Retrievable disposal
of radioactive waste in The Netherlands

Summary

Ministry of Economic Affairs

Commission on Radioactive Waste Disposal

The Hague
February 2001

Preface

The simple facts that radioactive waste exists and that Man and the environment need to be protected for a long time to come force us to look for a safe, long-term solution.
The quality of the protective barrier between the waste and the biosphere is an important aspect of any solution for this problem. The CORA* study distinguishes between protective elements that are important in the case of surface storage and those that are relevant to underground disposal. As regards of surface storage the quality of the barrier is largely controlled by Man. In the case of underground disposal, Man still largely controls barrier quality, but the natural, insulating capacity of a specific geological cover formation offers additional, extremely long-lasting, protection.

The 1993 policy directive of the Dutch Government decrees that deep underground disposal of highly toxic waste, such as radioactive waste, will only be permitted if that waste remains retrievable for a long time. The CORA study therefore focussed on the technical feasibility of long-term retrievability of the waste.
Aboveground storage options are by definition retrievable and the protective properties of a store, such as the COVRA** facility, are considered proven. The main unsolved issue is that of safety in the very long term, i.e. tens of thousands of years.
In addition to concerns about the stability of our society, a major problem remains Man's capability to maintain a waste-disposal facility, including periodic renovation every couple of centuries. Another major problem is the capacity of a surface storage facility to withstand the catastrophic, dynamic natural processes that regularly affect the surface of the earth. Such processes would be almost insignificant for a retrievable deep underground disposal facility. In fact, should human control over such an underground disposal facility fail, the natural insulating capacity of rock salt or clay would ensure passive fail-safe protection. Our studies show that such an underground disposal facility is technically feasible.

A final solution for radioactive waste must take advantage of the strong points of both options, i.e. initially storage at the surface, followed by retrievable underground disposal. We should therefore focus on choosing the optimum timing schedule for these surface and retrievable underground disposal facilities, rather than opting for one or the other.

Even though the assignment of the Commission had a technical-scientific emphasis, disregarding the objections of society against various storage or disposal options, would not be very realistic. This prompted the Commission to include potential acceptance by society as a boundary condition in its studies. The Dutch studies are not unique in this respect. Internationally, awareness is growing that "confidence building" should be a key element of any study.

* *Commissie Opberging Radioactief Afval (Commission on Radioactive Waste Disposal)*
** *Centrale Organisatie Voor Radioactief Afval (Central Organisation for Radioactive Waste)*

The Dutch policy of assured access to any storage or disposal facility to guarantee retrievability resolves many objections amongst the public. Most of these objections are summarised in the traditional saying: 'seeing is believing'. The objectives of retrievability and ensuing accessibility have the following consequences:

Resulting from retrievability

- Future transmutation of the waste would be possible if techniques that are currently being developed permit - partial - deactivation some time in the future.
- The waste remains available for recycling.
- The waste can be removed in case of undesirable events.

Resulting from accessibility

- Practical research can be carried out in the actual setting to verify modelling results.
- Technical improvements can be made as new know-how and expertise become available.
- 'Second-opinion' studies can be conducted.
- Information can be disseminated widely by means of (underground) visits during a demonstration phase and by media coverage.

The Commission believes this would broaden the basis for a meaningful community-wide debate. The main questions to be addressed in such a debate are, for the short term, what our priorities should be in the light of the above aspects, what features should be evaluated and what issues should be addressed in further studies.

Moreover, the retrievable option does not require us to take irrevocable decisions, rather step-wise incremental decisions. The final decision-making process can be based on the knowledge and experience acquired during a long period of fact finding and monitoring.

Retrievability can provide a solid base for a community debate on radioactive waste, not only building confidence in potentially acceptable technical options, but especially leading to agreement about the procedures that should be followed to implement these options.

Bob P. Hageman
Chairman Commission on Radioactive Waste Disposal

Retrievable disposal of radioactive waste in The Netherlands

Summary

Introduction

In The Netherlands a research programme on retrievable disposal of radioactive waste was initiated in line with the 1993 policy directive of the Dutch Government. This directive states that underground disposal of highly toxic waste (including radioactive waste) is permitted provided it is retrievable for a long period of time.
The Commission CORA (Commission on radioactive waste disposal) has been established to co-ordinate such a programme aimed at a comparison of the merits of long-term surface storage with (deep) underground disposal in various host rocks. In addition, attention had to be given to the prospects of transmutation of actinides and direct disposal (without reprocessing) of spent fuel from the research reactors as well as to any other risk reduction methods.
Research was focussed on three options for retrievable storage or disposal: long-term aboveground or underground in either rock-salt formations or deep clay deposits. For each of these three options, the retrievability and safety aspects have been evaluated.
Obviously, safety is a crucial prerequisite for any option. A multi-barrier system consisting of artificial and natural barriers has to ensure isolation of the waste to avoid the creation of a hazard. Preferably, a disposal facility should be fail-safe, in case of the possible loss of human control over the facility.
Retrievability of the waste allows future generations to make their own choices. but is dependent on the facility being kept accessible for a long time for inspection and monitoring. However, it entails a greater risk of exposure to radiation and requires a long-term organisational effort involving maintenance, data management, monitoring and supervision. In particular for underground disposal retrievability will make the construction and operation more complex and results in additional costs.
The study includes an estimate of the costs and briefly addresses the prospects of other risk reduction methods.
The programme has greatly benefited from the collaboration with research institutes in Belgium and Germany. International collaboration is also considered essential for the future.
The task of the CORA Commission was of a technical-scientific nature. However, in view of the public awareness of the waste-disposal issue, the Commission included two studies of the societal and ethical aspects.

The research programme is concerned primarily with highly active waste, as this forms the greatest challenge. The main types of waste are the vitrified high-level waste (HLW) from the nuclear power plants at Dodewaard and Borsele and the spent fuel (SF) from the Dutch reactors for medical and scientific research in Petten and Delft. The total volume of this highly active waste is approximately 125 m^3. The bulk of nuclear waste is low to medium active and have short half-life times and decays within a few hundred years to non-radio-active industrial waste.

As a result of the high percentage of enriched uranium present in the SF, the IAEA (International Atomic Energy Agency) non-proliferation regulations also apply to the storage and disposal of this material.

The CORA research programme comprises 21 projects, with contributions from 20 research institutes both in the Netherlands and abroad. The programme was carried out during the period from 1996 to 2000 at a cost of around € 3.5 million. The Dutch Ministry of Economic Affairs contributed € 2.5 million, the European Commission € 0.3 million and the research institutes themselves approximately € 0.7 million.

Long-term surface storage

The study of the long-term retrievable storage at the surface has been based on the existing COVRA facility at Borsele (near Flushing) and examines the technical feasibility of extending the storage period from the currently envisaged 100 to some 300 years.

Retrievability

Individual waste containers from an surface storage facility such as at COVRA (Central Organization for Radioactive Waste) can be retrieved comparatively fast and simply. Storage of HLW and SF may require complete, c.q. partial replacement of the building every 100 years.
It is concluded that adequate maintenance and replacement will indeed enable to extend the life span of the existing and planned buildings to approximately 300 years.

Safety

A scoping study analysing the consequences of a possible inundation of the COVRA facility within the next 300 years indicated that inundation will have only a minor effect on the radiation levels in the biosphere. Inundation will increase the levels by only a fraction of the average ambient dose rate prevailing in The Netherlands (~ 2.4 mSv/y).
The study assumes that only containers with low and medium-level waste (LLW/ILW) end up in sea, remain in tact and only small amounts of the waste dissolve by diffusion. The consequences of a HLW-storage facility becoming flooded are supposed to be manageable. The storage facility is watertight up to a water level of 10 metres above mean sea level.
Sea level rise, resulting from climate changes is expected occur gradually such that additional protective measures can be taken in time.

Retrievable disposal in a rock-salt formation

An underground facility is similar to a conventional mine and consists of shafts and galleries in a rock-salt formation at a depth of approximately 800 metres. Such mines exist at many places over the world and are considered proven technology.

Retrievability

Salt shows creep under high pressure and will gradually compress any voids thereby ensuring that the waste will eventually be sealed off regardless of human intervention. In other words, the long term disposal in salt offers the advantage of a fail-safe situation. However, creep is a slow process and experience shows that, with adequate maintenance, mines in rock salt can be kept open for more than 100 years.

The disposal concept contains short horizontal disposal cells drilled into the side walls of a gallery, each accommodating one HLW container. The annular space around the container is filled with crushed salt and the cell is sealed off with salt blocks. Retrieval requires a special machine to drill out the salt around the waste container. It is concluded that retrievable disposal of HLW in a rock-salt formation is technically quite feasible.

Safety

A worst case scenario of inadequate maintenance is considered, resulting in flooding of the underground disposal facility, causing the HLW to be dissolved and dispersed in the groundwater. It has been calculated that under these conditions the annual dose rate-level to a representative individual in the biosphere will gradually increase and reach a maximum after 100,000 years. This level, however, is still much lower than the ambient dose rate of approximately 2.4 mSv/y, also if the facility contains SF from research reactors.

Criticality (spontaneous nuclear chain reaction) does not present a safety hazard for the proposed concept for disposal of SF containers from research reactors. Water ingress in the form of saturated brine will actually reduce the criticality factor to a value below 0.4 due to the high absorption cross section of chlorine for thermal neutrons.

Laboratory investigations indicate that ionising radiation from the waste may create damage to the crystal lattice of the salt by the creation of minute voids giving rise to sudden energy releases. It appears that this effect can be reduced by sealing off the waste containers with materials that are less prone to radiation damage.
An other study indicates that backfilling of waste containers with a hygroscopic material such as calciumchloride can reduce corrosion and gas production.

Retrievable disposal in a clay deposit

Since 1980 experience has been gained with the construction of underground caverns in clay deposits for the disposal of radioactive waste in Belgium. The Belgian design therefore has served as a prototype, albeit adapted to permit retrieval of HLW from clay deposits at a depth of at least 500 metres.

Retrievability

The limited technical data available for clays in The Netherlands were supplemented with data on Belgian clay deposits. The disposal and retrieval concept is essentially the same as for rock salt, except that in this case clay/bentonite is used to seal off the disposal cells and that the galleries must be supported by a concrete wall. Moreover, the containers either have an extra overpack or are placed in a lined disposal cell as a protection against corrosion by moisture from the clay. Technical implementation of the adapted design seems feasible.

Safety

Assuming the same worst case scenario as for rock salt, it was found that for HLW disposal the maximum annual dose rate to a representative individual in the biosphere occurs after about 200,000 year and will be higher than for salt, but remains still low in comparison with the ambient dose rate. The calculations are based on assumptions that may be on the pessimistic side but which were adopted for want of reliable data on the properties of deep clay layers in The Netherlands.

In the disposal situation of SF containers from the research reactors ingress of water can not be ruled out. Criticality can be avoided by using small containers containing a small number of spent fuel elements, or by filling the spaces in the containers with special materials.

Other options to reduce risks

Internationally reduction of the effective half-life time of the waste is investigated by separating highly radiotoxic, long-lived nuclides (such as the actinides plutonium, americium, uranium, neptunium) from the bulk of the waste and the transmutation of these into nuclides that have a much shorter half-life. To reduce the radiotoxicity research is also being done on the possibilities of immobilising those nuclides that are hard to transmute and relatively mobile such as caesium, technetium and iodine. The immobilised materials should keep their properties during long-time disposal. These investigations show some promise, but are yet in an early stage of development.
At present the transmutation or "burning" of plutonium takes already place by using MOX fuel (a mixture of uranium and plutonium) in existing nuclear reactors, but eventually, accelerator-driven reactors would be required to burn the actinides more efficiently.
Most of the Dutch HLW is reprocessed, i.e. the uranium and plutonium has been substracted from the waste for potential re-use. The remaining waste is presently embedded in molten glass or cement and separation and transmutation would therefore be difficult.

Societal aspects

In the community debate on disposal of radioactive waste, risk perception is a key element. Advantages of retrievable disposal are that no irrevocable decisions have to be taken, that it allows continuous monitoring and that the possibility of alternative solutions remains open as long as the facility is accessible. Moreover, the community at large has to be involved more closely in the technical and societal aspects of the waste issue.
A scoping study into the societal aspects, including an inquiry among Dutch environmental organisations, confirms that the waste problem is associated with the negative image of nuclear power and with the fear that solving the waste problem could imply renewed deployment of nuclear energy. The organisations express a lack of confidence in the feasibility and safety of underground disposal.
Experience in other countries with inquiries where stakeholders could express their opinion on the selection of disposal options and sites indicates that it is very difficult to reach a consensus.

Cost aspects

The cost of extending the life span of a surface storage facility such as COVRA, from approximately 100 years to about 300 years amounts to some 90 M€ in capital and operating expenses.
Constructing, operating and closing down a retrievable underground disposal facility in rock salt will cost about 250 M€, and in clay deposits about 600 M€. Keeping an underground disposal facility open for retrieval of the waste would entail an annual expenditure of around 1.8 M€ for maintenance, management and inspection.

International co-operation

Joint international research on the disposal of radioactive waste is essential in view of the complexity of the problem. Proving the technical feasibility and safety of disposal concepts requires extensive and expensive testing under in-situ conditions. Countries that are studying the feasibility of underground disposal in similar rocks (granite, clay or salt), therefore often combine forces, so as to optimise the use of knowledge and resources and enhance the quality of the research.

To demonstrate the safety of underground disposal options bore hole samples from the salt or clay deposits are necessary, as well as tests in an underground laboratory. The Netherlands lacks such a laboratory and collection of in-situ data for this purpose by drilling is not permitted. Collaboration therefore is proposed with countries where these restrictions do not exist, such as Germany (salt) and Belgium (clay). This is also desirable in view of our relatively small volume of radioactive waste. Such a collaboration also fits in the European Union concept, but will have considerable financial implications.

Other reasons for co-operation on a European level are the prospects of a regional European approach that might lead to an optimum solution both from a safety and from an economic viewpoint and optimising environmental protection beyond national borders.

Another issue requiring a joint European approach stems from the more stringent regulations regarding radioactive material recently issued by the European Commission. This would lead to large volumes of residues of a natural origin being classified as low-level material for which no storage or disposal concept exists as yet.

Most of the current international co-operation projects were initiated through international organisations such as the European Union (EU), the International Atomic Energy Agency (IAEA/United Nations) and the Nuclear Energy Agency (NEA/Organisation for Economic Co-operation and Development). It will be desirable for The Netherlands to extend this co-operation in the future. Our particular interest lays in probabilistic analysis of retrievable disposal, participation in experiments in underground laboratories, developing monitoring techniques and strategies and in further development of ways to assess the societal/ethical aspects.

Conclusions and recommendations

Conclusions

Retrievability

1. The studies performed did not reveal any factors prohibiting the technical feasibility of the three options for retrievable disposal examined: long-term surface storage and deep underground disposal in either salt or clay deposits. For the underground options retrievability requires extra facilities. In addition a fall-back surface storage may be needed to accommodate any waste retrieved from the underground disposal facility. Based on to-day's knowledge retrievability can only be guaranteed for a few hundred years.

Comparison of the options

2. For surface storage the data used are more reliable and the retrieval operation is simpler than for underground storage. However, in contrast with underground disposal, the surface option lacks the natural multi-barrier and the fail-safe features. Therefore, eventually, underground disposal will be necessary anyhow.

Compared to rock salt, the basic data for clay are less reliable and the galleries must be supported.

Safety

3. For the case of long-term surface storage, only the risks of flooding of a properly maintained COVRA facility have been studied. On the basis of comparatively favourable assumptions a very low annual dose rate was found.
   A worst case scenario considered for underground disposal is that of inadequate maintenance, resulting in flooding of the facility. Under these conditions the annual dose rate to a representative individual in the biosphere would reach a maximum after some 100,000 years which is higher for clay than for rock salt, but still much lower than the ambient dose rate in the Netherlands of about 2.4 mSv/y.
   The calculations did not take into account the probability of these scenario's which can be expected to be much smaller than 1. On the other hand part of the basic data are subject to a large margin of uncertainty.

Risk reduction through waste treatment

4. In the long term processes for separation, transmutation and immobilisation of actinides and fission products may help to solve the waste problem. However, these processes are at an early stage of development and far from proven. Moreover, in the Netherlands, HLW remaining after reprocessing of the spent nuclear fuel, is generally embedded in molten durable glass, most likely precluding application of the processes mentioned.

Societal aspects

5. The public perception of the waste problem is influenced by the negative image of nuclear energy, the fear of renewed nuclear power generation and a lack of trust in the feasibility and safety of underground disposal.

6. An evaluation of the various options for retrievable disposal against a set of ethical/societal criteria has not yet taken place. This is considered necessary in order to reach an acceptable solution for the radioactive waste problem.

Costs

7. The long-term waste management process would probably include a phase of surface storage followed by underground retrievable disposal and final disposal. Total costs can only be calculated for a specific combination and timing of the different storage and disposal phases.

International co-operation

8. Joint international research into disposal of radioactive waste is essential, because of the complexity of the problem which calls for extensive and costly experiments in an underground laboratory. These facilities are available in e.g. Germany (for rock salt) and Belgium (for clay), but not in the Netherlands. Nor is it permitted here to collect in-situ data by means of bore hole sampling.
   Co-operation is also desirable with a view to a possible regional solution of the waste problem, common environmental problems and the fact that all EU countries are confronted with the more stringent regulations of the European Commission.

Recommendations

On the basis of these conclusions, the Commission recommends continuation of the research programme, covering both technical and societal aspects, in co-operation with other countries, notably Belgium and Germany.

Technical aspects

Further research should focus on:

1. analysis of all potential hazard scenarios for both the surface and the underground options, taking into account the probability of occurrence;

2. in-situ experiments in underground laboratories to study the responses of salt and clay to the combined effects of pressure, temperature and radiation under in-situ conditions;

3. developing, constructing and testing the monitoring systems for the period of retrievability, for all options;

4. investigation of an integrated waste management concept incorporating storage and disposal facilities, providing for different final destinations of the various types of waste, including large volumes of low-level waste of natural origin.

5. further evaluation of the long-term risks associated with flooding of the COVRA site; assessment of long-term surface storage elsewhere in The Netherlands;

6. evaluation of storage in shallow underground bunker-like structures;

7. investigation of the consequences of radiation damage in rock salt under in-situ conditions.

Ethical and societal aspects

An acceptable solution for the waste problem will eventually only be achieved if, in a public debate, the societal and the technical aspects are considered on an equivalent basis.

This calls for:

1. an inventory of all aspects and stakeholders involved in the decision-making process;

2. development of relevant societal/ethical criteria to evaluate the options for retrievable disposal;

3. an incremental decision-making procedure under independent supervision, involving all stakeholders at an early stage, based on all information available, avoiding any preconceived ideas and supported by sociological/ethical expertise.