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# LONG-TERM STORAGE OF RADIOACTIVE WASTE: IAEA PERSPECTIVES ON SAFETY AND SUSTAINABILITY

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## ABSTRACT

As the amounts of radioactive waste in surface storage have increased, concern has grown over the safety and sustainability of storage in the long term. In response to increasing concerns, the International Atomic Energy Agency (IAEA) has included an action to address the safety implications of the long-term storage (LTS) of radioactive waste in its action plan for waste safety; the action plan was endorsed by the IAEA's Member States in 2001 [1]. In 2003, the IAEA published a position paper on the safety and sustainability of LTS as part fulfilment of the action in question. A key theme of the position paper is the contrast of safety and sustainability implications of LTS with those of disposal. The present paper provides a summary of the position paper, describes current IAEA activities that deal with the subject of LTS, and discusses findings from the 2004 Cordoba symposium on disposal of low activity radioactive waste that pertain to LTS.

## I. INTRODUCTION

Storage and disposal of radioactive waste are complementary rather than competing activities, and both are required for the safe management of wastes. Storage has been carried out safely within the past few decades, and there is a high degree of confidence that it can be continued safely for limited periods of time. In some countries, radioactive waste has been stored for periods that exceed the original design life of containers and storage facilities. In other countries, plans to implement disposal of radioactive waste have been delayed or postponed, and hence LTS has become the default management option. As the amounts of radioactive waste in surface storage have increased, concern has grown over the sustainability of storage in the long term and the associated safety and security implications.

The growing concern with LTS of radioactive waste has been reflected in IAEA programmes. At the international conference on the *Safety of Radioactive Waste Management* that was held in Cordoba, Spain, from 13 to 17 March 2000 it was concluded that uncertainty about eventual disposal causes problems for predisposal management (e.g. the possible need to recondition waste for a different disposal concept), and these problems will increase if disposal continues to be delayed. These findings were incorporated into the IAEA's 2001 action plan for waste safety [1] as: *Action #2: Assess the safety implications of the extended storage of radioactive waste and of any future reconditioning which may be necessary.* This action was revised in 2003 to include an additional clause that called for the development of safety standards for the LTS of radioactive waste [2].

In response to Action #2, the IAEA has undertaken several activities. Experts were brought together to write a position paper, intended for general readership, on the safety and sustainability aspects of the LTS of radioactive waste [3]. A project to explore systematic methods for safety assessment of predisposal waste management activities was launched in

2004 that includes safety assessment of LTS. In 2005, the IAEA will hold a series of meetings to draft a safety report on LTS, to further develop the lines of thought captured in the position paper. The present paper provides a summary of these activities, and includes a discussion of findings relevant for LTS from a recent IAEA symposium.

## II. STORAGE AND DISPOSAL

In 1995 the IAEA published "The Principles of Radioactive Waste Management" [4]. These safety fundamentals reflected an international consensus on principles important to the safety of radioactive waste management. Principle No. 5 is that "Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations". It has been broadly interpreted to imply that the generation that creates radioactive waste should make all the arrangements needed for the disposal of the waste.

In most countries, nuclear power generation and other applications of radioactive materials started before plans for the disposal of the resulting radioactive waste were well developed. As waste arose, it was most frequently stored in various types of engineered containment on the surface and at sites to which access was controlled.

Research and development work on waste disposal has shown that, in principle, all types of radioactive waste can be disposed of in a manner that provides protection for the health and safety of people and the environment. Disposal of low-level radioactive waste (LLRW) in engineered, near-surface facilities is now common practice. For high-level and long-lived radioactive waste, the consensus of the waste management experts internationally is that disposal in deep underground engineered facilities—geological disposal—is the best option that is currently available, or likely to be available in the foreseeable future [5]. This option is under investigation in most countries with significant amounts of such waste, and two countries have now made formal Government decisions to go ahead with facilities for the disposal of high-level waste (HLW).

Storage is an important element in the safe management of radioactive waste and may be required for different purposes at different stages in the management of waste. It is necessary to store spent nuclear fuel (SNF), HLW and some other types of waste for a period of time, to allow radioactive decay to reduce the levels of radiation and heat generation. For other types of waste, it is an interim step in the overall process of waste management and lasts for comparatively short periods of time.

The characteristics of storage and disposal facilities may vary significantly. It is useful to summarize the features and characteristics of storage and disposal facilities that are pertinent to the discussion that follows. In the present paper, storage means holding the waste material in engineered facilities on surface; storage is inherently temporary, with the implication that the waste material will be transferred at some future time to a permanent repository, i.e. a disposal facility.

### *Storage Facilities*

Up to the present, storage facilities for SNF and HLW have typically been above ground or at very shallow depth. SNF is stored either dry or under water. Most SNF, for example, is stored under water for a period of at least three to five years after removal from the nuclear reactor, the water serving as radiation shielding and also as a means of maintaining the spent fuel elements at an acceptably low temperature. In some countries, the spent fuel is then transferred to storage in dry conditions. SNF can also be reprocessed and the resulting highly radioactive liquors are solidified by vitrification. Most other solid radioactive waste is stored in dry conditions.

Depending on its characteristics, the waste may undergo conditioning before being packaged inside a container. Some containers used for this purpose are designed to be extremely durable and resistant to corrosion or other forms of degradation for many years. The containers are then stored inside a suitable structure, often constructed from concrete, to provide radiation shielding and security. These structures, whether buildings in the conventional sense or other types of massive form, are usually located at a secure site inside a perimeter security fence.

*Disposal Facilities*

Among technical experts, the generally accepted method for disposing of radioactive waste is to adequately contain the waste, and isolate it from the environment generally accessible to humans pending its natural radioactive decay. For short-lived LLRW, isolation and containment must only be maintained for comparatively short periods of time, typically 300 years. Near-surface disposal facilities, by means of siting, engineered barriers and active controls, provide the required containment and isolation for short-lived LLRW. For SNF and HLW, isolation of wastes is thought to be best achieved through its emplacement at significant depths underground in stable geological formations, that is, by "geological disposal". Containment and isolation of the waste is provided both by the containers into which the waste is put before being emplaced in the repository and by various additional engineered barriers and the natural barrier provided by the host rock. The essence of disposal is that protection of present and future generations and the environment is provided by a passive system made up of engineered and stable natural barriers.

The defining characteristic of disposal, as distinct from storage, is that there is no intention to retrieve the waste material, and there is minimal reliance on long-term active controls. In other words, the emplacement of the waste is intended to be permanent. Ultimately, a disposal facility will be closed and sealed, and from the surface there might or might not be any indication of the facility that is at some considerable depth below. In most rock types, a repository can be designed such that closure of the facility can be delayed for a period of several tens to a few hundred years. In this period, monitoring of the repository and the surrounding environment can be performed if desired, and the facility can be designed to allow for retrieval of the emplaced material.

## III. POSITION PAPER ON LONG-TERM SAFETY AND SUSTAINABILITY

In the position paper [3], sustainability and safety aspects of LTS are compared with those of geological disposal. Sustainability is achieved by: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]. Regardless of the type of development, the challenge for sustainability is to balance competing environmental, social and economic dimensions in a sustainable manner [7]. A number of factors are examined from different points of view, factors such as safety and security, need of maintenance, institutional control and information transfer, community attitudes and availability of funding. The timing and duration of the process of moving from storage to disposal, which are influenced by factors such as the long timeframes required to implement disposal and changing public attitudes, are also discussed.

The position paper focuses on the storage of three main types of waste: HLW from the reprocessing of SNF, SNF that is regarded as waste and long-lived intermediate level radioactive waste. LTS of mining and milling waste, and other large volumes of waste from processes involving the use of materials containing naturally occurring radionuclides were not discussed.

*Safety*

The feasibility of safely storing radioactive waste over periods of decades has been clearly demonstrated during the operation of existing facilities. When waste packages are stored it is inevitable that some structural degradation of the packages and their contents will occur over time [8]. This deterioration will require that the waste be transferred at some time in the future, if not to a disposal facility, then to another storage facility. The longer the waste is stored before transfer to another facility, the greater are the probabilities that such degradation will occur, with resultant potential of radiation exposure for the workers who will eventually have to carry out the transfer and handling operations. In this regard, long-term safety is not well served by very long periods of storage. Furthermore, waste stores are vulnerable to inadvertent or deliberate intrusion by humans if not kept under close surveillance, and to more extreme disruptive natural events. This places obligations on future generations to maintain active surveillance of waste stores.

Geological disposal promises to provide containment and isolation of radioactive waste from the human environment for the very long periods required for safety. As discussed earlier, geological repositories are designed to provide this isolation without the need for active controls, i.e. they are passively safe. Safety concerns due to possible human intrusion into the waste or impact by natural events are very much reduced as compared to surface storage, owing mainly to the significant depths under the surface at which geological repositories will be located. However, while most experts are convinced that geological disposal provides the best solution for the management of high level waste, experience of operating repositories has not yet been obtained.

*Maintenance / Institutional Control*

Maintenance requires both the detection and repair of deficiencies. Not only is it easier to repair anything that needs to be repaired when it is on the surface and accessible, compared with when it is underground, but it is also easier to detect deficiencies at their formative stage in a facility that is located on the surface of the ground. Effective maintenance, therefore, is favoured by a surface location. On the other hand, geological disposal systems are designed so that any degradation in a protective barrier should not result in an impact on people and the environment because of the presence of other independent engineered and natural barriers. Maintenance should not therefore be required.

Since adequate protection of humans and the environment will continue only as long as maintenance and security are continued on storage facilities, and since some of the radioactive material in storage will remain hazardous for many thousands of years, institutional control would be required for such periods of time or until permanent disposal is implemented. Institutional control requires the continued existence of authorities and institutions that can ensure that necessary maintenance and security are carried out. History indicates that change and turmoil usually occur in much shorter periods of time, and therefore that it is unlikely that any societal infrastructure currently in place or envisaged would last for the time period needed. Surface or near-surface storage facilities will also be more vulnerable to extreme disruptive natural events.

*Retrieval*

An advantage of surface storage is the ease of retrieving material, if it should be decided to do so. Having the possibility of retrieving the waste preserves for future generations the option of making different decisions concerning the existing radioactive waste inventory than the present generation might make. It preserves for future generations, for example, the option of recycling the material by reprocessing. Work has been done recently in several national programmes to evaluate the feasibility of retrieval from geological disposal facilities.

Provisions for retrievability can be incorporated into both storage facilities and geological disposal facilities. However, retrievability remains an option only as long as institutional controls and the necessary technical expertise exist and where a suitable alternative management option for the waste has been developed. If all these elements exist, retrievability would be possible for both storage and disposal.

*Security*

Over the last few decades, security of nuclear materials has been of increasing concern. Occurrences of illicit trafficking and recent terrorist events have heightened these concerns.

The security threat is one of either unauthorized possession, theft of the material for illicit use later, or sabotage to cause incidents on-site, e.g. by dispersing the material to the environment.

While nuclear material has traditionally attracted security precautions to prevent it falling into unauthorized possession, it is now recognized that non-fissile material must also be protected because of the possible threat of deliberate spreading of contamination by terrorists. The material is much more vulnerable to attack if placed on the surface. In geological disposal facilities, it is beyond the reach of all but the most determined and sophisticated of individuals or groups.

Long-term surface storage is not the best option from the security point of view because SNF and HLW in surface storage are more vulnerable to theft and sabotage. Security considerations, which carry increasing weight, lead strongly and unequivocally to disposal being desirable, at as early a date as is reasonable to be achieved. Placing the waste material underground, even without finally closing the facility, greatly increases the difficulty of access to the material by unauthorized persons, however, it imposes the additional burden of maintaining the disposal facility.

*Costs*

In the context of storage and disposal, sustainability would require that the costs for ongoing and long-term management of storage and disposal facilities be internalised; internalised costs are costs that are borne directly by those who receive the benefits. The United Nations Commission on Sustainable Development has called upon governments to internalise radioactive waste management costs, to the maximum extent possible [9]. If LTS is to be sustainable, then sufficient funds should be set aside to maintain ongoing storage and to address future management actions, such as refurbishments, reprocessing or disposals. Long-term interest and inflation rates cannot be predicted with accuracy; cost projections for actions beyond one generation (about 30 years) would have a great deal of associated uncertainty. Hence, any estimate for the funding required for sustaining LTS will have large uncertainties.

The very large capital cost associated with a disposal facility is a significant factor, especially given the long time (of the order of 20 years and more) between starting work towards a geological disposal option and emplacing waste in the facility. Many jurisdictions have taken the step of requiring utilities that generate nuclear power to set aside funds on a continuing basis to pay for the future cost of disposal of the related waste (i.e., costs are internalised). Although ongoing storage requires the continuing expenditure of resources to ensure safety and security, the annual resource requirement is very much less than is needed during the limited period for developing, constructing and operating an underground disposal facility.

Economic considerations are complex and variable depending, for example, on whether a fund has been created specifically to pay for disposal and is protected against use for other purposes. Internalised environmental costs are a key indicator for the long-term sustainability of a practice. If a fund exists to internalise disposal costs, there is an economic argument for proceeding with disposal, but if it does not exist, the capital cost of a disposal facility can result in economic considerations favouring the continuation of storage.

*Community Attitudes*

For several reasons, there may appear to be less opposition to siting or expanding a storage facility compared with a disposal facility. It is well established that the level of acceptance of new or expanded storage facilities is greater in communities that have lived alongside nuclear installations for many years—often because it is just a continuation of existing practice. Establishing a disposal facility is a process with many decision points, any one of which can lead to rejection—there are generally fewer decision points in the process to expand existing storage facilities. Storage is understood to be an intermediate step in the management of wastes and disposal is permanent—perhaps another reason why storage appears to have greater acceptance.

The current societal opinion, although not uniform, does not appear to be strongly in favour of disposal. This results in de facto continued storage on the surface. Political considerations put a great deal of weight on societal opinion since those affect the way the electorate votes. Although there are good reasons to favour disposal, they do not provide a strong political driving force towards disposal.

Community acceptance for siting a geological disposal facility is linked to a number of issues. Concerns are often expressed about the safety of such facilities and the ability to detect and mitigate any problems that may occur. The permanence of disposal is unattractive to some because it deprives future generations of the option to choose how the wastes are managed. Transport of waste is also sometimes cited as an issue where community acceptance is low, in spite of an impressive record of transport safety worldwide. In contrast to this, new storage capacity may simply be an extension to an existing licence at a site where nuclear installations are already operating. This perhaps contributes to a perception that storage facilities are more accepted than disposal facilities.

*Transfer of Information*

The operations needed to ensure the safety of LTS, such as security, regulatory oversight and inspections, require that a great deal of information is retained. Since one must expect to carry out maintenance operations on the fac ility, and eventually transfer the waste packages, the information required relates to the waste inventory, its characteristics and storage location, the technology used for conditioning and packaging, and the design of the storage facility. All this information must be retained for the entire life of the storage facility. Not only must this information be retained, but it must also be readable and understandable to future generations.

Ideally, the same information would be available to future generations for a waste disposal facility as for a storage facility. But if the information transfer into the future is incomplete, the consequences in the case of a disposal facility should be of no safety concern, given that its design and construction are intended to place little or no reliance on human activity for long-term safety. Therefore, from the perspective of information transfer, safety in the long-term is better assured by disposing of the waste material as soon as practicable.

*International Safeguards*

For nuclear materials, safeguards have to be applied to assure that nuclear material is not diverted. States that are signatories of the Treaty on the Non-Proliferation of Nuclear Weapons [10] are required to ensure that nuclear materials within their control are not diverted for undeclared or non-peaceful uses. The IAEA through its safeguards role is responsible for providing independent, international verification that governments are abiding by their commitments with respect to the Treaty on the Non-Proliferation of Nuclear Weapons. The system of safeguards is well established for surface storage facilities.

IAEA Safeguards Policy Series 15 (July 1997) establishes requirements for IAEA safeguards implementation at geological repositories; the specific measures that will be taken to meet these requirements are still to be determined. During the operational phase, safeguards for geological disposal facilities will likely require additional measures and effort compared with surface storage facilities. Safeguards of nuclear material in geological disposal will have to continue even after facilities have been closed and sealed. However, it is expected that in the post-closure phase of geological repositories safeguards assurances could be obtained with a limited effort.

## IV. FINDINGS FROM THE 2004 CORDOBA SYMPOSIUM

The IAEA organized a symposium on Disposal of Low Activity Radioactive Waste that was held in Cordoba, Spain from the 13 to 17 of December, 2004. The term "low activity radioactive waste" used in the title of the Symposium is not one of the defined international waste categories but was used to describe a wide range of waste types, many of which are not currently categorized in international and national radioactive waste classification schemes. Although the symposium was largely concerned with disposal of radioactive waste, a number of issues arose that concern LTS.

Developing countries usually have comparatively small amounts of radioactive waste making the normal methods used for waste management in countries with nuclear power plants very costly in terms of cost per waste volume. Hence, in many countries, LTS rather than disposal has become the default management option. Economies of scale can be achieved through regional solutions and countries within a region were encouraged to consider such approaches. The subject can be politically sensitive but progress might be made by means of a step-by-step approach, starting, for example, with regional waste processing facilities before moving eventually to the more difficult area of disposal. In discussions it was suggested that an important first step towards indicating that a country has a serious commitment to managing its radioactive waste safely is to have an established national waste management strategy setting out priorities, plans and responsibilities.

There was a presentation describing work undertaken to demonstrate the potential for boreholes, sunk to intermediate-depth in thick alluvial deposits, to safely isolate disused sealed sources. This is a conceptually simple, low-cost, option, potentially of interest to countries having small amounts of waste and limited resources to deal with the problem. Work is underway to explore the potential for employing the technique for the safe disposal of spent sealed sources in some of the IAEA's African Member States.

There was also continued debate about the effectiveness of institutional controls, and additional guidance and examples of their use would be of benefit to countries that have to rely on them. One issue concerns the amount of reliance to be placed on passive controls, such as markers, as compared with active controls, such as monitoring. Both points of view were debated. In any case, it seems inevitable that institutional controls will be used, but that steps will have to be taken to ensure that they are effective, and better understood. It was noted that the consequences of their failure need to be considered, for example, as part of a safety assessment, because they can range from very large, if a highly radioactive sealed source is dug up, to very small, if a fence is breached and an unplanned land use occurs on land contaminated with relatively low concentrations of radioactive material.

## V. CURRENT IAEA ACTIVITIES

The position paper touches upon many of the key issues for LTS, however, the discussion is not exhaustive, nor does it provide quantitative or semi-quantitative analysis of the issues raised. As such, it partially fulfils the objectives of Action #2.

Safety assessment studies, laboratory and field experiments, and investigations carried out in underground research laboratories have created an impressive body of knowledge to support the safety and feasibility of geological disposal. There has been less effort to examine the safety implications of LTS, even though a large inventory of wastes might eventually be managed under LTS arrangements in the foreseeable future. In current IAEA programmes, there are two activities to develop further the safety implications of LTS: the SADRWMS Project that was launched in 2004, and a project that begins in 2005 to develop a safety report on the LTS of radioactive waste.

SADRWMS stands for Safety Assessment Driving Radioactive Waste Management Solutions. For over a decade, the IAEA has coordinated and led projects that have focused on safety assessment for near-surface disposal of radioactive waste (e.g., the NSARS, ISAM and ASAM projects). However, there has not been any international effort to compare the techniques and methods applied for safety assessment of predisposal waste management practices, although such assessments have been carried out for many years now. The SADRWMS project will provide a forum for the exchange of information and good practices on safety assessment methodologies used worldwide. It will also provide an opportunity for reaching broad consensus on the methodologies used to perform safety assessments for storage facilities. A particular focus of the SADRWMS project will be the application of safety assessment methodologies for issues that arise from LTS.

In addition, a Technical Meeting (TM) will be held at IAEA Headquarters from the 23 to 27 of May, 2005 to develop a safety report on LTS of radioactive waste including spent nuclear fuel. The safety report will be a continuation of the position paper, but is intended to provide a more detailed and quantitative exploration of the issues raised in the latter. It will also provide new material to serve as a foundation for development of safety standards (or sections thereof). The TM, which will be the first of several meetings, will be used to identify and discuss safety and sustainability issues to provide a basis for development of the safety report.

## VI. CONCLUSIONS

The issue of whether to pursue LTS or dispose of radioactive waste is not one that is solely technical. Factors of a socio-economic and ethical nature are also very relevant—factors that do not all influence the debate in the same direction. It is undesirable to leave an unsolved problem to a future generation, although it is also undesirable to deprive future generations of certain options because of actions taken by the present generation. It is sometimes claimed that this argument would quickly lead to justifying no actions by the current generation on many issues, and that pre-emption of future options is acceptable ethically, provided that the current action leads to a result that is well-motivated and reasonable in the light of current knowledge.

With respect to safety, there are two conflicting arguments. The fact that safe surface storage requires ongoing inspection and maintenance is a strong argument for underground disposal, since at some point in the future, one must expect discontinuation of the present infrastructures that provide for such inspection and maintenance. The main contradictory argument is the claim that the ease of corrective action in surface facilities can contribute to an improved level of assurance of safety.

Storage is a necessary phase in safely managing most types of radioactive waste. Storage has been carried out safely within the past few decades, and there is a high degree of confidence that it can be continued safely for limited periods of time. Concerning LTS, the arguments that have been presented in the position paper can be summarized as follows:

- Storage of radioactive waste has been demonstrated to be safe over some decades and can be relied upon to provide safety as long as active surveillance and maintenance is assured. In contrast, geological disposal promises long-term safety without surveillance and maintenance;
- Maintenance is easier on the surface than underground, but institutional controls cannot be maintained for the period that the wastes remain hazardous;
- Retrieval of material is easier from surface facilities than from underground facilities; but geological disposal can be developed in stages so that the possibility of retrieval is retained for a long time;
- Putting hazardous materials underground increases the security of the materials;
- Disposal has a large capital cost; storage has a significant operating cost;
- Storage facilities tend to generate less public opposition than disposal facilities;
- LTS of radioactive waste requires transfer of information to future generations.

The main conclusion of the position paper is that the safety of LTS requires the maintenance of the industrial, regulatory and security infrastructure—active controls. Active controls cannot be guaranteed in perpetuity because there is no guarantee that the necessary societal infrastructure can be maintained in perpetuity. Therefore, for wastes that remain hazardous for thousands of years, LTS does not appear to be either feasible or acceptable.

Ongoing IAEA activities will further examine issues such as surface storage versus underground storage, deferral of conditioning, requirements for maintaining the technical expertise and infrastructure to support future management of SNF and HLW, burdens to future generations, and the radiological impacts of various management alternatives. The financing of LTS also has a safety dimension; efforts to evaluate the cost uncertainties of LTS strategies, and in turn economic risks, would be of benefit for understanding long-term safety implications. It is expected that IAEA activities pertaining to the safety and sustainability of LTS will be of value to national policy and decision makers, and that these efforts will also inform the development of the IAEA's safety standards.

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