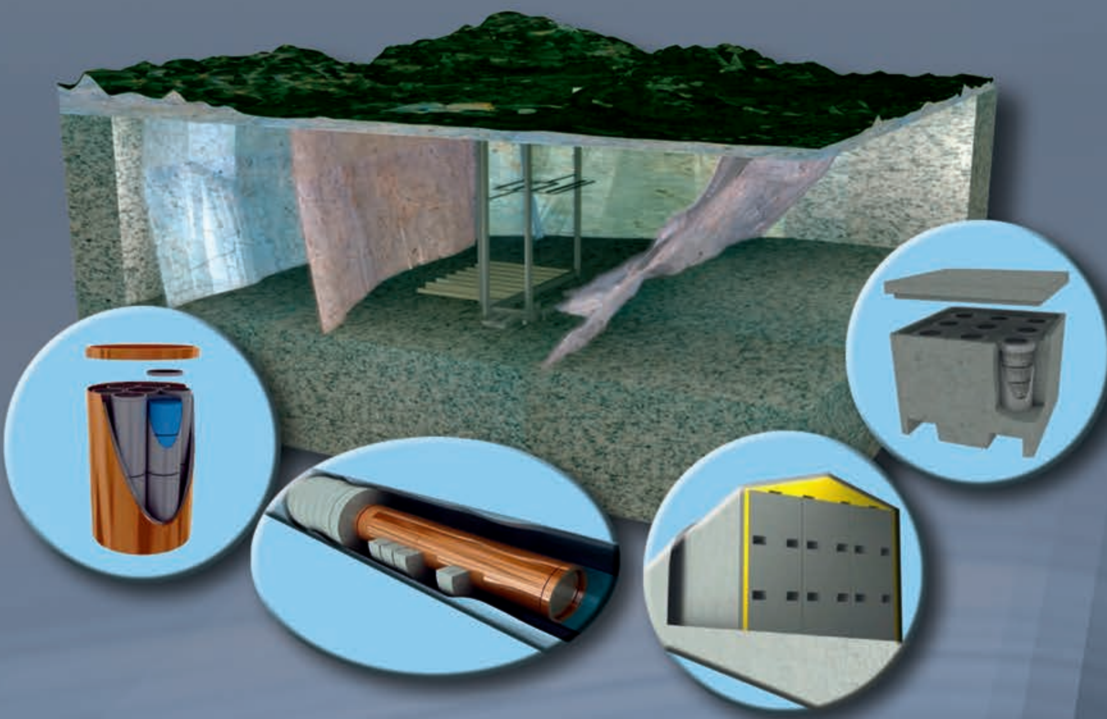
An International Peer Review of the Programme for the Deep Geological Disposal of High Level Radioactive Waste from Pyro-Processing in the Republic of Korea

Report of an IAEA International Review Team



IAEA
International Atomic Energy Agency

AN INTERNATIONAL PEER REVIEW OF THE PROGRAMME FOR THE DEEP GEOLOGICAL DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE FROM PYRO-PROCESSING IN THE REPUBLIC OF KOREA

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHRAIN
BANGLADESH
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWAZILAND
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIETNAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

AN INTERNATIONAL PEER REVIEW OF THE PROGRAMME FOR THE DEEP GEOLOGICAL DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE FROM PYRO-PROCESSING IN THE REPUBLIC OF KOREA

Report of an IAEA International Review Team

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
September 2013
IAEA-ROK

FOREWORD

The development of a radioactive waste disposal system is indispensable in maintaining the sustainability of nuclear energy. The Korea Atomic Energy Research Institute (KAERI) has studied the direct geological disposal of spent nuclear fuel since 1997. KAERI has also focused on the development of processes suitable for reducing the volume of spent nuclear fuel and the recycling of valuable fissile material. One of the most promising technologies investigated by KAERI is the pyro-processing of spent nuclear fuel followed by the geological disposal of the generated high level waste (HLW).

Since 2007, KAERI has been running a research programme focusing on the recycling of spent nuclear fuel, as well as studies aimed at the development of a relevant geological disposal system able to accept the resulting HLW. The core aims of the KAERI study were to characterize the geological media, design a repository system and assess the overall safety of the disposal system.

The development of pyro-processing technology is ongoing and has not yet been demonstrated at the commercial level. Thus, the Government of the Republic of Korea requested an assessment of the technical feasibility of this technology. The assessment also included the appraisal of a disposal solution for waste generated by pyro-processing. With regard to the latter, KAERI requested that the IAEA review the status of the disposal project within the Waste Management Assessment and Technical Review Programme (WATRP).

Peer reviews are increasingly being acknowledged as an important element in building broader stakeholder confidence in the safety and viability of related facilities. This report presents the consensus view of the international group of experts convened by the IAEA to perform the review.

CONTENTS

SUMMARY

The Korea Atomic Energy Research Institute (KAERI) is investigating the pyro-processing of spent nuclear fuel, followed by the geological disposal of the high level waste (HLW) generated from this process. During the pyro-processing procedure, spent nuclear fuel is treated in a number of stages during which the uranium and transuranium elements are separated from different waste streams. The intention is for the uranium and transuranium elements to be reused and burned in fast reactors. The different waste streams consist of:

- Metal waste (fuel cladding and structural material);
- High level waste, as ceramic monazite containing most of the rare earth fission products and some transuranium elements;
- Air filters trapping iodine and technetium;
- Silicate ammonium phosphate (SAP) glass containing most of the strontium;
- Fly ash containing most of the caesium.

It is proposed that the SAP and fly ash will be stored and left to decay over several hundreds of years and then disposed of as low level waste (LLW). Proposals for iodine and technetium management include future transmutation. The disposal of SAP, fly ash, iodine and technetium has not been considered in the present proposal for the deep geological disposal of HLW and metal waste.

By introducing pyro-processing, the volume (or mass) of HLW, as well as the heat load, can be reduced significantly. It is expected that the required disposal area will be ten times smaller than if the spent fuel were disposed of directly.

DISPOSAL SYSTEM

For more than a decade, KAERI has been investigating spent nuclear fuel disposal options. In order to support these efforts, it operates the KAERI Underground Research Tunnel (KURT), located in a mountainous area inside the KAERI complex in Yusung Gu. KURT functions as a major facility for the study and validation of the safety and feasibility of the proposed deep geological disposal system. Though the site for a geological repository has not yet been selected, research performed at KURT is expected to provide important inputs for the design and safety case of the planned disposal facility.

In the absence of an actual disposal site, and for the purposes of this peer review, KAERI has designed a hypothetical disposal facility at the KURT site. The proposed disposal facility is composed of two distinct disposal zones, one

at around 200 m deep for the disposal of metal waste and a second zone around 500 m deep for the disposal of HLW.

The HLW is disposed of in copper/cast iron canisters, i.e. a cast iron inner container with a 1 cm thick copper coating. A new process has been developed for the copper coating process and for the sealing of the lid. Canisters are disposed of either horizontally in long boreholes or vertically in short boreholes from the bottom of the tunnels. In both cases the canisters are surrounded by a clay buffer made up of compacted domestic Ca-bentonite. Following disposal, the tunnels and shafts are backfilled. The design is similar to that proposed by other countries, e.g. Finland and Sweden.

It is proposed that the metal waste will be packed into steel canisters placed inside concrete containers and disposed of in a concrete structure in the tunnels. The empty space between the packages and the concrete structure will be filled with Ca-bentonite and the area between the concrete and the tunnel walls will be backfilled using a mixture of crushed rock and bentonite.

PEER REVIEW

KAERI requested that the IAEA organize an international peer review to assess, on the basis of the IAEA safety standards and best international practice, the feasibility of the KAERI approach for the development of a geological disposal system for HLW and metallic waste from the pyro-processing of spent nuclear fuel (SNF).

The KAERI approach review addressed several topics, including:

— The assessment of the overall approach to the development of a geological disposal system;
— The assessment of the technical feasibility of the proposed system (geology and engineered barrier system);
— Advice on the methodology for the development of the safety case and supporting safety assessment;
— Recommendations for further studies.

RESULTS

The results of the review are summarized below.

Boundary conditions

- The team reviewed the disposal system only and did not attempt to evaluate the feasibility and reality of pyro-processing itself.
- The policy, strategy and regulations concerning geological disposal are being developed in the Republic of Korea.
- No disposal site has yet been selected in the Republic of Korea.
- The project at its current stage cannot be considered to be a disposal development project or a feasibility study. It is instead a study aimed at demonstrating an appropriate approach performed against criteria based on LLW disposal regulations and international safety standards, experience and best practice.

Overall comments

- The encapsulation of ceramic waste and the construction and operation of a disposal facility, as described, is based on experience gathered from various programmes around the world.
- The new method for producing copper/cast iron canisters by means of the cold spray technique seems promising based on tests performed to date. Further studies, however, are required on the mechanical and corrosion properties of the finished canister.
- The use of the cold spray technique for the sealing of the copper canisters also appears promising. Further studies and demonstrations of the quality of the seal and the applicability of the method in a hot cell environment are required.
- The safety of disposal can probably be ensured, but further studies of the robustness of the system are required. The review team has not identified any issues that would halt progress.
- In the current safety assessment, calculated doses are many orders of magnitude larger for the metal waste repository than for the ceramic waste repository. Further action should therefore be undertaken to optimize the system. This could include both improving the metal waste repository and relaxing the requirements governing the ceramic waste repository.

Good practice

- Requesting a peer review at this stage of development was a good decision.
- Studies in the Republic of Korea on disposal are helping to broaden knowledge on radioactive waste disposal since they include components that are complementary to R&D programmes in other countries.

— It is commendable that a study on the management and disposal of radioactive waste from pyro-processing is being performed in parallel with the development of pyro-processing itself.
— KAERI has demonstrated a sensible overall approach to safety assessment that includes key steps recognized internationally.
— The overall strategy of utilizing the KURT underground research facility for data acquisition, methodology development and model testing is considered a good approach in terms of providing the relevant input for studies on the development of a geological disposal facility.
— The move from safety assessment oriented studies to the development of the safety case represents an important step forward.
— The establishment of the CYPRUS database for documenting the process and selection of FEPs (features, events and processes) ensures the systematic collection and traceability of data.

Recommendations

General

— KAERI should define the functional requirements (including safety functions, the possibility of handling, technical feasibility) for all the components of the repository system.
— The strategy behind the individual programme development and investigation stages should be clearly set out and explained.
— The subsequent R&D programme should be driven by needs identified by the ‘end user’ (safety assessors) formulating their key areas of interest and related objectives.
— The safety assessment needs to be applied iteratively as the disposal programme develops and should be used to help guide the development of the disposal concepts and the necessary R&D.
— As the disposal programme progresses, increasingly more realistic safety assessments should be conducted so that the assessments provide better guidance on the disposal concepts and engineered barriers that are needed.
— It is important that a well developed management system (QA, QC and quality management) is used for data gathering, including consistency checks, systems design and safety assessment.
— It should be ensured that the further development of the disposal system is fully in line with the appropriate IAEA safety standards.

Geology

— The investigations at KURT should be used for developing strategies and methodologies for site characterization and modelling for real disposal sites.

System

— Further characterization studies of the waste are recommended, including assessments of the separation of radionuclides during pyro-processing.
— Further development work is required with regard to the cold spray coating method used in the manufacture of the canisters.
— The evolution over time of the different barriers and site conditions should be analysed. In this context, the interaction between different barriers should also be considered, e.g. the waste/canister and canister/buffer.
— The amount of contamination with TRU and the content of Cs-135 need to be considered in the decision on how to dispose of the SAP and fly ash after decay storage.
— The possibility of there being trapped fuel in the metal waste and its influence on heat generation and design should be considered.
— The disposal of metal waste at the same depth as ceramic waste should be considered.
— When co-locating a repository for high level ceramic waste along with that for metal waste, possible interactions should be considered based on the results of safety assessment.
— With regard to the development of the repository system, the possibility of co-disposing several types of waste, e.g. spent fuel and pyro-processed wastes, should be considered both in terms of design and safety assessment.
— The design of the access shafts/ramps and of the various plugs should take into account safety case implications, as should the sealing of deep investigation boreholes.

Safety assessment

— Clearer links should be established between the scenarios and the key physical processes that have the potential to significantly affect the safety functions of the disposal system components.
— More emphasis should be put on modelling the evolution of the disposal system and particularly of the engineered barrier system to demonstrate that the barriers will work together as a system to contain the wastes and retard radionuclide transport over time.

— Further sensitivity and uncertainty analyses should be conducted and the analyses should consider the entire disposal system (including the source term as well as the near field, far field and biosphere) to assess the importance of a wider range of parameters and processes.
— Sensitivity analysis could be developed as a tool for understanding the role and relative importance of different barriers and processes.
— The safety assessment and the safety case being developed should be used to strengthen the integration of information from the different disciplines and work teams involved (e.g. the teams involved in safety assessment, disposal system design, research and pyro-processing).

1. INTRODUCTION

1.1. THE IAEA WATRP SYSTEM

The IAEA's Waste Management Assessment and Technical Review Programme serves Member States by providing technical assessments and peer reviews of their national policies, programmes and facilities related to the management of radioactive waste. Following a request from a Member State, or an organization within a Member State, the IAEA convenes an international panel of experts to perform a peer review in accordance with the terms of reference established by the requesting Member State or organization and with the support of the IAEA, as necessary. The mechanism used for this purpose typically includes a review of source material, an exchange of information with the applicant's experts in a review meeting and a compilation of the findings in a review report.

A peer review allows the requesting Member State or organization to obtain independent opinions and advice from international experts. The experts act in a personal capacity, which means that the final review report presents their consensus view, which may not necessarily coincide with that of their country or organization or the IAEA. The findings, conclusions and recommendations of the WATRP experts are based on IAEA safety standards and 'good international practice', as reported in IAEA technical recommendations and through demonstrations of proven radioactive waste management solutions.

1.2. BACKGROUND

The Korea Atomic Energy Research Institute (KAERI), located in Daejon, was established in 1959 as the sole professional research oriented institute for nuclear power in the Republic of Korea. It has rapidly built a reputation for R&D in various fields, including spent fuel recycling and radioactive waste management.

One of the most promising technologies currently under investigation at KAERI is the pyro-processing of spent nuclear fuel followed by the geological disposal of the HLW generated. Pyro-processing is based on the extraction of U, Pu and minor actinides (MA) using molten salt. Thus, the basic concept of pyro-processing is group recovery, which significantly enhances proliferation resistance. A part of the U recovered from spent fuel can be blended with a Pu and MA mixture and the blended material fabricated as fuel for sodium cooled fast reactors (SFRs). The process leads to the generation principally of metallic and ceramic LLW that will need to be disposed of at a geological disposal facility.

In order to support the development of a national disposal facility for HLW, KAERI operates the KAERI Underground Research Tunnel (KURT), located in a mountainous area inside the KAERI complex at Yusung Gu. KURT provides the infrastructure for the study and validation of the safety and feasibility of the proposed deep geological disposal system. Even though the site for a geological repository has not yet been selected, investigation work being performed at KURT provides input for both the design and safety case of the future disposal facility. Several 500 m deep boreholes have been drilled in the area in order to sample the host rock. In addition, KAERI has designed a hypothetical repository at the KURT site specifically for the purposes of this peer review; the documentation summarizes the geological and hydrological properties of the research site.

One of the unique characteristics of the geological disposal system in the Republic of Korea is the waste that will have to be disposed of. By introducing pyro-processing, the volume (or mass) as well as the heat load of HLW can be significantly reduced. The required disposal area is expected to be ten times smaller than if the spent fuel were to be disposed of directly.

1.3. TERMS OF REFERENCE

The objective of the review was to assess, on the basis of IAEA safety standards, the feasibility of the KAERI approach to the development of a geological disposal system for HLW from the pyro-processing of spent nuclear fuel (SNF) and to summarize the findings in the WATRP review report.

The feasibility of the KAERI approach has been reviewed by independent experts in order to provide recommendations and advice on the continuation of R&D as indicated in the following:

- Assessment of the overall KAERI approach for the development of a geological disposal system;
- Assessment of the technical feasibility of the proposed geological disposal system (geology and engineered barrier system);
- Advice on the methodology to be employed for developing the safety case and the supporting safety assessment for the geological disposal system;
- Recommendations for further studies.

When conducting the peer review, the expert team considered:

- The national HLW disposal programme;
- The nature of the radioactive wastes (source term) to be disposed of, including the inventory, radionuclide content, physicochemical characteristics, heat generation, etc.;
- The methodological approach to siting and the technical and technological basis for the selection and characterization of the site;
- The relevance and completeness of site characterization studies and their appropriateness for site selection;
- The design concept and the selection of engineered barrier materials;
- The alignment of the design basis and derived requirements and procedures with safety standards;
- Proven scientific and systems engineering practice;
- The quality management system and its implementation.

The full text of the terms of reference can be found in Appendix I.

1.4. CONDUCT OF THE REVIEW

The review was conducted by a team of four senior international experts in different topics relevant to the scope of the peer review. They were selected from IAEA Member States, were familiar with the IAEA safety standards and had extensive experience in the geological disposal of radioactive waste, in particular in crystalline rock. The members of the Peer Review Team were selected by the IAEA Secretariat and accepted by KAERI. The Peer Review Team assembled by the IAEA comprised H. Forsström (Sweden), D. Bennett (UK), M. Vahanen (Finland) and W. Kickmaier (Switzerland). The team was supported by two Scientific Secretaries from the IAEA, L. Nachmilner from the Waste Technology Section, Department of Nuclear Energy (who did not take part in the Review Mission) and G. Bruno from the Waste and Environmental Safety Section, Department of Nuclear Safety and Security. Brief curriuclum vitae are included in Appendix II. The review was carried out according to the terms of reference described above.

The review comprised an evaluation of materials provided in advance by KAERI, followed by meetings and discussions at the mission established at KAERI's premises in Daejon.

For the purpose of the review, KAERI prepared a report [1] on the KAERI geological disposal feasibility project for pyro-processed waste. The report was delivered to the reviewers well in advance of the meetings in the

Republic of Korea and contained three substantial chapters on geology, the repository system and safety analysis. The report stimulated a large number of questions from the reviewers which were delivered to KAERI in advance of the meetings as the basis for KAERI to prepare complementary presentations. During the presentation sessions, it was realized that the report did not accurately reflect the depth of the work that had already been performed at KAERI. The presentations thus led to extensive discussions at the review meetings. The views of the reviewers, as reflected in this report, are thus based both on the KAERI report and, to a large extent, on the complementary information provided in Daejon on the different topics of interest for the review.

As background material for the review, a long list of references was also provided in the terms of reference. The reviewers, however, did not analyse these references in detail, but have based their comments and judgements on the presentations and discussions during the review meetings and the overview report presented before the meetings.

1.5. STRUCTURE OF THE REPORT

This review report has introductory sections which describe the role of pyro-processing in the waste disposal programme in the Republic of Korea, the waste arising from pyro-processing and a short description of the proposed disposal system. The observations and recommendations of the review team are then presented under three separate headings: geological investigations, disposal facility design and safety case and safety assessment. For each of the review topics, reference is first made to the appropriate part of the IAEA Safety Requirements publication on the Disposal of Radioactive Waste [2]. Subsequently, a short description is provided of the KAERI approach, followed by a series of recommendations from the experts.

2. PYRO-PROCESSING IN THE WASTE DISPOSAL PROGRAMME IN THE REPUBLIC OF KOREA

The Republic of Korea has an advanced nuclear energy programme. At present, 21 reactor units (17 PWRs and 4 PHWRs) are in operation. A further seven PWRs are under construction. Spent fuel from the reactors is currently stored at reactor sites. In total, around 12 000 tonnes of heavy metal (t HM) are in storage. This is expected to rise to 30 000 t HM by 2030. Planning for a central storage facility is ongoing.

The future national policy will be decided through public participation, taking into consideration national and international trends on policy and technology development. A draft plan is being developed featuring two parallel tracks for the future management of spent nuclear fuel. One track involves the direct disposal of both PWR and PHWR fuel, while the second track proposes that PWR fuel will be subjected to pyro-processing for the recycling of U, Pu and minor actinides in fast reactors and the subsequent disposal of the resulting smaller volumes of HLW in a geological disposal facility.

Two organizations play key roles in the development of the spent fuel management system, KRMC and KAERI. KRMC, the Korea Radioactive Waste Management Corporation, is responsible for the transportation and disposal of low and intermediate level waste (LILW), the interim storage and disposal of spent fuel, the siting, construction and operation of radioactive waste management (RWM) facilities, R&D on radioactive waste and spent fuel management and the administration of the RWM fund on behalf of the Government. KRMC reports to the Ministry of Knowledge and the Economy. KAERI, the Korea Atomic Energy Research Institute, which reports to the Ministry of Education, Science and Technology, is responsible for basic and fundamental technology development regarding advanced fuel cycles and for the management of HLW from such fuel cycles.

KAERI is thus involved in the development of pyro-processing technology. The main objectives of pyro-processing are:

— To extract uranium, plutonium and minor actinides for recycling in sodium cooled fast reactors (SFRs);
— To minimize the thermal load of the HLW, and thus the footprint of the repository;
— To remove certain long lived radioisotopes for later transmutation.

3. WASTE FROM PYRO-PROCESSING

The different steps involved in pyro-processing and the various product and waste streams are shown schematically in Fig. 1.

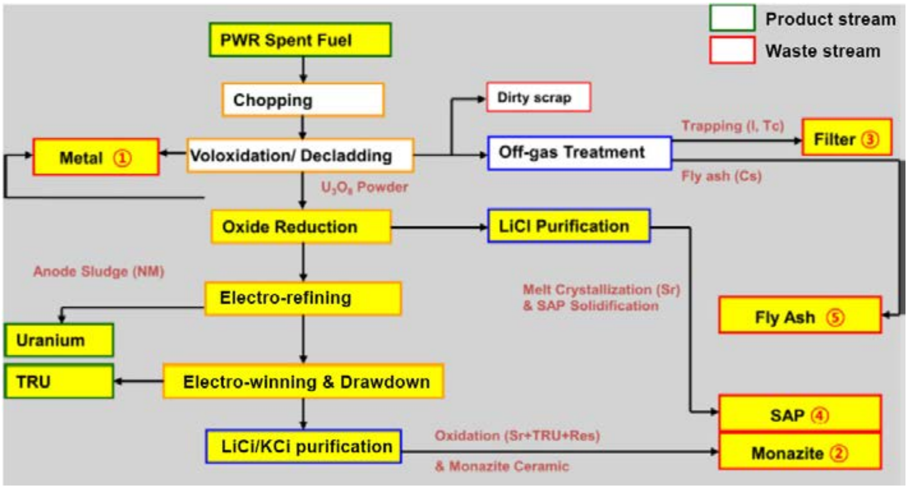


FIG. 1. Scheme and flow diagram of the pyro-processing system for spent nuclear fuel.

Pyro-processing includes the following steps:

— The chopping up of the fuel pins to expose the uranium fuel;
— Voloxidation/decladding to remove the metal components (including the cladding), drive out volatile waste components (I, Tc and Cs) and to render the fuel into powder form for subsequent treatment in molten salt (LiCl/KCl);
— Oxide reduction to remove Sr;
— Electro-refining to separate out the U;
— Electro-winning and drawdown to remove the transuranium elements (TRU, i.e. Pu and MAs);
— Purification of the LiCl/KCl to collect the remaining fission products and traces of separated material.

The Review Team did not examine pyro-processing as such, but used the information as a starting point for the further assessment of the repository system. Based on the information provided, the following waste streams emanate from pyro-processing:

(1) Metal waste consisting of cladding hulls and fuel element support structures. The metal waste is compacted (or melted). The contamination of the metal waste with fuel material is assumed to be less than 0.001% (of the total fuel).

(2) Ceramic waste, i.e. HLW solidified into a monazite ceramic containing mainly non-separated fission products such as rare earth materials and traces of Cs (0.2%), Sr (0.1%), U (0.1%) and TRU (0.1%).
(3) Filters containing most of the I and Tc. This material is stored for later transmutation.
(4) SAP waste, i.e. separated Sr vitrified in sodium–aluminium–phosphate (SAP) glass. The SAP waste contains most of the Sr (99.9%) and is assumed not to be contaminated with TRU.
(5) Fly ash containing most of the Cs (97.8%). It is assumed not to be contaminated with TRU. The further treatment of the fly ash has not yet been determined. As with the SAP waste, the fly ash will be stored for heat decay.

SAP waste exhibits, together with fly ash, the highest level of heat generation and thus will be stored for a hundred years or so to allow the heat to decay. It will then be disposed of as LILW.

4. MAIN FEATURES OF THE PROPOSED DISPOSAL SYSTEM

The reviewed disposal system has two components: the deep geological disposal of high level ceramic waste (type 2 in the list above), and an intermediate depth disposal system for metal waste (type 1 in the list). As became evident during the review, the HLW disposal system has been elaborated in more detail than that for metal waste disposal; nevertheless, both were reviewed.

4.1. DISPOSAL SYSTEM FOR HIGH LEVEL CERAMIC WASTE

The main components of the disposal system for high level ceramic waste are shown in Fig. 2. They are:

— A copper/cast iron disposal canister containing ceramic waste in steel storage containers. The 1 cm thick copper layer is attached to the cast iron canister using a new cold spray coating method which has been shown to produce good copper quality. The same method is also used for sealing the copper lid to the copper body. The cast iron inner container provides the mechanical strength of the canister, while the copper coating provides corrosion protection. The thickness has been chosen with a margin of resistance of more than 1000 years, which corresponds to the required expected functional time period. The copper/cast iron canister is around 1 m in diameter and 1.7 m high.

— The canister is disposed of either in long, wide boreholes as shown in the figure, or in boreholes drilled in the bottom of the tunnels. Following placement in the boreholes, the canisters are surrounded with domestic Ca-bentonite.
— It is proposed that disposal will be at a depth of around 500 m in good quality granitic bed rock.

FIG. 2. Disposal system for high level ceramic waste from pyro-processing.

The design is similar to that proposed in other countries, e.g. Finland and Sweden, and also to that which has been proposed in the Republic of Korea for spent fuel disposal. For all these examples the amount of waste or fuel that can be disposed of in a canister is determined by the heat load, which must be such that it produces a temperature within the bentonite and the bed rock of well below 100°C. Since most of the heat generating radionuclides (e.g. Sr-90, Cs-137 and Am-241) will have been removed from the HLW, and since the volume of HLW will be small, it will be possible to dispose of waste from around 20 t HM of fuel in one canister, which corresponds to roughly ten times less than for direct disposal.

4.2. DISPOSAL SYSTEM FOR METAL WASTE

The volume of metal waste is about three times larger than the volume of HLW. However, such waste is assumed to have a very low level of TRU contamination. The metal waste is compacted in steel storage containers that are placed in cube shaped concrete metal waste disposal packages (1.3 m per side) made of polymer concrete.

The packages are then disposed of in a concrete structure in tunnels excavated at a depth of around 200 m (Fig. 3). The empty space between the packages and the concrete structure is filled with bentonite blocks and the space between the structure and the wall is filled with a mixture of crushed rock and bentonite.

5. GEOLOGICAL INVESTIGATIONS

5.1. IAEA SAFETY REQUIREMENTS

Requirement 9 of SSR-5 [2]: Isolation of radioactive waste

The disposal facility shall be sited, designed and operated to provide features that are aimed at isolation of the radioactive waste from people and from the accessible biosphere. The features shall aim to provide isolation for several hundreds of years for short lived waste and at least several thousand years for intermediate and high level waste. In so doing, consideration shall be given to both the natural evolution of the disposal system and events causing disturbance of the facility.

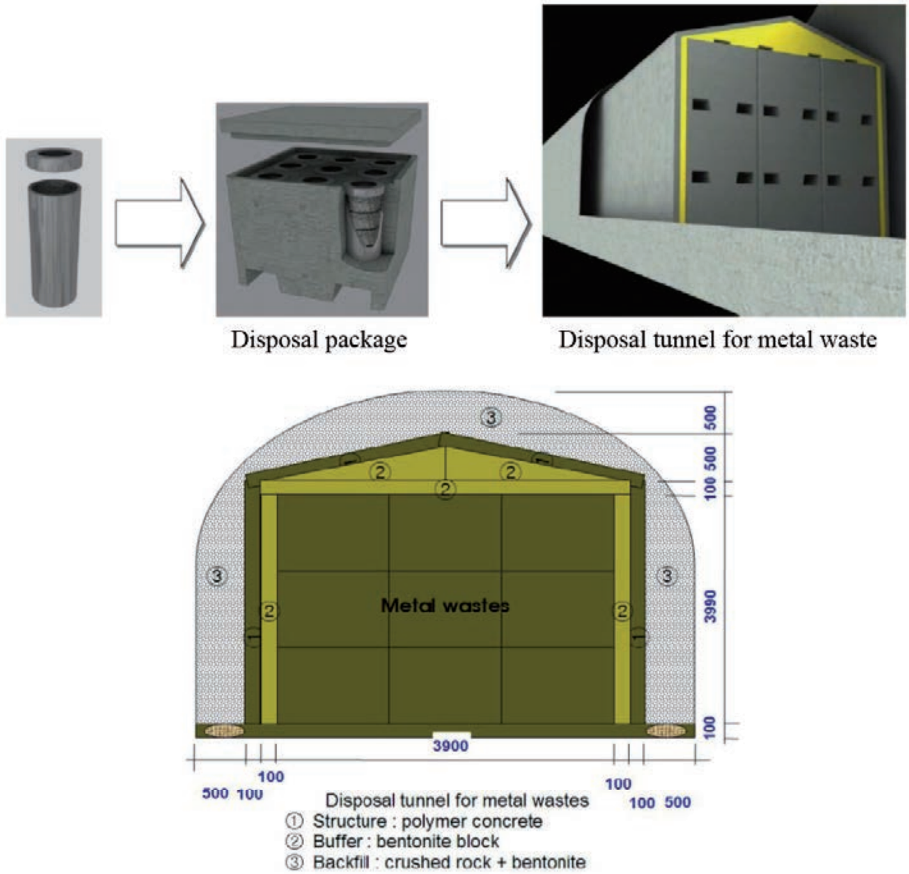


FIG. 3. Disposal system for metal waste from pyro-processing.

Requirement 15 of SSR-5 [2]: Site characterization for a disposal facility

The site for a disposal facility shall be characterized at a level of detail sufficient to support a general understanding of both the characteristics of the site and how the site will evolve over time. This shall include its present condition, its probable natural evolution and possible natural events, and also human plans and actions in the vicinity that may affect the safety of the facility over the period of interest. It shall also include a specific understanding of the impact on safety of features, events and processes associated with the site and the facility.

5.2. OVERALL APPROACH

For the purpose of the review, KAERI considered a hypothetical site to which the data obtained at the KAERI Underground Research Tunnel have been transposed.

The investigations performed by KAERI as part of the potential development of a geological disposal facility for pyro-processed waste provide a general overview of the geological environment of the Republic of Korea. KAERI performed detailed investigations in the KURT area using an integrated approach ranging from the regional scale to the local and site scales.

The investigations performed at different scales were composed of studies conducted from the surface complemented by subsequent underground characterization using the KAERI Underground Research Tunnel specifically developed for the purposes of the project.

Good practice

- The overall strategy of utilizing an underground research facility (KURT) for data acquisition, methodology development and model testing is considered to be a good approach in terms of providing the relevant inputs for the study of the development of a geological disposal facility.
- The strategy adopted by KAERI, involving different scales of investigation (regional, local and site) as well as the stepwise approach to implementing surface and subsequent underground investigation, is a good practice.
- Taking the generic character of the project into account, KAERI has implemented an R&D programme which covers the various disciplines of interest involved in developing a geological disposal facility including geology, hydrogeology, geophysics, geochemistry and rock mechanics. Such an approach has provided the opportunity to develop the methodology required in order to produce a consistent dataset that will serve as the basis for generic safety assessment.
- The use of the data from KURT as a basis for generic safety assessment is very useful.

Recommendations

- The overall process of data acquisition for the purpose of site characterization is appropriate considering the generic character of the project and its stage of development. However, there is still much work to perform with respect to data acquisition for a detailed characterization of a real site in terms of developing the safety case for the disposal facility.

— Discussion of the report during the review meeting revealed that additional data sources were used, e.g. geophysical measurements to develop and test the geological/hydrogeological model. In order to provide a complete picture and allow the conclusions drawn to be followed, the report should at least summarize the key findings and refer to relevant supporting document/literature data.

5.3. SITE CHARACTERIZATION ACTIVITIES

An important site investigation programme has been under way in and around the KURT facility since 1997. The first investigations had the purpose of defining a site for the underground research tunnel and the undisturbed situation surrounding it. Later investigations assisted in interpreting the experiments performed at KURT and also to characterize the rock at depth in order to prepare a hydrogeological model of the deep underground geology that could be used for generic safety assessment purposes. The investigations were conducted by means of 15 boreholes with depths of 100 m to 500 m, and two 1000 m deep boreholes.

On the basis of the data obtained from the surface and underground geological, hydrogeological and geochemical investigations at different scales, KAERI proposed a structural and hydrogeological model deriving the main characteristics of a potential disposal area at the KURT site. In some cases, however, such as the description of the location and orientation and the sequence of boreholes drilled, KAERI did not explain and provide clear insight into the strategy and methodology applied. From the discussions held during the review meeting it was apparent that there had been no consideration of potential alternative geological and hydrogeological models which could also fit the data obtained from site characterization.

For the purposes of safety assessment, and in particular the development of the geological and hydrogeological models, the amount of information should be increased and the representativeness of the data obtained confirmed. For example, when KAERI reported that *"…the hydraulic conductivity ranged from* 10^{-11} *to* 10^{-5} *m/sec and it was difficult to determine a representative value...", "...no representative values could be obtained…",* a methodology for detailed investigation had to be planned and proposed for the collection of additional data to support and consolidate subsequent modelling and safety assessment studies.

In the same way, the rock mechanical and geochemical data at the level of the assumed ceramic waste disposal facility still need to be confirmed, in particular through an additional investigation programme. The analysis of already obtained data and safety assessment results should drive the additional data collection programme (the locations of investigations, amount of data required). During discussion at the review meeting, KAERI indeed indicated that an additional investigation programme is planned.

At the current stage of the project, in particular because of its generic character, some of the conclusions drawn for site characterization are of a preliminary nature. Further investigation programmes, model development and iteration steps together with the safety assessment group will contribute towards an in-depth understanding of the geological environment and will allow the improvement of the site characterization methodology.

Good practice

— The data set and the site characterization methodologies as presented in the report form a sound basis for a conceptual understanding of the relevant processes and model development. The complementary approach of developing laboratory and in situ characterization and modelling is in accordance with good practice.
— Taking the generic character of the project into account, the approach of applying R&D programmes in various disciplines (geology, geophysics, geochemistry, etc.) will provide the opportunity to develop the methodology involved and derive a consistent geosynthesis data set.

Recommendations

— The site chosen for the purpose of the review is a hypothetical site to which data from the KURT site have been applied. The review team recommends that an evaluation of the site specific data be performed and a strategy developed as to how this might be addressed in the future in view of the development of the safety case.
— The strategy behind the individual investigation steps should be set out and explained; the drilling programme strategy with respect to location, orientation and borehole depth and the subsequent test, sampling, and monitoring programme might be considered an example here.
— Although the programme provided a good data set for the KURT site, the review team concluded that the site characterization strategy/methodology needs to be further improved before it can serve as the basis for the ‘real case’. KAERI should use the investigations at the KURT site to develop an iterative strategy/methodology.

— The review team felt that the sampling strategy used to obtain groundwater samples and the interpretation of the geochemical data still leave room for improvement. These issues should be considered when starting the new drilling and investigation programme for the KURT site.
— In some cases, difficulties in deriving certain host rock properties may be encountered. The documentation of such ‘key uncertainties or data gaps’ is important in order to allow the identification of further R&D needs or methodology development.
— It is important that a well developed management system (quality assurance, quality control and quality management) is employed for data gathering, including consistency checks.
— Alternative interpretations of the hydrology should be considered and an investigation programme developed in order to improve the model. The hydrological model for the KURT site is based on a limited number of boreholes. In particular, the fracture zones that have been interpreted from the data have, with one exception, been detected only in one borehole each. A critical approach must be taken to the proposed model in order not only to consolidate its validity, but also to define the strategy/methodology to be adopted for additional data acquisition.
— If several disposal levels are to be used it is important that hydrogeological investigation and modelling describe any potential hydrogeological interaction between disposal levels in order to provide an understanding of any potential influence between the various disposal levels, e.g. in terms of radionuclide transport or chemical interaction.
— The interpretation of the transmissivity ‘spectrum’ and the transfer of these data to the hydrological model will require great care and caution. A strategy should be developed for the performance of transmissivity measurements at a real site and its subsequent transfer into the model.
— The future R&D programme at KURT should be driven by needs identified by ‘end users’ (safety assessors) when formulating their key areas of interest and related objectives.
— The review team considers that R&D characterization programmes such as those concerning rock mechanics, the engineering disturbed zone (EDZ), in-depth characterization of the water conducting features (WCF) and geochemistry should be further developed. The iterative process linked to safety case development will allow the refining of the R&D programmes.
— With regard to the assessment of a potential site, the longer term geological evolution and resulting impact on, for example the fracture network, groundwater flow and transport properties, the interaction between the engineered barrier system (EBS) and the geo/hydro/chemical environment should be addressed.

- The characterization performed by KAERI provides a picture of the present situation at the site. The review team recommends that the evolution of the characteristics of the site be studied (e.g. weathering and palaeohydrology) at least in terms of time durations compatible with the hazard potential of the waste.
- With regard to the R&D programme, emphasis should be placed on improving understanding of the deeper geological environment at the level of the proposed ceramic waste disposal facility (rock mechanics, groundwater geochemistry).
- The conceptual understanding of the EDZ and the related key properties (development, extent, continuity, etc.) as well as the transport and retardation mechanisms within the fracture network should be addressed by means of further R&D programmes.

6. DISPOSAL FACILITY DESIGN

6.1. IAEA SAFETY REQUIREMENTS

Requirement 8 of SSR-5 [2]: Containment of radioactive waste

The engineered barriers, including the waste form and packaging, shall be designed, and the host environment shall be selected, so as to provide containment of the radionuclides associated with the waste. Containment shall be provided until radioactive decay has significantly reduced the hazard posed by the waste. In addition, in the case of heat generating waste, containment shall be provided while the waste is still producing heat energy in amounts that could adversely affect the performance of the disposal system.

Requirement 9 of SSR-5 [2]: Isolation of radioactive waste

The disposal facility shall be sited, designed and operated to provide features that are aimed at isolation of the radioactive waste from people and from the accessible biosphere. The features shall aim to provide isolation for several hundreds of years for short lived waste and at least several thousand years for intermediate and high level waste. In so doing, consideration shall be given to both the natural evolution of the disposal system and events causing disturbance of the facility.

Requirement 16 of SSR-5 [2]: Design of a disposal facility

The disposal facility and its engineered barriers shall be designed to contain the waste with its associated hazard, to be physically and chemically compatible with the host geological formation and/or surface environment, and to provide safety features after closure that complement those features afforded by the host environment. The facility and its engineered barriers shall be designed to provide safety during the operational period.

Requirement 17 of SSR-5 [2]: Construction of a disposal facility

The disposal facility shall be constructed in accordance with the design as described in the approved safety case and supporting safety assessment. It shall be constructed in such a way as to preserve the safety functions of the host environment that have been shown by the safety case to be important for safety after closure. Construction activities shall be carried out in such a way as to ensure safety during the operational period.

Requirement 18 of SSR-5 [2]: Operation of a disposal facility

The disposal facility shall be operated in accordance with the conditions of the licence and the relevant regulatory requirements so as to maintain safety during the operational period and in such a manner as to preserve the safety functions assumed in the safety case that are important to safety after closure.

Requirement 19 of SSR-5 [2]: Closure of a disposal facility

A disposal facility shall be closed in a way that provides for those safety functions that have been shown by the safety case to be important after closure. Plans for closure, including the transition from active management of the facility, shall be well defined and practicable, so that closure can be carried out safely at an appropriate time.

6.2. GENERAL FEATURES AND MANAGEMENT OF REQUIREMENTS

Chapter 3 of the KAERI report addresses the design and design basis for the geological disposal system for HLW from the pyro-processing of PWR spent nuclear fuel. The system is designed to contain and isolate the radioactive material from the human environment and is based on the multi-barrier, defence in depth and radiation protection principles. The design of the EBS, in particular, is based on international references since the Republic of Korea does not yet have regulations in place regarding EBS performance for HLW.

The general features of the design have been presented in Section 4. The KAERI report also provided comprehensive information on the design basis, waste and source term, canister development and manufacture, buffer characteristics and disposal system layout. With regard to the canister and buffer, information was provided on the R&D performed to date and experience gained from earlier tests. For example, the results of corrosion experiments on the selected copper material and measurements of the hydraulic and pressure behaviour of Ca-bentonite, as well as the construction of a 1/10 scale model of the copper/cast iron canister with a cold spray coating method were presented in the report. Section 4 also presents an overview of the various waste handling stages from encapsulation to disposal.

In order to adapt information from international programmes, requirements have to be set according to the case in the Republic of Korea. The requirements for a disposal system and its various components should be derived from their safety and practical functions. This provides the design basis for the system, which concerns the specification of the loads the barriers must be able to withstand and material restrictions which are relevant to the reference scenario. With regard to tracing changes in requirements and their effect on safety functions, requirements should be controlled in a systematic manner.

Good practice

- The proposed repository system has been adapted to the different types of waste generated in the pyro-processing process and is based on international experience as well as experience gained from the waste disposal programme in the Republic of Korea.
- The development of new methods for applying a copper coating to the disposal container and for sealing the canister appears promising.
- The use of a domestically available buffer material is useful and will broaden world knowledge on potential buffer materials.
- The development of practical tests regarding barrier application is timely.
- The thermal analysis of the repository has been well performed.

Recommendations

General

- Define the functional requirements (including safety functions, handling possibility, technical feasibility) for all the components of the repository system (see 'Management of requirements' below).
- The evolution over time of the different barriers should be analysed based on a basic understanding of processes and experimental results and taking into account external influences. The time period should include both the transition period directly following disposal and subsequent closure and the long time period of relatively stable conditions.
- Consider the interaction between the different barriers. The choice of materials should be considered carefully with regard to possible negative effects on other barriers or safety functions. The use of simple, well understood materials should be encouraged; the use of harmful substances (organics, high pH, cement, etc.) should be avoided.

Management of requirements

- Requirements concerning the repository system and its components derived from their safety and practical functions should be established. This will provide the design basis for the system which concerns the specification of the loads the barriers must withstand and material restrictions which are relevant in the reference scenario.
- Requirements could be categorized within the requirements management system into different levels for management purposes. The system should include all the relevant requirements, their origin and rationale along with solutions which are currently able to fulfil those requirements. The system will enable an effective review of the compliance and dependencies between separate specifications and requirements. An example of requirement categorization is provided in Fig. 4.

Stakeholder requirements arise from legislation, regulatory requirements, decisions in principle and other stakeholder requirements. For example, the long term safety of the disposal facility shall rely on safety functions achieved through mutually complementary barriers so that a deficiency in an individual safety function or a predictable geological change will not jeopardize the long term safety of the disposal facility.

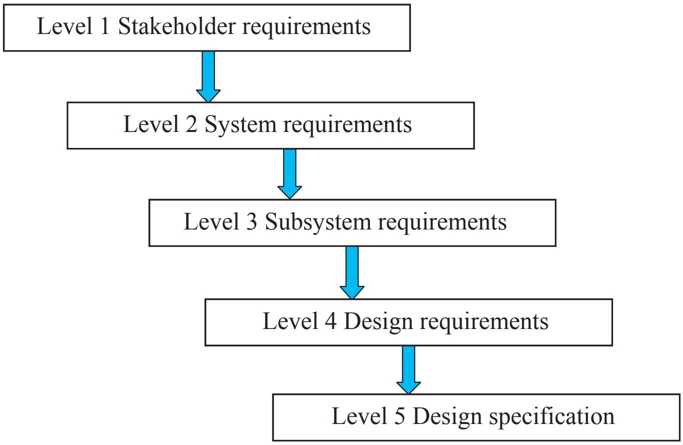


FIG. 4. Example of a requirements system structure.

System requirements define the EBS components and the functions of the EBS and host rock. Example: The spent fuel elements shall be disposed of in a disposal facility located deep in the bedrock. The release of radionuclides shall be prevented by a multi-barrier disposal system consisting of an EBS and host rock such that the system effectively isolates the radionuclides from the living environment.

Subsystem requirements consist of specific requirements for the canister, buffer, backfill, closure, host rock and underground openings. Example: The buffer shall limit microbial activity.

Design requirements further clarify and add more details to the requirements of Level 3. Example: The buffer shall be so designed that the possibility of the microbially induced corrosion of the canister by sulphide will be minimized.

Design specifications consist of the quantitative specifications to be used in design, construction and manufacture. Example: The density of the buffer is xx kg/m^3.

6.3. WASTE CHARACTERIZATION

The waste streams from pyro-processing have been described in Section 3. Ceramic and metal wastes only have been considered for disposal. Information on the characteristics of the waste products is, however, rather sparse in the material reviewed. Moreover, the assumptions made concerning the ‘contamination’ of the waste with TRU and/or heat generating caesium and strontium are, so far, based on theoretical studies and have not been backed up by practical experience.

Recommendations

- Perform further studies to qualify the separation of radionuclides into the different waste streams. In anticipation of such results it is recommended that sensitivity analyses are performed in the safety assessment for the repository system with varying content of trace materials (primarily TRU).
- Consider also including Tc and I in the ceramic waste.
- Further characterization studies of the waste are recommended in order to prepare a better understanding of the release model for ceramic waste and metal waste.
- The amount of contamination by TRU and the content of Cs-135 need to be considered in the decision on how to dispose of the SAP and fly ash following decay storage.
- Heat release from the metal waste, although low, should be considered in terms of disposal to assess whether it has an influence on design. Sensitivity analysis with remaining fuel content.

6.4. CANISTERS, BUFFER AND BACKFILL

Detailed descriptions have been provided on the technology used in the manufacture of canisters and buffer blocks and on their technical application. A comprehensive R&D programme has been undertaken in order to define the properties and characteristics of the materials used and their behaviour under external strains, e.g. corrosion, pressure and temperature.

Recommendations

Canister for ceramic waste

- Although the copper canister will not be needed for more than 1000 years, it would be advantageous to base the assessment of the behaviour of the copper canister on theoretical grounds and use the results in the safety assessment.
- Further development work on the cold spray coating method for the manufacture of canisters is needed, e.g. demonstrating its effectiveness on a full scale canister. The sensitivity of the copper coating to external stresses and its long term behaviour should be assessed.
- The requirements regarding the sealing of the copper lid to the copper coating should be defined and the development of cold spray coating or other methods should be continued.

- Continue the development of non-destructive testing (NDT) of the canister and the sealing, with emphasis on the quality of the canister.
- Any corrosion experiments should be performed under relevant groundwater conditions to ensure that the right processes are simulated.

Canister for metal waste

- Reconsider the use of polymer concrete since polymers can create problems with regard to the safety assessment.

Buffer and backfill

- Before introducing a new element to the buffer system, e.g. graphite to improve thermal conductivity, the implications of such elements on the safety assessment should be considered carefully.
- Further work is needed on the techniques and materials to be employed for backfilling the tunnels.

6.5. DESIGN AND LAYOUT OF THE DISPOSAL FACILITIES

The design of the two types of repositories for ceramic waste and for metal waste is described in Section 4.

Recommendations

Design and layout for ceramic waste disposal

- The design of the tunnels should take into account the stress field in the rock in order to minimize both rock disturbance and the extent of the EDZ.
- In co-locating the repository for high level ceramic waste and that for metal waste, possible interactions should be considered based on the results of safety assessments.
- The access shafts/ramps and of the various plugs should be designed with due consideration to the implications for the safety case. The same is the case for the sealing of deep investigation boreholes.
- Continue development work on both horizontal and vertical disposal methods.

Design and layout for metallic waste disposal

- — Consider the disposal of metal waste at the same level as ceramic waste;
- — The possibility of gas generation and its influence on the design should be considered;
- — The possibility of trapped fuel in the waste and its influence on heat generation and design should also be considered.

7. SAFETY CASE AND SAFETY ASSESSMENT

7.1. IAEA SAFETY REQUIREMENTS

Requirement 7 of SSR-5 [2]: Multiple safety functions

The host environment shall be selected, the engineered barriers of the disposal facility shall be designed and the facility shall be operated to ensure that safety is provided by means of multiple safety functions. Containment and isolation of the waste shall be provided by means of a number of physical barriers of the disposal system. The performance of these physical barriers shall be achieved by means of diverse physical and chemical processes together with various operational controls. The capability of the individual barriers and controls together with that of the overall disposal system to perform as assumed in the safety case shall be demonstrated. The overall performance of the disposal system shall not be unduly dependent on a single safety function.

Requirement 12 of SSR-5 [2]: Preparation, approval and use of the safety case and safety assessment for a disposal facility

A safety case and supporting safety assessment shall be prepared and updated by the operator, as necessary, at each step in the development of a disposal facility, in operation and after closure. The safety case and supporting safety assessment shall be submitted to the regulatory body for approval. The safety case and supporting safety assessment shall be sufficiently detailed and comprehensive to provide the necessary technical input for informing the regulatory body and for informing the decisions necessary at each step.

Requirement 13 of SSR-5 [2]: Scope of the safety case and safety assessment

The safety case for a disposal facility shall describe all safety relevant aspects of the site, the design of the facility and the managerial control measures and regulatory controls. The safety case and supporting safety assessment shall demonstrate the level of protection of people and the environment provided and shall provide assurance to the regulatory body and other interested parties that safety requirements will be met.

Requirement 14 of SSR-5 [2]: Documentation of the safety case and safety assessment

The safety case and supporting safety assessment for a disposal facility shall be documented to a level of detail and quality sufficient to inform and support the decision to be made at each step and to allow for independent review of the safety case and supporting safety assessment. Further guidance on the safety case and safety assessment is provided in IAEA Safety Standards Series No. SSG-23, the Safety Case and Safety Assessment for the Disposal of Radioactive Waste [3] and in No. SSG-14, Geological Disposal Facilities for Radioactive Waste [4]. Detailed examples and discussions of safety assessment models and modelling are contained in various report series from IAEA coordinated research projects (e.g. the ISAM [5] and BIOMASS projects [6]).

7.2. OVERALL APPROACH

For the purposes of the safety assessments and safety case which, it is planned, will be developed in the next phase of the project, KAERI refers to international and country specific safety principles and radiation protection standards.

KAERI's approach to safety assessment proceeds via the screening of FEPs and scenario development, model development, the modelling of radionuclide release from the waste and transport through the near field, far field and biosphere.

The approach to safety assessment also includes consideration of the evaluation of the robustness of the proposed disposal facility and the recognition of the need to ensure the improvement of the proposed project by engaging in an iterative process throughout the duration of the programme leading to disposal facility development.

The current safety approach at KAERI relates to performing safety assessments of the proposed disposal facility which constitute just one component of the safety case. The safety case makes up a broader concept of the collection of arguments (quantitative as well as qualitative), which contribute towards demonstrating the safety of the disposal facility. KAERI has indicated at discussion sessions that the development of a safety case for the disposal facility constitutes one of the next steps in the project.

Good practice

— KAERI has a sensible overall approach to safety assessment that includes the key steps recognized internationally.
— Many approaches from other countries have been taken into account. Systematic methods are used even though there is no regulatory guidance for the work.
— The approach is 'open minded' and the level of scientific work is good. It forms a good basis and provides tools for commencing the development of safety case methodology.
— KAERI is planning the development of a safety case which, it is planned, will be developed in a broader and more comprehensive way than that of the safety assessment reported to date.

Recommendations

— The safety case consists of the integration of the relevant arguments which support the long term safety of the disposal facility. Hence the traceability and transparency of the safety case as a whole is important, i.e. the selection of the scenarios and data has to be evaluated and justified in order to achieve confidence.
— The overall content and plans for the safety case should be developed: timetable, essential elements to be included in the safety case and the relationships between them, input data, etc.
— The safety case should include topics such as system robustness and defence in depth.
— A safety function concept should be developed and used to link the objectives of the disposal system to the design of the facility. In addition, the project should rely more explicitly on multiple safety functions.
— The safety assessment needs to be applied iteratively as the disposal programme develops and should be used to help to guide the development of disposal concepts. This would help to define and better identify those essential topics, issues and components that require more understanding, the compilation of additional studies and development and would contribute towards the identification of the various uncertainties involved and the

elaboration of a strategy to manage them (additional R&D, sensitivity analyses, etc.).
— An understanding of system behaviour at different periods of time should be presented. Information should be provided on the realistic and likely performance of the disposal facility using realistic model assumptions and data also taking into account the evolution of the disposal facility and site.

7.3. FEPs AND SCENARIOS

Scenarios have been identified by considering KAERI's FEP list, which has been compiled over several years from international as well as FEPs specific to the Republic of Korea. The KAERI FEP list has been adapted to the situation in the country and the importance of the FEPs assessed. On the basis of the screened FEP list, and considering the situation in the Republic of Korea specifically, several scenarios have been identified for the purposes of safety assessment by constructing process influence diagrams (PIDs) and rock engineering system (RES) matrices.

KAERI has developed and considered a wide range of scenarios which have been categorized into 'main scenarios' and 'what if scenarios' as follows:

- Main scenarios
  — The reference scenario (the normal scenario) which includes water abstraction and use from wells and rivers as well as the use of marine water;
  — An initial defects scenario in which some of the waste containers are assumed to have manufacturing defects;
  — An earthquake scenario;
  — A scenario in which an 'abnormal' water well is assumed to be drilled close to the repository into an aquifer next to the disposed of metallic wastes (this scenario is considered by KAERI to be a human intrusion scenario).
- What if scenarios
  — A long term climate change scenario.

As indicated in Geological Disposal Facilities for Radioactive Waste (IAEA Safety Standards Series No. SSG-14 [4]), the safety case for the period following closure should address scenarios referring to the more likely evolution of the geological disposal facility and its regional setting over very long time periods (e.g. a time period comparable to that over which the waste remains hazardous) and less likely events that might affect the performance of the facility. In order for geological disposal facilities to meet the requirements, it is necessary that the safety case and supporting assessments:

— Present evidence that the key features, events and processes that might significantly affect the geological disposal system are understood to such an extent that scenarios for possible evolutions are properly generated;
— Provide estimates of the performance of the geological disposal system regarding compliance with all the relevant safety requirements;
— Identify and present an analysis of the associated uncertainties.

Good practice

— The selection of FEPs seems to be quite comprehensive and a stylized database is used. External expert opinions have been collected in order to select the most important FEPs.
— Several scenarios have been formulated and they capture all the relevant events relating to the case in the Republic of Korea.
— The screening of radionuclides is conducted in a comprehensive manner and provides for the capture of the most important nuclides for assessment.

Recommendations

— The selection of scenarios and the selection and screening of FEPs must be documented in order to enhance traceability and transparency. In addition, in view of the development of a safety case, particular attention must be devoted to the approach adopted in order to describe the scenarios identified through the FEP screening process.
— The formulation of scenarios should take into account the safety functions of the main barriers of the disposal facility and uncertainties in the FEPs that may affect the disposal system (i.e. the disposal facility and the surface environment) from the time the waste is emplaced and into the future.
— The number of scenarios is broadly appropriate, but the reasons for the current classification of the scenarios into main scenarios and what if scenarios should be better explained and documented.
— Further scenarios might be identified and used to consider alternative or refined engineered barrier system designs, and to demonstrate the robustness of the disposal system by exploring the consequences of barrier failure. The possible need for scenarios that include glacial effects, surface erosion, land uplift, etc., should be considered.
— Scenarios involving human intrusion need to be better defined. The abnormal water well scenario cannot be considered strictly as a human

intrusion scenario as generally considered internationally. The well (borehole) does not intersect the waste.

- The review team considers that clearer links should be established between the scenarios and the key physical processes that have the potential to significantly affect the safety functions of the disposal system components. For example, scenarios that include failure of the copper canister should be more clearly linked to the processes (such as those that KAERI has studied in its supporting research), and should include both mechanical and chemical/corrosion effects.
- The current safety assessment uses data from the KURT site, but the assessment is applied to a conceptual, generic disposal site located by the coast. The specificities that could arise from siting a disposal facility by the coast should be further considered. As an example, it would be sensible to consider the possible influences of the ingress of saline marine waters into the disposal facility.
- Gas transport and pathways should be considered.

7.4. MODELS AND DATA

KAERI has developed and applied a wide range of models to support its safety assessments.

The description of the source term model considers different assumptions made for the modelling approach. The assumptions relate to the timing and rate of waste canister failure, but also relate to the rate of waste form dissolution.

KAERI has developed several alternative conceptual models of the source term, including some that feature a more explicit representation of waste dissolution.

The description of the near field models focuses on the model implemented in GoldSim and also considers the various supporting studies and modelling that KAERI has performed as part of its research programme. KAERI has assumed that a canister that is in contact with groundwater could be affected by any of the following near field transport models, or their combination: upward flowing; downward flowing; and stagnant (not flowing) groundwater.

KAERI’s approach to modelling the far field involves using GoldSim for simulating radionuclide transport through fractures in the rock and matrix diffusion using a single pipe model to represent real fractures connected with each other in the fractured rock. For the metallic waste facility, KAERI uses a bundle of single fractures to represent faster flow through wider fractures. This is an appropriate and fairly standard approach, but has to be supported by more explanation and justification of the assumptions.

KAERI’s approach for modelling the biosphere considers the use of a compartment type model with equilibrium radionuclide transfers between compartments representing entities in the biosphere. The model considers potentially exposed groups comprising farmers and freshwater and marine water fishermen, and includes exposure from the ingestion of contaminated water (from a well or river) and food and by external irradiation. This is considered to be an appropriate and fairly standard approach.

Good practice

- Overall, KAERI has a strong modelling capability, particularly for radionuclide transport.
- Data used for the near field (e.g. buffer) have been gathered from the literature which has been reviewed and published. In addition, in situ testing is ongoing at KURT which will provide new data for modelling.

Recommendations

General

- In view of the development of a safety case, in a general manner, the review team considers that KAERI’s way of using the data should be better justified.
- In addition, the presentation of the models should be clear (pictures of the conceptual models are easier to communicate than figures from a particular programme), and the data used in the models need to be fully documented and quality assured.

Source term

- More details should be provided on the properties of the wastes and on the approaches taken to modelling the source term, i.e. assumptions relating to the waste form and radionuclide release.
- Sensitivity analyses should be used to investigate alternative assumptions about the release of radionuclides from the wastes and the content of contamination.

Near field

- In order to understand the near field system, the actual/relevant processes (e.g. corrosion, water chemistry and speciation, bentonite re-saturation

and swelling) have to be modelled and additional experiments need to be considered in case of a lack of data. The experiments conducted should be representative of conditions in the Republic of Korea. In the case of using data from the literature, the suitability of the data should be evaluated.
— More emphasis should be devoted to modelling the evolution of the disposal system and particularly of the engineered barrier system to demonstrate that the barriers will work together as a system to contain the wastes and retard radionuclide transport over time.
— The values for EDZ have been taken from the literature. The relevant EDZ values for the case in the Republic of Korea need to be evaluated.
— The generation of hydrogen gas and its effects on waste dissolution, barrier functionality and transportation has to be taken into account.

Far field

— Fracture filling materials should be taken into account in radionuclide transport calculations (i.e. possible retardation).

Biosphere

— The evolution of the surface environment has to be taken into account as it could affect, for example, the location of discharge points.

7.5. TREATMENT OF UNCERTAINTIES, SENSITIVITY

KAERI is currently considering various approaches to the identification and treatment of uncertainties with regard to safety assessment. In addition to the safety assessment calculations performed, KAERI has undertaken a probabilistic assessment which considers a wider range of scenarios, and has conducted various probabilistic parameter sensitivity analyses.

The KAERI approach addresses uncertainties in several ways:

— Scenarios are used to represent uncertainty arising from significantly different potential system behaviours (e.g. associated with external events and processes).
— Probabilistic calculations have been used to assess the effects of uncertainty in the values of certain parameters identified by expert judgement.

Recommendations

- A systematic methodology for identifying and dealing with uncertainties should be formulated (uncertainties in the data, conceptual models, etc.).
- The treatment of uncertainties should be documented.
- Further sensitivity and uncertainty analyses should be conducted which consider the disposal system as a whole (including the source term as well as the near field, far field and biosphere) in order to assess the importance of a wider range of parameters and processes. Sensitivity analysis could be developed as a tool for understanding the role and relative importance of the various barriers and processes.

7.6. FEEDBACK FOR R&D AND DESIGN

- KAERI's safety assessment process includes recognition of the need for iterative improvement throughout the duration of the disposal facility development programme. However, KAERI does not provide much information or detail on this aspect of feedback.

Recommendations

- The results of the uncertainty and sensitivity analyses conducted for the disposal system should be used to help in prioritizing future work in the forward programme of R&D.
- An assessment of the system and its evolution will show whether and for how long safety functions are being fulfilled. Feedback will be provided for design development with regard to possible changes, which will lead to the redesigning of the barrier in order to improve performance in terms of fulfilling its various safety functions. This could lead, in turn, to changes in design requirements; this should be an iterative process.
- As the disposal programme progresses, increasingly more realistic (less conservative) safety assessments should be made so as to provide better guidance on the disposal concepts and engineered barriers that are required.
- More emphasis should be placed on evaluating the evolution of the disposal system and the interactions between the various components of the system.

7.7. INTEGRATION

KAERI’s disposal programme in the coming years will focus on developing a safety case that will serve to better integrate the wide range of research and assessment studies which have been conducted (i.e. including EBS data as well as site data from KURT). Key aspects of safety case development relate to the integration of knowledge of different types and from various sources.

Recommendations

— The safety assessment and the safety case being developed should be used to strengthen the integration of information from the different disciplines and work teams involved (e.g. the teams involved in safety assessment, disposal system design, research and pyro-processing).
— More studies are needed to calculate risks from a combination of scenarios in order to comply with safety criteria in the Republic of Korea, which require the assessment of risk. International experience should be considered in developing the approach, for example the integration of several types of waste, or spent fuel and pyro-processed wastes in terms of the development of the disposal facility. The implication is that the design of the disposal facility and both the safety case and safety assessment ought to include a full range of wastes, including all the waste streams from pyro-processing that would be subject to geological disposal (e.g. I and Tc filter wastes).
— The programme will need to consider waste acceptance criteria and how they might be developed from the safety case.

Appendix I

TERMS OF REFERENCE OF THE PEER REVIEW OF THE DEEP GEOLOGICAL DISPOSAL CONCEPT IN THE REPUBLIC OF KOREA

SUBJECT OF THE MISSION

An international peer review of the programme in the Republic of Korea for the deep geological disposal of high level waste (HLW) from pyro-processing.

OBJECTIVE OF THE MISSION

To assess, on the basis of the IAEA safety standards, the feasibility of the KAERI approach for developing a geological disposal system for HLW from the pyro-processing of spent nuclear fuel (SNF) and to summarize the findings in the WATRP Review Report.

BACKGROUND

KAERI has been studying processes suitable for reducing the volume of spent fuel to be disposed that is generated by pressurized water reactors, including recycling and the reuse of valuable fissile material. One of the promising technologies under investigation at KAERI is the pyro-processing of SNF, followed by the geological disposal of the HLW generated.

Pyro-processing is a technology under development; it has not yet been demonstrated at the commercial scale; the Government of the Republic of Korea is in the process of addressing the technical feasibility of the fuel cycle with pyro-processing. Thus, the Government would like the potential geological disposal system for HLW from pyro-processing to be independently reviewed.

SCOPE OF THE MISSION

The feasibility of the KAERI approach is to be reviewed by independent experts and advice on the continuation of future R&D provided as indicated:

- Assessment of the overall KAERI approach for the development of a geological disposal system;
- Assessment of the technical feasibility of the proposed geological disposal system (geology and engineered barrier system);
- Advice on the methodology of developing the safety case and the supporting safety assessment for the geological disposal system;
- Recommendations for further studies.

In conducting the peer review, consideration will be given to the following:

- The national HLW disposal programme;
- The nature of the radioactive waste (source term) to be disposed of, including inventory, radionuclide content, physicochemical characteristics, heat generation, etc.;
- The methodological approach to siting and the technical and technological basis for the selection and characterization of the site;
- The relevance and completeness of site characterization studies and their appropriateness for site selection;
- Design concept and selection of engineered barrier materials;
- The alignment of the design basis and derived requirements and procedures with safety standards;
- Proven scientific and systems engineering practice;
- The quality management system and its implementation.

COUNTERPART TEAM

The counterpart team will be headed by Jongwon Choi of KAERI.

The team itself will consist of members of KAERI staff involved in SNF pyro-processing and the development of deep geological repositories.

In addition, representatives of the regulatory body and other State institutions will be invited to join the meeting.

REVIEW TEAM

The Peer Review Team will consist of four senior international experts familiar with the geological disposal of high level radioactive waste and two IAEA staff members (technology and safety).

BACKGROUND AND SUPPORTING MATERIAL

KAERI has developed a set of documents describing the geological disposal system in three areas (see Annexes I and II to Appendix I):

(a) The geology of the disposal site

Even though the site for a geological repository has not yet been selected, KAERI is carrying out investigation work in an underground research tunnel (KURT — the KAERI Underground Research Tunnel). Several 500 m deep boreholes have been drilled in order to sample the host rock. These data have been used for outlining the generic design and safety assessment of the facility. Specifically for the purposes of this peer review, KAERI has designed a hypothetical repository at the KURT site. The documentation summarizes the geological and hydrogeological properties of the research site.

(b) The repository system

The major specific of the geological disposal system in the Republic of Korea is the waste to be disposed of. By introducing pyro-processing, the volume (or mass) of HLW can be reduced significantly. However, the performance of this waste form needs to be thoroughly assessed. The documentation includes details on the characteristics of the disposal canisters, buffer blocks and disposal tunnels (together with an assessment of performance under host rock conditions). The goal of such studies was to select an adequate and efficient engineered barrier system.

(c) Safety assessment

The results of the long term safety assessment following closure are outlined in the third part. Scenarios and mathematical models have been briefly introduced and the input data employed listed. The final results have been compared with standards in the Republic of Korea.

Supporting materials will include legislations, regulations and Governmental decisions relevant to the disposal of HLW from pyro-processing.

MISSION MILESTONES

The following time schedule for mission preparation and performance is proposed:

— 23 September 2011: Official request for the peer review arrives at the IAEA (to the Deputy Director General, Head of the Department of Nuclear Energy) from KAERI through the Permanent Mission of the Republic of Korea).
— 31 October 2011: Final version of the Terms of Reference approved at the technical level (KAERI and the IAEA).
— 30 November 2011: Selection of experts (IAEA in consultation with KAERI).
— 9 December 2011: Background and supporting material delivered to the IAEA (KAERI).
— 31 January 2012: Questionnaire/comments from the expert team delivered to KAERI (IAEA).
— 29 March 2012: Sending brief reactions to the questionnaire issues/comments to the IAEA (KAERI).
— 23–27 April 2012: Peer review meeting in Daejon (KAERI and IAEA).
— 25 May 2012: Draft peer review report sent by the IAEA to KAERI for factual revision (IAEA).
— 15 June 2012: Comments on the draft report forwarded by KAERI to the IAEA (KAERI).
— 13 July 2012: Final peer review report forwarded by the IAEA to KAERI.

Annex I

CONTENT OF THE KAERI DOCUMENT PRESENTED TO THE WATRP TEAM

I. Introduction
II. Geology (KURT site)
  II.1. Characteristics of geological medium (KURT)
    II.1.1. Topography
    II.1.2. Geological feature
  II.2. Groundwater hydraulics
    II.2.1. Conceptual model
    II.2.2. Hydraulic properties
  II.3. Groundwater geochemistry
    II.3.1. Granitic rock
    II.3.2. Mineral
    II.3.3. Buffer solution
    II.3.4. Groundwater evolution
III. Repository system
  III.1. Design bases
  III.2. Ceramic wastes: HLW
    III.2.1. Wastes and source terms
    III.2.2. Canister
    III.2.3. Buffer
  III.3. Metal wastes: ILW
    III.3.1. Wastes and source terms
    III.3.2. Canister
    III.3.3. Buffer
  III.4. Layout and depth
  III.5. General architecture and process
IV. Safety analysis
  IV.1. Safety principle
  IV.2. Scenario
  IV.3. Model
    IV.3.1. Source terms
    IV.3.2. Engineered barrier system
    IV.3.3. Geosphere model
    IV.3.4. Biosphere model

Annex II

SUPPORTING DOCUMENTATION

BAIK, M.-H., et al., Review and compilation of data on radionuclide migration and retardation for the performance assessment of a HLW repository in Korea, Nucl. Eng. Technol.

BAIK, M.-H., et al., Characterization of aquatic groundwater colloids by a laser-induced breakdown detection and ICP-MS combined with an asymmetric field-flow fractionation, Korea J. Chem. Eng.

BAIK, M.-H., et al., Erosion of bentonite particles at the interface of a compacted bentonite and a fractured granite, Eng. Geol.

BAIK, M.-H., et al., Retention of uranium (VI) by laumontite, a fracture-filling material of granite, J. Radioanal. Nucl. Chem.

BAIK, M.-H., et al., Sorption of ^{14}C, ^{99}Tc, ^{137}Cs, ^{90}Sr, ^{63}Ni, and ^{241}Am onto a rock and a fracture-filling material from the Wolsong low- and intermediate-level radioactive repository, Gyeongju, Korea, J. Radioanal. Nucl. Chem.

BAIK, M.-H., LEE, S.-Y., Colloidal stability of bentonite clay considering surface charge properties as a function of pH and ionic strength, J. Ind. Eng. Chem.

CHO, D.-K., et al., Waste classification of 17×17 KOFA spent fuel assembly hardware, Nucl. Eng. Technol.

CHO, W.-J., et al., Analysis of functional criteria for butter material in a high-level radioactive waste repository, J. Korean Nucl. Soc.

CHO, W.-J., et al., Thermal conductivity of compacted bentonite and bentonite–sand mixture, J. Korean Radioact. Waste Soc.

CHOI, H.-J., CHOI, J., Double-layered buffer to enhance the thermal performance in a high-level radioactive waste disposal system, Nucl. Eng. Design.

CHOI, H.-J., et al., Application of a cold spray technique to the fabrication of a copper canister for the geological disposal of CANDU spent fuels, Nucl. Eng. Design.

CHOI, H.-J., et al., Preliminary conceptual design of a geological disposal system for high-level wastes from the pyroprocssing of PWR spent fuels, Nucl. Eng. Design.

EBASHI, T., et al., Application of the comprehensive sensitivity analysis method to a Korean geological disposal concept, J. Nucl. Sci. Technol.

KIM, B.-Y., et al., Effect of carbonate on the solubility of neptunium in natural granitic groundwater, Nucl. Eng. Technol.

KIM, S.-S., et al., Comparison between experimentally measured and thermodynamically calculated solubilities of UO_2 and ThO_2 in KURT groundwater, Nucl. Eng. Technol.

KIM, S.-S., et al., Estimation of the corrosion thickness of a disposal container for high-level radioactive wastes in a wet bentonite, J. Ind. Eng. Chem.

IM, S.-S., et al., Solubilities of actinides in a domestic groundwater and a bentonite porewater calculated by using PHREEQC, J. Ind. Eng. Chem.

KIM, S.-S., et al., Solubility of neptunium oxide in the KURT (KAERI Underground Research Tunnel) groundwater, J. Radioanal. Nucl. Chem.

KIM, S.-S., et al., The dissolution of ThO_2(cr) in carbonate solutions and a granitic groundwater, J. Radioanal. Nucl. Chem.

LEE, S.-Y., BAIK, M.-H., Uranium and other element's distribution in Korean granite: Implications for the influence of iron oxides in uranium migration, Environ. Geochem. Health.

LEE, S.-Y., et al., Adsorption of U(VI) ions on biotite from aqueous solutions, Appl. Clay Sci.

LEE, S.-Y., et al., Adsorption of uranyl ions and microscale distribution on Fe-bearing mica, Appl. Clay Sci.

LEE, S.-Y., et al., Biogenic formation and growth of uraninite (UO_2), Environ. Sci. Technol.

LEE, S.-Y., et al., Chemical weathering of granite under acid rainfall environment, Korea Environ. Geol.

KANG, K.-C., et al., Sorption of Cu2+ and Cd2+ onto acid- and base-pretreated granular activated carbon and activated carbon fiber samples, J. Ind. Eng. Chem.

LEE, Y.-M., HWANG, Y. A., Goldsim model for the safety assessment of an HLW repository. Progr. Nucl. Energy.

PARK, C.-K., BAIK, M.-H., Diffusion of some chemical species through a granite considering their geochemical properties, Korean J. Chem. Eng.

Appendix II

EXPERT TEAM MEMBERS

David G. BENNETT (United Kingdom)

D. Bennett, Director, TerraSalus Limited, has over 20 years of experience in providing strategic and technical consultancy advice on radioactive waste management and its regulation. He has a PhD in geochemistry and water–rock interaction, is a Fellow of the Geological Society, and has contributed to over one hundred published papers and reports in the area of radioactive waste disposal. Mr Bennett has many years of experience in contributing to national and international review panels.

Mr Bennett's expertise includes undertaking and managing complex projects related to radioactive waste disposal facility authorization and licensing, risk and safety assessment, safety cases, engineered barrier systems, waste immobilization, geochemistry and radionuclide behaviour. His research experience includes developing and applying various models for the chemistry and transport of radionuclides in radioactive waste disposal systems.

In the United Kingdom, Mr Bennett has worked on behalf of several Government Departments, the regulators and various industry clients involved with near surface and geological radioactive waste disposal. He has contributed to radioactive waste management programmes in several other countries (e.g. Sweden), and also to international programmes run by the European Commission, the IAEA and the OECD Nuclear Energy Agency (OECD/NEA). For example, from 2003 to 2007 he was involved in all aspects of the joint European Commission/OECD Nuclear Energy Agency Engineered Barrier System Project for geological disposal.

Hans FORSSTRÖM (Sweden)

H. Forsström is Senior Adviser at SKB International, the wholly owned subsidiary of the Swedish Nuclear Fuel and Waste Management Company (SKB), which provides international services based on the know-how, expertise, laboratories and facilities developed and operated in SKB's programme.

He has a Master of Science in applied physics from the Chalmers University of Technology in Gothenburg, Sweden.

He started his career as a reactor physicist in 1972 for the Ringhals 1 BWR. He then turned to the field of radioactive waste management. In 1979, he joined SKB where he has held several different positions in the area of research and development for waste management and disposal. During his last few years at SKB, he was Technical Director with responsibility for the development and operation of the Swedish Waste Management Systems and Facilities.

From 1998 to April 2005, Mr Forsström worked at the European Commission as Head of the Unit for Nuclear Fission and Radiation Protection in DG Research, where he was responsible for the implementation of the Euratom Framework programme for research and training activities on nuclear fission and radiation protection.

Mr Forsström joined the IAEA in April 2005 and, until June 2010, was Director of the Division of Nuclear Fuel Cycle and Waste Technology in the Department of Nuclear Energy.

Wolfgang KICKMAIER (Switzerland)

W. Kickmaier has almost two decades of experience in radioactive waste management. He has worked for Nagra, the Swiss national waste disposal organization, where he managed the Grimsel Test Site, and was also Deputy Head of the International Services and Projects Division. His responsibilities included:

— Planning of the research programme, Grimsel Test Site Phase V/VI, 1997–2013.
— Managing in situ experiments at the URL, focusing on large to full scale engineered barrier system demonstration experiments for HLW and ILW.
— Planning, coordination and implementation of international research projects.
— Chairing the Technical Advisory Committees for Grimsel Experiments.
— During this time he was appointed Swiss Representative to the IAEA Network of Centres of Excellence in Training and Demonstration in Underground Research Facilities. He was also a Member of the Board of the ITC (International School of Underground Waste Storage and Disposal), which ran many IAEA supported courses for international participants.

Following his time at Nagra, he was Head of Research at the University of Applied Sciences in Switzerland for four years. He is currently a Senior Consultant at MCM Consulting in Switzerland. He coordinates waste management projects, providing strategic and technical advice to numerous national waste management programmes. Recently, he has been directly engaged in an MCM team developing a radioactive waste management strategy for the United Arab Emirates, where a major new nuclear power programme is being initiated.

Mr Kickmaier has a Bachelor of Science in geology from the University of Münster in Germany and a PhD in geology from the University of Berne in Switzerland.

Marjut VÄHÄNEN (Finland)

M. Vähänen is the Research Manager at Posiva Oy. She has over ten years of experience with RTD on nuclear waste disposal, especially in near field issues such as canister and buffer performance.

Ms Vähänen holds a Master of Science in engineering physics (1999) and also gained a Licentiate in Technology (2006) at the same university.

Her professional career commenced at Tampere University of Technology in 1999, where she worked as a post-graduate student researching the dry corrosion of copper and copper based materials. After joining Posiva in 2003, she was in charge of canister corrosion studies and later became the unit's research manager responsible for long term safety studies of geological disposal in general. Currently, she is in charge of research related to the long term safety and performance assessment of Posiva's planned repository for spent nuclear fuel at Olkiluoto.

Gerard BRUNO (IAEA)

G. Bruno has been working in the field of radioactive waste disposal for more than 15 years. After gaining his PhD in geology, he joined the French Institute for Radiological Protection and Nuclear Safety, IRSN, the technical safety organization which supports the French Nuclear Safety Authority (ASN), where he worked mainly on a review of feasibility studies for the deep geological disposal of HLW in argillaceous formations.

In 2006, he was seconded to the Directorate General for Transport and Energy at the European Commission and joined the IAEA as a waste safety specialist in 2009. Since August 2010, he has been the Head of the Radioactive Waste and Spent Fuel Management Unit at the IAEA. The main activities of the unit consist of the development of safety standards on the predisposal and disposal of radioactive waste as well as their application through assistance missions, peer reviews and the organization of international harmonization projects.

Lumir NACHMILNER (IAEA)

L. Nachmilner has 36 years of experience in research and development, safety studies, planning, budgeting, strategic studies, and managing projects in the processing of radioactive waste and its disposal in near surface and geological repositories. After graduation from the Institute of Chemical Technology, Prague, he started his career at the Nuclear Research Institute, Řež. He completed his PhD studies there in the area of waste acceptance for disposal and reached the position of Director of the Fuel Cycle Chemistry Division.

Between 1997 and 2003, he managed the Czech project on geological repository development at RAWRA (the national waste management agency). From 2003 until his retirement in 2012, he worked in the Waste Technology Section of the Division of Nuclear Fuel Cycle and Waste Technology at the IAEA, his final position being that of Disposal Team Leader.

REFERENCES

[1] KOREA ATOMIC ENERGY INSTITUTE, Geological Disposal of Pyroprocessed Waste from PWR Spent Fuel in Korea, Rep. KAERI-TR-4525-2011, KAERI, Daejon (2011).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSR-5, IAEA, Vienna (2011).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Case and Safety Assessment for the Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSG-23, IAEA, Vienna (2012).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Geological Disposal Facilities for Radioactive Waste, IAEA Safety Standards Series No. SSG-14, IAEA, Vienna (2011).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment Methodologies for Near Surface Disposal Facilities, ISAM, Vol. 1 — Review and Enhancement of Safety Assessment Approaches and Tools, Vol. 2 — Test Cases, IAEA, Vienna (2004).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Biospheres for Solid Radioactive Waste Disposal, Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASSessment (BIOMASS) Programme, IAEA, Vienna (2003).

ORDERING LOCALLY

In the following countries, IAEA priced publications may be purchased from the sources listed below, or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

AUSTRALIA
DA Information Services
648 Whitehorse Road, Mitcham, VIC 3132, AUSTRALIA
Telephone: +61 3 9210 7777 • Fax: +61 3 9210 7788
Email: books@dadirect.com.au • Web site: http://www.dadirect.com.au

BELGIUM
Jean de Lannoy
Avenue du Roi 202, 1190 Brussels, BELGIUM
Telephone: +32 2 5384 308 • Fax: +61 2 5380 841
Email: jean.de.lannoy@euronet.be • Web site: http://www.jean-de-lannoy.be

CANADA
Renouf Publishing Co. Ltd.
Telephone: +1 613 745 2665 • Fax: +1 643 745 7660
5369 Canotek Road, Ottawa, ON K1J 9J3, CANADA
Email: order@renoufbooks.com • Web site: http://www.renoufbooks.com

Bernan Associates
4501 Forbes Blvd., Suite 200, Lanham, MD 20706-4391, USA
Telephone: +1 800 865 3457 • Fax: +1 800 865 3450
Email: orders@bernan.com • Web site: http://www.bernan.com

CZECH REPUBLIC
Suweco CZ, spol. S.r.o.
Klecakova 347, 180 21 Prague 9, CZECH REPUBLIC
Telephone: +420 242 459 202 • Fax: +420 242 459 203
Email: nakup@suweco.cz • Web site: http://www.suweco.cz

FINLAND
Akateeminen Kirjakauppa
PO Box 128 (Keskuskatu 1), 00101 Helsinki, FINLAND
Telephone: +358 9 121 41 • Fax: +358 9 121 4450
Email: akatilaus@akateeminen.com • Web site: http://www.akateeminen.com

FRANCE
Form-Edit
5, rue Janssen, PO Box 25, 75921 Paris CEDEX, FRANCE
Telephone: +33 1 42 01 49 49 • Fax: +33 1 42 01 90 90
Email: fabien.boucard@formedit.fr • Web site: http://www.formedit.fr

Lavoisier SAS
14, rue de Provigny, 94236 Cachan CEDEX, FRANCE
Telephone: +33 1 47 40 67 00 • Fax: +33 1 47 40 67 02
Email: livres@lavoisier.fr • Web site: http://www.lavoisier.fr

L'Appel du livre
99, rue de Charonne, 75011 Paris, FRANCE
Telephone: +33 1 43 07 50 80 • Fax: +33 1 43 07 50 80
Email: livres@appeldulivre.fr • Web site: http://www.appeldulivre.fr

GERMANY
Goethe Buchhandlung Teubig GmbH
Schweitzer Fachinformationen
Willstaetterstrasse 15, 40549 Duesseldorf, GERMANY
Telephone: +49 (0) 211 49 8740 • Fax: +49 (0) 211 49
Email: s.dehaan@schweitzer-online.de • Web site: http://www.goethebuch.de/

HUNGARY
Librotade Ltd., Book Import
PF 126, 1656 Budapest, HUNGARY
Telephone: +36 1 257 7777 • Fax: +36 1 257 7472
Email: books@librotade.hu • Web site: http://www.librotade.hu

INDIA
Allied Publishers Pvt. Ltd.
1st Floor, Dubash House, 15, J.N. Heredi Marg
Ballard Estate, Mumbai 400001, INDIA
Telephone: +91 22 42126969/31 • Fax: +91 22 2261 7928
Email: arjunsachdev@alliedpublishers.com • Web site: http://www.alliedpublishers.com

Bookwell
3/79 Nirankari, Dehli 110009, INDIA
Tel.: +91 11 2760 1283 • +91 11 27604536
Email: bkwell@nde.vsnl.net.in • Web site: http://www.bookwellindia.com/

ITALY
Libreria Scientifica "AEIOU"
Via Vincenzo Maria Coronelli 6, 20146 Milan, ITALY
Tel.: +39 02 48 95 45 52 • Fax: +39 02 48 95 45 48
Email: info@libreriaaeiou.eu • Web site: http://www.libreriaaeiou.eu/

JAPAN
Maruzen Co., Ltd.
1-9-18 Kaigan, Minato-ku, Tokyo 105-0022, JAPAN
Tel.: +81 3 6367 6047 • Fax: +81 3 6367 6160
Email: journal@maruzen.co.jp • Web site: http://maruzen.co.jp

NETHERLANDS
Martinus Nijhoff International
Koraalrood 50, Postbus 1853, 2700 CZ Zoetermeer, NETHERLANDS
Tel.: +31 793 684 400 • Fax: +31 793 615 698
Email: info@nijhoff.nl • Web site: http://www.nijhoff.nl

Swets
PO Box 26, 2300 AA Leiden
Dellaertweg 9b, 2316 WZ Leiden, NETHERLANDS
Telephone: +31 88 4679 263 • Fax: +31 88 4679 388
Email: tbeysens@nl.swets.com • Web site: www.swets.com

SLOVENIA
Cankarjeva Zalozba dd
Kopitarjeva 2, 1515 Ljubljana, SLOVENIA
Tel.: +386 1 432 31 44 • Fax: +386 1 230 14 35
Email: import.books@cankarjeva-z.si • Web site: http://www.mladinska.com/cankarjeva_zalozba

SPAIN
Diaz de Santos, S.A.
Librerias Bookshop • Departamento de pedidos
Calle Albasanz 2, esquina Hermanos Garcia Noblejas 21, 28037 Madrid, SPAIN
Telephone: +34 917 43 48 90
Email: compras@diazdesantos.es • Web site: http://www.diazdesantos.es/

UNITED KINGDOM
The Stationery Office Ltd. (TSO)
PO Box 29, Norwich, Norfolk, NR3 1PD, UNITED KINGDOM
Telephone: +44 870 600 5552
Email (orders): books.orders@tso.co.uk • (enquiries): book.enquiries@tso.co.uk • Web site: http://www.tso.co.uk

On-line orders:
DELTA International Ltd.
39, Alexandra Road, Addlestone, Surrey, KT15 2PQ, UNITED KINGDOM
Email: info@profbooks.com • Web site: http://www.profbooks.com

United Nations (UN)
300 East 42nd Street, IN-919J, New York, NY 1001, USA
Telephone: +1 212 963 8302 • Fax: +1 212 963 3489
Email: publications@un.org • Web site: http://www.unp.un.org

UNITED STATES OF AMERICA
Bernan Associates
4501 Forbes Blvd., Suite 200, Lanham, MD 20706-4391, USA
Tel.: +1 800 865 3457 • Fax: +1 800 865 3450
Email: orders@bernan.com • Web site: http://www.bernan.com

Renouf Publishing Co. Ltd.
812 Proctor Avenue, Ogdensburg, NY 13669, USA
Tel.: +800 551 7470 (toll free) • +800 568 8546 (toll free)
Email: orders@renoufbooks.com • Web site: http://www.renoufbooks.com

Orders for both priced and unpriced publications may be addressed directly to:

IAEA Publishing Section, Marketing and Sales Unit, International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22488 • Fax: +43 1 2600 29302
Email: sales.publications@iaea.org • Web site: http://www.iaea.org/books

13-30581

The development of pyro-processing technology is ongoing and has not yet been demonstrated at the commercial level. Consequently, the Government of the Republic of Korea requested an assessment of the technical feasibility of this technology. The assessment was also to include the appraisal of a disposal solution for waste generated by pyro-processing. With regard to the latter, the IAEA was requested by the Government of the Republic of Korea to review the status of the disposal project within the IAEA's Waste Management Assessment and Technical Review Programme. This report presents the consensus view of the international group of experts convened by the IAEA to carry out the review.

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA