-bearing waste disposal question seems to be one of the most serious problems and highest priority objectives facing the nuclear industry today. The construction and maintenance of interim surface storage facilities does not provide the final answer and may not reassure the public. Technology is available today to demonstrate and prove that certain geologic locations are acceptable for waste storage, hopefully leading to disposal. One might question if funds and resources used for constructing and maintaining surface storage facilities could be devoted better during the next ten years to evaluating and demonstrating geologic storage with disposal in mind.

Nuclear power is in trouble now because there has been no demonstrated approach or real-life resolution of the long-term radioactive waste disposal problem. Critics of nuclear power are using this point more and more effectively. One can expect public and political groups, particularly where fuel reprocessing plants are proposed, to listen seriously to these critical views. Once nuclear wastes are being stored in an acceptable geologic formation in a retrievable manner, demonstrating long-term applicability, and the method can be logically explained and defended in public forums, nuclear power and especially fuel reprocessing plants should become more acceptable.

REGIONAL FUEL REPROCESSING AND WASTE MANAGEMENT CENTRES

It seems probable that of the total 3500* GWe nuclear generating capacity which has been estimated to be operational by the year 1990, 3000 GWe will be located in about ten countries that will have fuel reprocessing facilities. The remaining 500 GWe will be located in a larger number of countries spread all over the world. The questions that arise in respect to these countries are: Will they opt for the reprocessing of their nuclear fuel themselves or by contract to those countries with reprocessing facilities? Who is to be responsible for the disposal of the radioactive wastes? What are the liabilities involved? Will they sell their irradiated fuel as a resource material to reprocessing countries? Or, will they opt for the discard of irradiated fuel elements as a radioactive waste? Whatever the answers to these questions may be, there would seem to be an advantage in international co-operation with regard to the safe management of the radioactive materials.

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* It now appears that this estimate may be somewhat optimistic but it will be used for illustrative purposes.

In October 1974 the Agency's staff made a cursory study to estimate the economic benefits which might result from regional centres for nuclear fuel reprocessing. What might be considered more or less a typical region was studied using a projected fuel reprocessing load of the region for the year 1990. The following three fuel reprocessing and waste management strategies were examined briefly to determine their comparative costs:-

I. One fuel reprocessing facility for the region.
II. Two fuel reprocessing facilities for the region.
III. Local fuel reprocessing facility for each country.

Capital and operating costs for the various reprocessing and waste management capacities that would be required were estimated and totalled for each strategy, and compared. It was assumed that each fuel reprocessing plant buried its low-level solid waste and stored its solid alpha-contaminated and high-level solidified wastes in surface storage facilities pending the availability of facilities for the ultimate dispositon of such wastes. An allowance was made for the impact of fuel transport casks and transportation charges if the fuel was not reprocessed locally. In addition, a comparison was included of storing the irradiated nuclear fuel at centralized facilities. To establish a common basis for a cost comparison, it was assumed that both waste and fuel storage facilities would be constructed with storage capability for 20 years of operation at the estimated 1990 fuel discharge rates of the region and all facilities were amortized over the 20-year operating period.

Assuming a cost index of one (1.0) for the estimated capital investment and, similarly, a cost index of one (1.0) for the estimated operating cost of the regional plant, the following tabulation presents the comparisons which were found for the region that was studied.

COST INDEX COMPARISON OF FUEL MANAGEMENT ALTERNATIVES*

	Capital Investment	Operating Costs
Fuel Reprocessing Strategies:**		
One Regional Facility	1.0	1.0
Two Regional Facilities	1.1	1.1
Local Facilities	1.5	1.6
Fuel Storage Strategy	0.6	0.3

It should be emphasized that the indices do not indicate the potential economic benefits to any individual country but only for the countries comprising the region studied. However, the studies did show the impact of fuel reprocessing and the management of the generated radioactive wastes on a nuclear power programme. **Figure 2** indicates that part of the nuclear power generation costs which can be attributable to fuel reprocessing and management of the radioactive wastes. The waste management costs include solid waste burial, which are relatively insignificant, and high-level waste solidification and interim storage of the solid high-level and alpha-bearing wastes.

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* Capital investment and operating cost indices are not additive.

** Includes waste management through solid waste storage.

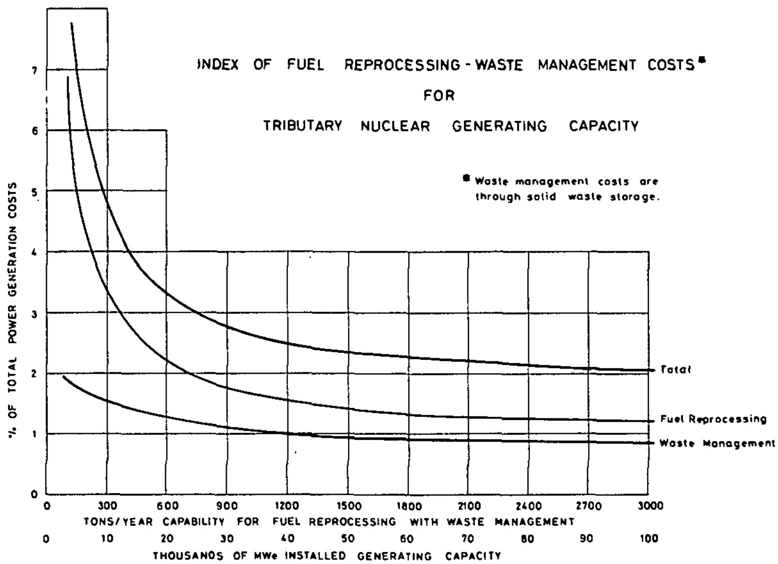

FIGURE 2

Both the cost index tabulation and Figure 2 show there are significant economic incentives for countries with smaller nuclear power programmes to co-operate in considering regional centres for fuel reprocessing and handling the radioactive waste therefrom. From Figure 2, it appears that the waste management costs will comprise from thirty-three to forty percent of the total fuel reprocessing — waste management costs, or range from about a half up to two-thirds of the fuel reprocessing costs. As previously qualified, the waste management costs included solid waste burial, high-level waste solidification and high-level and alpha-bearing solid waste storage in surface facilities, but not waste disposal.

Besides any economic advantages, there are at least two other good reasons, from a waste management standpoint, for international co-operation in using regional centres for nuclear fuel reprocessing and handling the radioactive wastes. One reason is to reduce the number of sources of radioactive contamination and the number of facilities contaminated with radioactivity. This would be particularly significant thirty to fifty or more years from now when many nuclear facilities constructed today will have served their useful lives and must be decommissioned to a safe condition. Another reason is that well-located, well-managed, well-staffed, well-operated regional centres should significantly reduce the risk of an accidental large release of radionuclides into the environment or of causing a major radiation exposure to a population group. Such a release or an exposure probably would cause a world-wide adverse public reaction, possibly to the extent of disrupting large nuclear power programmes in developed nations as well as having an adverse impact in developing countries. Consequently, it would appear to be in the best interest of those nations well advanced in nuclear power generation and nuclear technology to provide all possible co-operation and encouragement in the development of suitably located regional fuel reprocessing and waste management centres in order to minimize the number of smaller fuel reprocessing centres and radioactively contaminated sites, and also to avoid the possibility that some of them may be inadequately equipped or operated with respect to the safe handling of radioactive materials, especially wastes.

As was recently pointed out by a group of Senior Advisors convened by the IAEA to review radioactive waste management technology, "... it is not possible to separate considerations of spent fuel processing from waste management activities. The availability of an adequate and proven system for ultimate disposal of radioactive wastes will be an important element in the decisions concerning the installation of regional reprocessing centres." And one might add, this applies to the construction of any fuel reprocessing facility – no matter where it is located. Consequently, this suggests that there should be a concentrated co-operative effort among those countries having or considering nuclear power to resolve the question of high-level and alpha-bearing waste disposal as quickly as possible. This is not a small task. One or two countries cannot do it all. Both its urgency and the resources required call for international co-operation.

MATURITY OF NUCLEAR ENERGY

The theme for the First European Nuclear Conference was the Maturity of Nuclear Energy. Maturity should not necessarily mean that the best possible technology has been developed and is being applied but that existing technology can be successfully applied where it is needed. In this respect, one can say that radioactive waste management is one off-spring of nuclear energy which, while well on the road, has not reached maturity. What is there yet to be done? Hopefully, it is clear what we think should be done.

In spite of civil and public impediments, nuclear reactors are going to continue to be built and operated and spent nuclear fuels will be discharged in increasing quantities. What is to be done with them and their radioactive wastes? A criterion of maturity is reasonable co-operation. For nations to achieve nuclear maturity, there must be a co-operative effort amongst them to manage nuclear energy wisely and safely and join together in minimizing the impact of the disadvantages, such as the radioactive wastes, that arise from its use.

REFERENCES

1. Martin A. and ApSimon H. (1974) Population Dose Evaluation and Standards for Man and His Environment, pp. 15–26, IAEA, Vienna. STI/PUB/375