Nuclear Waste Management in the European Union:

Growing volumes and no solution

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Abbreviations

AKW	Nuclear Power Plant
BE	Fuel Element
HLW	High Level Waste
ILW	Intermediate Level Waste
LILW	Low and Intermediate Level Waste
LLW	Low Level Waste
Mg	Mega gram, formerly t = Ton
MOX	Mixed Oxide Fuels (Uranium and Plutonium)
HM	Heavy Metal, contents of uranium or uranium and plutonium in fuel elements
t	Tons
VLLW	Very Low Level Waste

1. Introduction

The EU Commissioner Oettinger responsible for issues in connection with nuclear energy has announced to submit a proposal for a Directive on the Handling of Spent Fuel Elements and Radioactive Waste in the European Union. As a basis for the discussion of this proposal for a Directive, this study is designed to identify the basic options for the handling of spent fuel and radioactive waste in accordance with the current state of the art and the respective situation in the Member States in the European Union.

The by far largest volumes of radioactive waste (nuclear waste) within the scope of the use of nuclear energy are produced by power generation (and partially parallel heat generation). The largest portion of the nuclear waste from research and industry can be assigned to this sector.

Radioactive waste generated in research and in the industry of other fields of application of nuclear energy as well as radioactive waste produced in medicine has a by far lower volume, smaller activity and does not contain nuclear fuels. This radioactive waste will not be referred to in the following sections due to the poor information situation and due to the overall lower danger potential. We would like to point out, however, that methods are available in many fields of applications of medicine and industry without using radioactive substances, which could significantly reduce the radioactive waste from these sectors if used on an EU-wide scale. Also radioactive waste generated as ancillary products through the exploration of mineral resources (such as petroleum and natural gas) will not be taken into account in this study.

The study presented is designed as a basis for a generally understandable Internet presentation. It is thus – in general – not drafted like an expertise. The addressees of the Internet presentation are laypeople and experts.

Chapter 2 of this study will, first of all, deal with general statements with respect to radioactive waste. This is followed by Chapter 3 describing the options for a waste management. The respective situation of the handling of radioactive waste is presented in Chapter 4 regarding the EU Member States using nuclear energy as well as for the Russian Federation and for the US due to the particular importance of these countries. Chapter 5 contains an assessment of the overall situation for the European Union.

2. Nuclear Waste

2.1 What is nuclear waste?

The use of nuclear energy for the generation of power does not only result in an operation of nuclear power plants but also of a large number of further facilities. A large volume of nuclear waste is produced.

This nuclear waste is radioactive, i.e. the waste contains atomic nuclei transforming (decaying or in less amount fissioning) to other atomic nuclei in the course of time without any external influence. During these processes, the radioactive waste will produce an ionising radiation. This is a so-called α-, β-, γ- or neutronradiation causing damage when penetrating into any other matter.

The number of the radioactive nuclei contained in the waste is very high. Billions of decays of atomic nuclei per second may occur in one single waste container. The unit stated for the decay per second is the Becquerel (Bq). The number of decays occurring in a specific waste at an actual point of time depends on the kind of chemical elements these radioactive atomic nuclei (named radio nuclides) belong to, how many of the respective kind of radio nuclides had existed in the waste at the beginning (radioactivity inventory) and how much time had elapsed since then.

The radio nuclides in the waste have different half-life periods. That means, that the question of how much time will elapse until half of the originally existing radioactive atomic nuclei have disappeared through decay will depend on the kind of radio nuclide. This will furthermore apply to the period of time, until the radioactivity in the waste has dropped to a value resulting in a significantly lower extent of damages in organic material.

The half-life periods for the different kinds of radio nuclides range from very small fractions of a second to millions of years.

In addition to the radiological danger potential, some of the waste also contains chemically toxic substances. This shall not be ignored, in particular in view of a pollution of ground- and surface water.

2.2 Where is nuclear waste generated?

The generation of nuclear waste through the use of nuclear energy for power generation may be divided up into five large sections:

- nuclear waste caused by the exploration and processing of uranium,
- nuclear waste caused by the operation of nuclear power plants,
- nuclear waste caused by reprocessing,
- nuclear waste caused by decommissioning of nuclear facilities and
- nuclear waste caused by handling radioactive waste.

2.2.1 Nuclear waste caused by the exploration and processing of uranium

The basis for today's utilization of nuclear energy is the fission of specific uranium atomic nuclei. Uranium is a radioactive substance naturally existing in the Earth's crust. Uranium deposits are more concentrated in some areas of the world, where the ore is exploited in mines and is processed to yellow cake. The mining waste resulting from the exploitation and the slurries generated during processing are the first kinds of nuclear waste generated.

The residual uranium remaining in the mining waste and the slurry and other substances and gases released during the mining are more hazardous for mankind compared with uranium remaining bonded to the Earth's crust. The radionuclide concentration in the waste is relatively low, but the large volumes of some hundred thousand tons (respectively mega grams) generated at the respective locations result in an access to a high radioactivity inventory. The mining waste towers up to enormous waste mountains on the Earth's surface. During the handling of the mining waste as well as through erosion during storage, dust is generated inhaled by people. The slurries are pumped into enormous basins and are permanently deposited there. This may result in a penetration of uranium into ground water. This problem with many million of tons of radioactive waste is been mostly far away from the European Union since a long time now, because the uranium is exploited – apart from minor quantities in the Czech Republic and Romania – today in other far-away countries. There had been some mining of uranium ore to a relative low extent in some of the EU Member States, which has been mainly stopped in the meantime. In France, for example, uranium had been exploited in some smaller mines. At the moment, the redevelopment is the subject of concept discussions and consulting. Larger quantities of uranium ore had been formerly mined in the former GDR. the respective legacy has been redeveloped in the meantime. The population, however, is bound to permanently live with higher radiation loads from the environment.

Several processing stages (conversion, enrichment, calcination) in various different facilities are then used to produce the fuel elements from the processed uranium oxide for use in nuclear power plants. One or several of these plants are located in the following Member States of the European Union: Belgium, France, Great Britain, Germany, The Netherlands, Romania, Sweden and Spain). Uranium-containing waste is generated in each of these plants.

With respect to the quantity of radioactive waste and the hazard potential, the uranium processing plants at Capenhurst (Great Britain), Almelo (The Netherlands), Gronau (Germany) and Tricastin (France) are particularly remarkable when looking at the uranium plants in the EU. These plants generate large quantities of depleted uranium in addition to the enriched uranium further used. This uranium is stored in the chemical compound uranium hexafluoride (UF_6) which is not only radioactive but also very toxic. Due to these properties, UF_6 may have disastrous consequences when released in the closer vicinity.

The depleted uranium UF_6 cannot be used anymore within the scope of the economic frame conditions of Western States and would have to be declared as waste for that purpose. In the past, the operator companies in France, Germany and The Netherlands have used the chance to transport the depleted UF_6 to Russia (more than 10,000 tU per year). The UF_6 has then been reprocessed without consideration of the real costs and the small percentage of the enriched part of the uranium delivered had been returned to the European sender. The large part of the UF_6 further depleted remained in Russia and is stored for unknown time in the open. Nobody knows about the future whereabouts on the long run. The European companies from the European Union have left the responsibilities for this waste to the Russians.

The agreements for this re-enrichment have expired in the meantime. Now the companies operating the enrichment plants in the EU have to keep the depleted UF_6. The UF_6 is transported from Almelo and Gronau to Southern France and is – like the French UF_6 – converted to a less hazardous kind (uranium oxide) and then returned to the sender, where an interim storage is maintained. The French uranium oxide is transported to Bessines (close to Limoges) for interim storage and the British depleted uranium from Capenhurst is stored on site. According to today's status, the depleted uranium has to be declared as waste any time in the future. No concept for a further handling has been presented yet in any of the 4 EU Member States. This will be a volume of some 100,000 t of waste.

2.2.2 Nuclear waste caused by the operation of nuclear power plants

When using uranium as nuclear fuel in the reactor of a nuclear power plant, various different processes of nucleus transformation occur due to the fission of atomic nuclei and particle capture, during which atomic nuclei of specific chemical elements (radionuclides) are produced which are radioactive.

Some of the radionuclides are directly caused by nuclear fission, the so-called fission products. A large number of these are generated in the fuel elements. The fuel elements are "spent" after a certain period of use in the reactor and the corresponding irradiation of the fuel. Unless these elements are reprocessed (see Section 2.2.3), these elements are to be treated as radioactive waste. This is the most dangerous waste generated through the use of nuclear energy.

Due to the nuclear fission and the resulting direct radiation, further kinds of radioactive waste are generated in the nuclear power pant through contamination (contamination of liquids or solid surfaces with radioactive substances) and activation (transfomation of atomic nuclei in solid matters) as well as through a contamination during control- and maintenance works. Liquid radioactive wastes are, for example, oils, slurries, vaporizer concentrates (cooling water contamination), ion exchanger resins (cooling circuit cleaning) and auxiliary filter substances). Solid radioactive waste includes metal parts, insulation materials, paper, plastic materials, textiles, tools, construction waste and structural components.

The amount of waste produced depends on the reactor type and on the age of the reactor. Roughly 50 m^3 of conditioned waste is generated, for example, in the newer reactors in the Federal Republic of Germany, namely for each reactor and year[1]. Due to the cost pressure and the existing safety requirements in Germany, relatively efficient conditioning processes are used. This is not the case in many other States.

[1] M. Volkmer: „Basic Knowhow Nuclear Energy“; brochure of the Information Circle Nuclear Energy, June 2007

For this reason, the nuclear waste volumes in other EU Member States are considerably higher. These amount to roughly 78 m^3 in France, for example, and are even higher in other countries.

The volumes stated do not contain waste generated through any large-scale repair- or back-fitting measures.

2.2.3 Nuclear waste caused by reprocessing

In some of the EU Member States, the Waste-Management Concept includes or included the so-called reprocessing of the spent fuel (see Section 3). During this process, the fuel elements are segmented, cut and dissolved in acid. The uranium and the plutonium generated in the reactor are separated from the solution and are temporarily stored for a possible or actual further use.

The remaining solution contains the nuclear fission products generated through fission in the reactor and the very long-lasting radionuclides generated in the reactor through particle capture (e.g. curium, neptunium), but also residues of uranium and plutonium. This solution is highly radioactive. In a melting furnace this solution will be mixed with other components to molten glass poured off into a steel canister. The high radioactive waste (HLW) canisters produced this way will then be temporarily stored in a storage facility at the site of the reprocessing plant or in a storage building of the company operating the nuclear power plant, from which the fuel elements had originated. The hazard potential of the HLW canisters is comparable with that of spent fuel.

In addition to this highly radioactive waste, the waste kinds of the cut sleeves and structural components of the fuel elements, the slurries from the residue in as well as the liquids from the cleaning of the components, the solid waste generated during the operation and the contaminated components and piping systems are generated.

The waste generated is conditioned in several ways and temporarily stored at the sites of the reprocessing plants. Waste caused by the reprocessing of spent fuel from foreign nuclear power plants will either be transported to a further interim storage in a conditioned state or in equivalent quantities of highly radioactive waste after a certain period of time to the respective country of origin.

At the moment, reprocessing plants are operated in the EU in France (La Hague) and Great Britain (Sellafield).

2.2.4 Nuclear waste caused by decommissioning of nuclear facilities

Any and all nuclear facilities – ranging from the uranium processing plants and nuclear power plants to reprocessing plants, conditioning plants and repositories must be shut down after a certain period of operation. According to international standards, this includes the speedy (that means: rough 15 years for nuclear power plants) demolition of the plants. In some countries, however, nuclear power plants are maintained sealed for a period of time of 30 to 60 years and will be demolished not before a partial decay of the radioactive materials existing in and at the internals and structural components of the facility.

Upon decommissioning nuclear facilities very large quantities of radioactive waste is generated. This amounts to roughly 6,000 t (Mg) of radioactive waste for a nuclear power plant, out of a total volume of waste of roughly 500,000 t (Mg). The radioactive waste mainly consists of construction waste and metal components.

2.2.5 Nuclear waste caused by handling radioactive waste

The radioactive waste generated during the operation and decommissioning of nuclear facilities must be conditioned, temporarily stored and disposed of. Also the nuclear facilities set up for this purpose generated radioactive waste during operation and decommissioning. When correctly operating interim storage and repository, only low levels of concentrations of contamination and no activation shall occur. It is slightly higher for processing and conditioning plants for radioactive waste. During this process, also plant components will be contaminated, which have to be treated as radioactive waste later on. Over all the quantity of waste generated in these facilities is relatively low as compared to the exploration of uranium, the operation of nuclear power plants and the reprocessing.

2.3 Classification of radioactive waste

The classification of radioactive waste varies in the different Member States of the EU. The criteria used for that purpose are, for example, the activity concentration, the overall radioactivity of a container, the origin or the heat generation of the waste. The Commission of the European Union has issued a recommendation for a classification system for solid radioactive waste because of harmonization in the EU[2]. This system has not yet been implemented bindingly in the Member States. But it mainly corresponds to the classification used in many Member States, divided up into the following categories:

- „ Transition radioactive waste“ (VLLW)
  Waste with radioactivity levels falling below the clearance levels defined immediately after generation or after a certain period of time of interim storage through decay. It is allowed to dispose of this waste conventionally – despite the remaining radioactivity inventory. This radioactive waste is also called “very low level waste” or “slightly radioactive”. This waste includes, for example, construction waste and decontaminated metal parts from the decommissioning, but also slightly radioactive waste from the operation of nuclear facilities as well as some part of the uranium-containing waste.

- „Low and intermediate level waste“ (LILW or LLW and ILW)
  Waste, for which the heat generation caused through the radioactivity inventory is uncritical for final disposal. The heat generation allowed will be defined for each specific location. A further subdivision is made with respect to radioactive waste with low and intermediate activity levels:
  - „Short-lived waste“
    Waste with half-life periods of the radionuclides mainly contained therein with less than 30 years and with a limited concentration of long-lived α emitters (400 Bq/g in the waste volume involved).
  - „Long-lived waste“
    All not short-lived waste.

  The waste described in Chapter 2.2 belongs to the low and intermediate level waste.

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[2] Commission Recommendation of 15 September 1999 on a classification system for solid radioactive waste, SEC(1999) 1302 final (1999/669/EC, Euratom), Official Journal of the European Union L 265, dated October 13, 1999

- „High level waste" (HLW)
  Waste, where the radioactivity inventory is so high that a relevant heat generation can be assumed during the complete interim storage period as well as after the depositing in a final repository.

This waste includes, for example, spent fuel elements and HLW canisters.

2.4 How dangerous is the nuclear waste?

2.4.1 Health hazards

The radioactive materials in the nuclear waste emit an ionizing radiation during decay. Ionizing means: the distribution of the electric charge distribution changes upon the irradiation of matter. Such charge distribution changes result in chemical reactions in organic tissue which mutate or kill the cells. Corresponding to the number of these events in the human body, the probability increases for damages, which the human body is unable to handle.

The most serious consequences are cancer diseases or genetic modifications having an impact on the next or future generations through deformities of children. But also metabolic diseases or a weakening of the immune system may be the result.

The probability of the occurrence of a disease depends on the level of radioactivity and on the duration the human being is subjected to the radiation. Thus, in general all kinds of radioactive waste – ranging from very low to highly radioactive – may trigger damages to health. The probability is higher, however, in case of high level waste.

There are three paths, via which radioactivity will become dangerous for human beings:

- The presence in the immediate vicinity of waste will subject the body to a direct radiation (gamma emission or neutron emission).
- When staying inside or close to facilities, in which radioactive waste is handled, the radionuclides released from the waste may penetrate directly into the body through breathing and indirectly (e.g. after depositing of radionuclides onto plants or in water) through the intake of food.

- A contact of radioactive waste or waste containers may result in a contamination of the skin.

All of the three paths are relevant for the operating staff in nuclear facilities. The third path is usually of no relevance for the normal population.

The path of direct radiation is relevant for persons from the population living or staying close to a frequently used transporting route for radioactive waste or staying at the fence of a nuclear facility with a high level of direct radiation (local dose rate), such as an interim storage facility for highly radioactive waste. The path of intake of radioactive substances into the body is mainly relevant for local residents of nuclear facilities directly handling the waste, such as reprocessing- and conditioning facilities.

The risk of health hazard is drastically increased, if the radioactive waste is involved in malfunctions of or accidents in nuclear facilities or in serious accidents during transport. The release of radionuclides from the waste may add up to a considerable extent. This particularly applies to purposeful acts of sabotage.

The above assessment of health hazards refers to a time period, during which the radioactive waste is handled; thus to some decades. But also at a time the radioactive waste will not be handled anymore but is finally disposed of, considerable hazards will emerge from this waste. Even the disposal in deep geological layers will not be a guarantee – due to the partially extremely long half-life periods of the substances – that the radionuclides will remain permanently isolated from the biosphere and thus from mankind.

There will be reactions in a repository over long periods of time encouraging a release. If the rock or the geological layer on site holding the waste will not react overall as predicted, the radionuclides may spread into the geosphere and may penetrate, for example, via the aquifer into the biosphere. This way ground water close to the surface and surface water and thus drinking water may become radiologically contaminated.

2.4.2 Further hazards

Misuse

The above section has dealt with the hazards for human beings directly evolving from the radioactive waste. But also a misuse of radioactive waste is possible.

The spent fuel elements contain nuclear fuel, in particular plutonium. After a separation from the fuel elements, the nuclear fuel may also be used in an atomic bomb.

Discussions held on an international scale – mainly within the scope of the International Atomic Energy Organisation (IAEO) - also point out to the option that terrorist groups may intend a propagation of or a contamination with radioactive substances even with conventional explosive charges (dirty bomb). Radioactive waste would also be suitable for this purpose.

Other protected resources

Not only human beings but also the environment, thus animals and plants, water, soil and air must be protected against the detrimental impacts of radioactivity.

Animals and plants are also living organisms, in which ionizing radiation will cause damages. Water, soil and air shall not be contaminated.

3. Waste-Management Concepts

The utilization of nuclear energy causes waste presenting a hazard to mankind and to the environment even after several hundred thousand years due to the long half-life periods of the substances contained in the waste. There are two fundamental options available to reduce this hazard with respect to the handling and storage of the radioactive waste, namely the principle of dilution and the principle of concentration.

The **Principle of Dilution** is designed to carry out an extensive resolution and distribution of the waste or of the radioactive contents into the environment (e.g. water, air), in order to prevent an inadmissible impact on the protected resources. This principle has been followed by many countries at the beginning of the use of nuclear energy. Low and intermediate level waste had been sunk into the sea. This practice has been forbidden within the framework of the London Convention for the Protection of the Sea of 1983 upon increasing concerns about this kind of disposal. No disposal of highly radioactive waste has probably occurred until that date.

The principle of dilution is being used, partially until today, since the beginning of the use of nuclear energy with respect to gaseous and aerosol-type radioactive waste.

As far as actually possible, these substances are retained through filters or other measures installed in the nuclear facilities only to an extent, so that with the released magnitude of radio nuclides through the dilution, defined load limits for the ambient air will be fulfilled. According to the prevailing opinion, a disease of the residents is supposedly improbable through this pollution.

During the past ten to fifteen years, a new category of radioactive waste has been introduced in some of the EU Member States for the use of the principle of dilution, namely very low level waste. This waste is released from the treatment under the Atomic Energy Act and Ordinances after more or less efficient radioactivity controls under the assumption that the waste will be diluted through the embedding into the conventional cycle of materials and that this cannot result in any kind of detrimental impacts onto men and onto the environment.

The **Principle of Concentration** means that the waste or the radioactive materials contained therein, respectively, are concentrated and isolated towards the environment. This principle is followed today on a world-wide scale for solid and liquid radioactive waste with low, intermediate and high level activities as well as for a part of the gaseous and aerosol-type waste.

The following section will shortly describe the basic Waste-Management Concepts, including some notes on different options, as well as the advantages and disadvantages compared with the other concepts.

3.1 Waste Management for highly radioactive waste

Until today, no implemented concept for the overall Waste Management of highly radioactive waste is available on a world-wide scale. At the moment, various different Waste-Management Concepts are being discussed or developed in the EU Member States using nuclear energy. The implementation of a concept developed has been commenced in some countries. These are the three main distinctive criteria of the Waste-Management Concepts:

- Disintegration of fuel elements or leave fuel elements intact.
- Storage in deep geological layers or storage on the surface of the earth.
- Final disposal or storage until research and development for new waste management options has been completed.

3.1.1 Handling of spent fuel

There are two basic options for the handling of spent fuel: either the spent fuel elements will be mainly left intact or the fuel elements will be cut and the kinds of radionuclides will be partially disintegrated.

Direct final disposal

The concept for the final moving of intact fuel elements is also called Direct Final Disposal. The spent fuel is kept in an interim storage facility after the discharge from the reactor. This interim storage is either carried out in a wet storage (thus water) or in a dry storage (in a gas atmosphere). The fuel elements will be conditioned after the safety requirements for the repository are known. The time of this conditioning will usually be more or less shortly before dispose of into a repository. The extent of the conditioning measures will depend on the requirements of the repository. This may, in the simplest case, solely result in transhipment into a container with a long-term stability.

Advantages:

- No large chemical plants are required for the partitioning of radionuclides, where the operation will be associated with the release of radionuclides into water and into the air as well as with a high risk of incidents or accidents.
- No additional radioactive waste streams will be generated.
- The nuclear fuels will remain integrated in the fuel matrix and an access for misuse is significantly hampered due to the long-term high radioactivity level.
- The number of transports is lower.

Disadvantages:

- All long-lived radionuclides will remain in the waste. For this reason, a proof of long-term safety for at least one million years must be provided for the geological final disposal.

Reprocessing

The option to partition nuclear fuel (uranium and plutonium) from the fuel elements is called reprocessing. This term clearly indicates the main target, namely to make available nuclear fuel for a re-use. This is a technically complicated and chemically complex process.

The fuel elements will be stored for a certain period of time – mainly in a wet storage – after the defueling from the reactor. After the activity inventory of specific radionuclides has decreased to a value relevant for the reprocessing, the fuel elements will be transported to this plant, disassembled, the fuel rods will be cut and the segments will be disintegrated in acid. Uranium and plutonium will be, first of all, jointly separated from the solution.

Uranium and plutonium will then be separated from each other and will be further processed. The uranium should be mixed with the plutonium as an oxide and used for the production of new fuel elements (mixed oxide or MOX fuel elements) originally. In the reality it will be used in another way or stored in an interim storage facility. It is doubtful at the moment, whether or not all of the reprocessed uranium may be used for a different application. The plutonium is used for new fuel elements, which are used again in a light water reactor. Until now, no large-scale technical tests have been carried out, whether or not MOX fuel elements may be reprocessed in any given quantity and frequency. It can be assumed that also spent MOX fuel will have to be finally disposed of.

The waste generated during reprocessing is described in Section 2.2.3.

<u>Advantage</u>

- The radionuclides of uranium and plutonium to be taken into account for the long-term safety of geological repositories will be, at least, mostly removed. But other long-lived radionuclides will remain in the waste.

<u>Disadvantages</u>

- The exposure to radiation of the personnel of nuclear facilities and of the population are integrally significantly higher that that of a direct final disposal.
- The spent fuel and the radionuclides generated in the reactor will be stored in a dissolved state for a longer period of time after the partitioning process. In case of incidents or accidents, the radionuclides may be directly released in large quantities. The consequences may well surpass the catastrophe of Chernobyl.

- A large number of waste streams will be generated, which have to be treated in nuclear facilities with a high amount of expenditure, temporarily stored and finally disposed of at a later stage.
- The overall waste volume will be increased.
- The number of handling processes and transports is significantly higher than exclusively handling fuel elements. This way, the risk of incidents and accidents is increased.
- Despite the easing of the burden of the proof of long-term safety through the partial removal of uranium and plutonium, the proof has to be furnished for a million years because of other long-lived radionuclides therein.
- The separation – especially of the plutonium – enables a much easier access to and a faster use as atom bomb material.
- The use of MOX fuel leads altogether to a reduced safety margin for the operation of the nuclear power plants involved.

Partitioning and transmutation

Partitioning and transmutation (P&T) is a Waste-Management Concept only working theoretically for a foreseeable period of time. This system is being developed mainly financed with tax funds in the European Union. The target of P&T is the partitioning of long-lived radionuclides from the spent fuel and its nuclear transmutation into stable atomic nuclei or short-lived radionuclides. This is aimed at reducing the safety requirements with respect to a proof of long-term safety for the repository.

The condition for the possibility of transmutation is the single-class isolation of the radionuclides to be transmuted. When using the P&T concept, the fuel elements have to be, first of all, fragmented and cut – as for the reprocessing – and the spent fuel has to be liquefied afterwards. Several different processing steps are used using different processing methods to partition long-life radionuclides; first of all, uranium and plutonium together, afterwards the following radionuclides individually. According to current scientific knowledge it is not clear, whether a sufficient degree of partition can be achieved for all relevant radionuclides, in order to sustainably reduce the burden of proof for a long-term safety.

The radionuclides partitioned have to be processed to fuel elements or targets and have to be used in reactors or accelerators afterwards for transmutation. Transmutation is carried out via nuclear fissions or nuclear transmutation through neutron bombardment. There are three different transmutation technologies available, which are – according to the current state of art – unable as a single process to transmute all relevant radionuclides.

Transmutation may be carried out in light-water reactors or fast breeder reactors in a critical assembly or in acceleration-controlled subcritical reactors. When using the technology with light-water reactors, the operating mode used today would have to modified, for which safety-related problems would have to be solved, however. In any case, a multiple recycling (partitioning, target production, re-use) of the radionuclide targets would be required. When using the option with fast breeder reactors, today's fast breeder technology – which is poorly functioning anyway - would have to be further developed. Also in this case, a recycling would be required. The implementation of the fast reactor concepts is still in the early stages. The acceleration-controlled technology is also in a relatively early development stage. Many safety-related issues need to be clarified. A recycling is absolutely essential in this case as well.

According to the current state of developments, a combination of at least two technologies is required. Whether or not a sufficiently high transmutation rate will be achievable for a sustained reduction of the burden of proof for a long-term safety is doubtful for all of the three technologies.

The P&T option is only conceivable on a centralized level that means EU-wide with large, central partitioning plants and transmutation reactors.

Advantages

- If the partitioning of the radionuclides relevant for final disposal as well as the transmutation will be achieved to a sufficiently high extent, the proof of long-term safety for repositories may be restricted to some thousand years.

- Some of the radionuclide classes separated may be used.

Disadvantages

- Any and all disadvantages stated for reprocessing are right to P&T to an increased degree.
- Investments for research and development in the range of tens of billions of Euros will be required.
- The large-scale implementation of the P&T option would last for decades and would still not cover all of the highly active nuclear waste. Above all, all of the highly active waste from reprocessing would have to be disposed of.

3.1.2 Definitive disposal

The term „ definitive "disposal refers to the intention to transfer the repository as soon as possible after the disposal of the waste (mainly spent fuel and/or HLW canisters) into a state of passive safety through back-filling. No maintenance or control is planned after the back-filling.

The final dispose of shall be carried out in deep geological layers. The concept is based on deposition in a mine. But also caverns or deep bore-holes would generally be possible.

The protection of mankind and environment shall be achieved through the geological barriers (host rock and surrounding rock) and, in addition, through geotechnical (back-fill material, shaft closure) and technical (waste matrix, container) barriers. The percentage of protection of the individual barriers will depend on the host rock. For hard rock, for example, the technical barriers have a core function, whereas the geological barrier shall represent the decisive protection in case of salt.

Advantages

- It is possible to set-up a long-term prediction (with some uncertainty) on the development of the environment (geology) of the radioactive waste.
- The isolation of the waste from mankind and environment shall be ensured after the closure of the final storage facility through a passively acting barrier system. No active technical safety systems are required.

- The safety of the repository shall also be ensured through the geological barrier, even if the knowledge about the repository may get completely or partially lost. The condition, however, is the choice of a suitable site.
- The probability of operating incidents and the exposure to radiation through operation will be restricted to the depositing stage.
- The impacts of possible external influences (e.g. earthquakes, weather, and acts of terrorism) are low.
- The succeeding generations will not be burdened with the handling of the waste and the financial expenditure for such handling (polluter pays principle) – insofar as the prediction for the long-term attitude had been accurate.
- The access to the radioactive substances for misuse is severely hampered through geological barriers and closure of the repository.

Disadvantages

- The permanent proper functioning of the barriers cannot be reliably proven for the long period of time required (one million years).
- The sphere of influence of the succeeding generations will be restricted with respect to a handling as safe as possible in accordance with the relevant state of the art

3.1.3 Disposal with retrieval option

The radioactive waste will be disposed of in a mine in deep geological formations. A closure of the repository will only be carried out to an extent allowing a relatively easy retrievability of the waste in case of any unforeseen system reaction. The retrievability is planned for a specific period of time depending on the actual concept design. The system reaction of waste to barriers will be monitored during this period of time. Afterwards, the repository will be closed in accordance with the current state of the art.

It is assumed that additional know-how on the system reaction will be available within a more or less manageable period of time (some decades up to some centuries) and new processing technologies for a reduction of the hazard potential of radioactive waste could have been developed. In some cases, also the further utilization of the waste is stipulated as a reason for the retrievability.

Advantages

- An intervention is possible at any time, in case any detrimental developments occur in the geological reaction, at the waste or in the interaction between both (e.g. impact of the heat generated by the waste).
- The impacts of external influences (e.g. earthquakes, weather) is low.
- The succeeding generations will have the option to decide about the future of the waste.

Disadvantages

- The system performance may be negatively influenced when keeping the mine open and allowing access to the waste (e.g. the stability of the technical barriers).
- An unforeseen geological system reaction is to be expected after long periods of time only. Thus, the permanent proper functioning of the barriers for the long period of time required (1 million years) cannot be reliably proven even after a period of time of keeping the mine open for some centuries.
- The choice of host rock is possibly restricted, because a high degree of expenditure would be required for rock with a high natural convergence over a long period of time of keeping the mine open.
- The access to the radioactive materials for misuse is not prevented through geological or geotechnical barriers.
- Succeeding generations will have the burden of handling the radioactive waste and of the financial expenditure required for this purpose.
- It is difficult to forecast the development of the societies for some future centuries when keeping the repository open.

3.1.4 Controlled geological long-time disposal

The radioactive waste will be disposed of in a mine in deep geological layers. The repository will consist of a test deposit, a pilot deposit and a main deposit. Within the scope of the step-by-step process, the test deposit will be set up as the first stage of the overall facility. This will be designed for site-specific tests in order to put forward evidence for the safety of the main deposit.

The pilot deposit will be set up to store and backfill a representative part of the total inventory planned. The technical and geotechnical barriers will be monitored exceeding the operating time of the main deposit. Appropriate tests shall be carried out to establish model assessments for the confirmation of the long-term safety evidence. In addition, the findings shall generate the basis for the decision made at regular intervals, whether the repository shall be finally sealed or whether the monitoring shall be continued, whether technical barriers in the main deposit have to be inspected or whether the waste has to be removed from the deposit.

The main deposit will be used to dispose of the vast majority of the radioactive waste. It will be backfilled and sealed section by section as soon as the waste has been deposited. These measures will be taken in such a way so that reversibility remains technically relatively simple. The access and operating tunnels will remain open. All actions taken shall not affect the passive safety barriers.

The operation of the pilot deposit is being discussed for a period of time of roughly 100 years. No further monitoring shall be carried out after the final sealing. This process is called reversibility in contrast to retrievability.

Advantages

- The step-by-step procedure will increase the credibility of the evidence for safety for the initial period of time (some centuries) of the final disposal.
- The impacts of any possible external influence are low.
- The succeeding generations will have the option to decide about the handling of the waste.

Disadvantages

- When keeping the mine open, this may have a negative impact on the system performance (e.g. stability of geotechnical barriers).

- The permanent proper functioning of the barriers – above all, the geological – cannot be reliably predicted or proven for the long period of time required (1 million years), also after a monitoring period of less than 100 years.
- It is difficult to forecast the development of society for a period of 100 years of keeping the mine open.

3.1.5 Long-term interim storage

The long-term interim storage shall be carried out up to some hundred years in a building constructed on or near to the surface of the earth. Also an existing mine may be qualified. This storage of radioactive waste shall be carried out until a decision can be made on a reliable basis about a final handling or storage. The storage will be monitored and repair works will be carried out, if required.

Advantages

- After the development of handling options safer than those of today, these may be implemented without problems.
- The sphere of influence of succeeding generations would not be restricted.

Disadvantages

- It cannot be predicted, whether or not improved handling options will be found and how long the development of such options would last.
- The development of society is much more difficult to predict than that of geological developments.
- The hazard potential of the waste is easily accessible and releasable in case of external impacts.
- A continuous monitoring of the waste and repair- and repacking measures at longer intervals will be required according to today's state of the art, which will result in an increase of the risk of incidents and in an additional exposure to radiation for personnel and population.
- The access to the waste for misuse is relatively easy.

- The problem of the definitive handling of the radioactive waste and the financing will be shifted to succeeding generations.

3.2 Waste Management for waste with low and intermediate level of radioactivity

The waste with low and intermediate levels of radioactivity is temporarily stored after generation. Before the successive interim storage or transport into a final repository ready for operation, the waste is processed and packed to reduce the hazard potential. Liquid waste is, for example, solidified or liquid and solid combustible waste is incinerated.

The final disposal of the waste will either be carried out in deep geological formations or near to the surface in polders covered with soil. Which of the two options is pursued, will mainly depend on the half-life periods of the radioactivity inventory allowed. When using a final disposal close to the surface, the percentage of radionuclides with a half-life period of more than 30 years will be significantly limited. Due to the different radionuclide inventory, also different safety requirements (e.g. long-term safety) must be met. Insofar, a direct comparison between the two options is only possible or only makes sense in a restricted way. The entirety of the low and intermediate level waste must be assessed.

3.2.1 Repository in deep geological formations

The disposal of the conditioned waste is usually carried out in a mine. The space between the waste containers will be filled up and the repository will be closed upon reaching the storage capacity provided for. No monitoring is planned after the closure.

Any waste with a radionuclide inventory with shorter half-life periods will also be stored in the geological repository.

Advantages

- The clearance between the waste in the final storage and the environment above ground is very large.

- All kinds of waste with low and intermediate radioactivity levels can be disposed of.
- A later access to the waste is connected with a large-scale expenditure.

Disadvantages

- The permanent proper functioning of the barriers cannot be reliably predicted or proven for the long period of time required (1 million years).

3.2.2 Near-surface repository

The technology of a near-surface repository has already been implemented for many years now. The safety-related requirements had to be increased in the course of time due to negative experience made (e.g. in the repository Manche/France shut down in the meantime). When using modern-type near-surface repositories, the solid waste to be stored must be conditioned and packed into containers. The safety-related requirements with respect to the conditioning of the waste are usually lower than for a geological repository, also because it is waste with shorter half-life periods. The containers are stacked in a concrete cell which is roofed during this deposition. The concrete cell is usually built onto a clay layer. The space between the containers is filled up. As soon as the concrete cell is filled up, it is closed with a concrete lid and covered with a water-repellent foil. After the closure of the concrete cells of the complete repository, these will be covered with clay, other additional materials and soil. The repository shall be monitored for roughly 300 years afterwards.

Advantages

- The proof of long-term safety is restricted to some centuries due to the shorter half-life periods and is thus subject to fewer uncertainties.
- Near-surface repositories are faster available.
- The monitoring is relatively simple, insofar as this had been incorporated into the concept right from the beginning.

Disadvantages

- In case of a release, the radionuclides will get into the surface water without delay.

- Impairment through earthquakes or serious external impacts cannot be excluded for near-surface repositories.
- The waste stored shall only contain a low percentage of radionuclides with a half-life of more than 30 years. Any waste with low and medium radioactivity level with longer half-life periods must be disposed of in another repository.

3.3 Waste Management for radioactive waste with very low activity level

There are two different options available for the handling of radioactive waste with a very low level of activity in addition to the handling as low level waste, namely the release of the waste into the conventional sector and the final disposal under reduced safety-related conditions as compared to the near-surface repositories described above.

3.3.1 Clearance

Article 5 of the Directive 96/29/EURATOM provides the permission of the clearance of radioactive waste out of the Atomic Law. For this purpose, the radioactivity inventory of this waste must be lower than the clearance levels nationally stipulated. The clearance can be granted for deposition or incineration, recycling or further use.[3]

To what extent the EU Member States make use of this regulation is up to them.

<u>Advantages</u>

- The volume of radioactive waste to be stored in a geological or near-surface repository for low and intermediate level waste is reduced.
- The exposure to radiation of the personnel of the repository is reduced.

[3] Council Directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation; Bulletin of the European Union L 159, 39th Issue, June 29, 1996

Disadvantages

- The very low level waste is withdrawn from controlled sectors and distributed in the environment. This will increase the background radiation on the long run.
- Because of more and more concentration of radionuclides from waste released into the environment or the increased handling of such waste it may result in an increased exposition of the population to radiation.

3.3.2 Disposal of with lower safety requirements

The very low level waste is stored - similar to the low and intermediate waste – in a near-surface repository. The safety-related requirements for the conditioning of the waste and for the sealing of the repository towards the environment as well as the expenditure incurred for monitoring measures are lower, however.

Advantages

- The volume of radioactive waste to be stored in a geological or near-surface repository for low and intermediate level waste is reduced.
- The waste is concentrated in a facility and not distributed in the environment in contrast to the clearance.
- The retention of the radionuclides will be monitored for a certain period of time.

Disadvantages

- Due to the lower safety-related requirements as compared to a repository for low and intermediate level waste, the probability of a release of radionuclides is higher.

3.4 Conclusions on the Waste-Management Concepts

One of the most serious problems incurred with the use of nuclear energy for power generation is the handling of the radioactive waste generated. The above description of the existing Waste-Management Concepts or those being developed shows, that there are at hand basic approaches to restrict the possible impacts of the hazard potential of the waste, but that there is no option available to completely eliminate the hazard potential.

This is applicable to all kinds of radioactive waste due to the graduated safety-related approach in relation to radionuclide inventory.

On the basis of the fact that a handling of the radioactive waste will be unavoidable even when withdrawing from the use of nuclear energy, a comparison of the Waste-Management Concepts shows advantages and disadvantages for all concepts. Due to the high risks incurred during reprocessing and P&T, these concepts must be completely rejected from a safety-related point of view.

The long-term interim storage does not offer the option of a sustainable prevention of the release of radioactive substances for several hundreds of years or even longer times. Furthermore there are the problems to pass the responsibility for the radioactive waste onto succeeding generations and the high degree of uncertainty when forecasting social developments (social system, safety culture, economic attitude) for more than a few decades.

It is a fact for all repository concepts that the alleged safety is solely based on empirical data retrospectively collected as well as on the basis of knowledge restricted for mankind to the current knowledge of the respective point of time.

An exact proof of long-term safety cannot be scientifically provided today (and also not within the foreseeable future according to present knowledge). The only possibility is a plausibility proof with a more or less profound substantiation. It should be noted in this context that the verification processes are limited, often incorporating subjective opinions (expert judgments) which – even though representing majority opinions – must not correspond to the actual system performance later on.

Result: the problem of nuclear waste cannot be solved through any of the Waste Management options currently discussed. It is just possible to balance reasons and to decide on this basis for the relatively best waste management concept.

4. Waste Management in the EU, RF and US

The following chapter will deal with the Waste-Management situation and the strategies pursued by the individual EU Member States, in which nuclear facilities for the use of nuclear energy for power and heat generation (uranium exploration, nuclear power plants, and supply- and waste management facilities) are being operated.

Due to the significance for the EU, also the Waste-Management strategies of the Russian Federation and of the USA are described as well as the respective problems are pointed out. This is, above all, very important for some of the Eastern European countries.

The following data and information sources are referred to: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management 2009, the answers to the questions on the reports of the countries within the scope of the Joint Convention as well as the Sixth Situation Report Radioactive Waste and Spent Fuel Management in the European Union of 2008. These sources do not contain volumes of waste generated for each kind of radioactive waste in each country. Due to the high research expenditure incurred for information on radioactive waste volumes from other sources, the supplementation had only been partially possible. For this reason, the volumes of radioactive waste cannot be completely stated here for some EU Member States.

Radioactive waste generated outside the scope of the use of nuclear energy for power or heat generation will only be considered in this chapter, if all radioactive waste is handled in the same facilities. Unless stated otherwise in the following subsection, the volumes stated for the respective radioactive waste have been taken from the Joint Convention Reports and refer to the status as of 31.12.2007. In most cases, no more updated data have been published. In addition, not all of the Convention Reports contain an itemization of the existing radioactive waste for individual facilities. In these cases, the following charts show the respective overall volumes.

The facilities designated as „ decommissioned “ in the following section are all facilities, which are in a stage after the shut-down and before the completion of demolition.

4.1 Situation and strategies in EU Member States

Belgium

Nuclear power plants and other causers of primary waste:

In Belgium, 4 power reactors are in operation at Doel and 3 at Tihange.

In addition, 3 research reactors are in operation at Mol.

Furthermore, a fuel element plant is operated.

The reprocessing plant EUROCHEMIC, the fuel element plant at Dessel, the old SCK/CEN waste centre and one research reactor each at Mol and Gent are in the process of decommission.

Waste-Management Concept:

- Interim storage of **spent fuel** at the sites of the nuclear power plants.
- No final decision has been made, whether spent fuel shall be reprocessed or directly disposed of into a repository. Only a moratorium for the reprocessing exists. In 2011, the Government shall present the basis for the decision. The probability for a restart of the reprocessing at La Hague is low, however.
- At the moment, the reference concept is the direct final disposal in a deep geological clay formation.
- Short-time buffer storage of **low and intermediate radioactive** waste at the locations of generation.
- Conditioning at the locations of generation or in a central waste treatment facility.
- Central interim storage of the waste.
- Final depositing of short-lived low and intermediate radioactive waste in a near-surface repository.
- **Very low level waste** can be cleared.

Status repository

Intensive tests and analyses are made with respect to the attitude of clay when disposing high level waste in a repository. An underground laboratory is in operation at Mol. No decision is intended, at the moment, with respect to a location. A hypothetical planning proceeds on the assumption of a commissioning of the geological repository for high level waste for 2080.

The above-ground final repository for low and intermediate level waste shall be set up at Dessel and shall be commissioned in 2016.

Waste-Management facilities and existing waste volumes:

Until 2001, spent fuel with a volume of 670 tHM had been reprocessed at La Hague. Only a small portion of the waste to be returned has been transported from France to Belgium so far.

Nuclear waste	**Type of storage**	**Storage site**	**Status**	**Volume stored**
Spent fuel	Reactor storage pool	Doel	in operation	2,675 tHM *
	Interim storage (dry)	Doel	in operation	
	Reactor storage pool	Tihange	in operation	
	Interim storage pool	Tihange	in operation	
HLW **	Interim storage	Dessel	in operation	35 m^3
	Interim storage	Mol	in operation	244 m^3
Spent fuel from research reactors	Interim storage (dry)	Dessel	in operation	2 tHM
BE / HLW	Repository	not defined	Commissioning possibly in 2080	-

Nuclear waste	Type of storage	Storage site	Status	Volume stored
LILW **	Interim storage	Mol	in operation	16,583 m^3
	Interim storage	Dessel	in operation	544 m^3
	Above-ground final storage	Dessel	Commissioning 2016	-
VLLW	No data on whereabouts and volume of the waste released			

All figures for 31.12.2007 from Joint Convention Report 2009, except for

* Data for 31.12.2004 from 6th Situation Report[4]. In the Joint Convention Report, information on spent fuel has been rejected for safety reasons.

** The 6th Situation Report[4] for 31.12.2004 already stated 444 m^3 for HLW or 17,000 m^3 for LILW. It had been impossible to clarify why the figures stated in the Joint Convention Report for 31.12.2007 had been lower.

Particular problems for Waste Management

The spent fuel and the high level waste must be stored in an interim storage facility for a very long period of time, because the final disposal in a repository is not provided for before the year 2080. It is not possible to predict the condition of the radioactive waste and the hazard potential of the waste at that stage.

Bulgaria

Nuclear power plants and other causers of primary waste:

Two reactors are in operation at Kozloduy. Two further reactors are planned for Belene but the financing options are not clear at the moment.

Four reactors are in the status of decommissioning at the location Kozloduy.

A research reactor has been shut down for the modification to a lower output.

[4] Commission of the European Communities: Sixth Situation Report Radioactive Waste and Spent Fuel Management in the European Union, COM(2008)542 final, September 2008

Waste-Management Concept:

- After storage for decay of the **spent fuel** in the reactor pool, the spent fuel is moved to the pools of the external interim storage at the same location.
- A reprocessing in Russia is planned for the majority of the currently produced spent fuel.
- A long-term interim storage for highly radioactive waste from the reprocessing in Russia shall be carried out in a dry storage facility after the commissioning of this facility. This is also designed to store spent fuel.
- **Spent fuel from research reactors** will be transported to the Russian Federation.
- Buffer storage of **low and intermediate level waste** inside the reactor buildings.
- Central conditioning at the location of the nuclear power plant and interim storage at that location.
- Final disposal in a near-surface repository
- **Very low level waste** shall be cleared at a later date.

Status repository

No works focussed on a repository for high level waste or spent fuel are known.

In 2009, a search for a location of a near-surface repository for low and intermediate level waste has been started. Four locations are taken into account.

Waste-Management facilities and existing waste volumes:

Within the scope of the reprocessing agreements concluded with the Russian Federation after 1998, 2,367 tHM spent fuel had been transported to Russia until 31.07.2008. The radioactive waste generated through the reprocessing has to be taken back.

Until 1992, uranium ore had been exploited in 40 mines and had been processed in Bulgaria. The waste generated had been left on site and isolated.

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Kozloduy 1-6	in operation	380 tHM
	Interim storage pool	Kozloduy	in operation	492 tHM
BE / HLW	Repository	Location not defined yet	no planning	-
LILW liquid	Reactor storage tanks	Kozloduy	in operation	6,928 m^3 *
	Reactor storage tanks	Sofia	in operation	50 m^3
LILW	Reactor storage	Kozloduy	in operation	1,506 m3 *
	Interim storage	Kozloduy	in operation	3,959 m3 *
	Near-surface repository	Location not defined yet	Commissioning 2015	-
Uranium-containing waste	Tips + slurry settling facilities	Buchovo	?	1.3·106 m3 + 4.5·106 t

All figures for 31.07.2008 from Joint Convention Report 2009., except for

* Figures for 31.12.2009 from Annual Report 2009[5]

Particular problems for Waste Management

The reprocessing of the spent fuel and the use of the fuel separated this way in new fuel elements require a manifold handling of radioactive materials. The consequences are:

- Exposure of personnel to radiation.
- Extensive release of radionuclides and thus increased. exposure to radiation of population and environment.
- High risk of incidents and accidents.
- High risk of proliferation.

[5] Nuclear Regulatory Agency Republic of Bulgaria: Report 2009

These impacts are shifted by Bulgaria into a country, which is not an EU Member State (Russian Federation). It should also be taken into account that in many cases a lower degree of safety requirements than in the EU is implemented in the Russian Federation.

Low and intermediate level waste is stored in Bulgaria in a liquid state and for a very long period of time. This presents an increased hazard potential.

To what extent the legacy of uranium mining and of uranium ore processing had been handled environmentally compatible cannot be assessed by us.

Czech Republic

Nuclear power plants and other causers of primary waste:

Four reactors at Dukovany and two at Temelin are in operation in the Czech Republic. The construction of two further reactors at Temelin has been temporarily stopped in October 2010.

In addition, a research reactor at Rez and two small critical units are in operation.

Furthermore, one uranium mine and one ore processing plant are in operation.

Waste-Management Concept:

- The concept preferred at the moment is the long-term interim storage of **spent fuel** from the power reactors in container interim storage facilities at the sites of the nuclear power plants and the commissioning of a central geological repository for spent fuel and other radioactive waste after 2065. The discussions also include reprocessing abroad and regional repositories.
- The **spent fuel from the research reactor** is reprocessed in the Russian Federation and highly radioactive waste generated hereby is taken back.
- Solid **intermediate level waste** is not conditioned for the time being. This waste is moved into an interim storage at the reactor or centrally in BAPP at Dukovany. A decision on the handling of this waste shall be made within the scope of the decommissioning of the reactors.

- Solid incombustible **low level waste** from the reactor operation are compressed on site and temporarily stored in an interim storage. Combustible waste is externally incinerated. The waste is moved to the near-surface repository in operation at Dukovany.
- Liquid radioactive waste is stored in tanks in interim storage facilities at the site of generation. This waste is solidified afterwards. As soon as the low and internediate level waste fulfils the radiological acceptance conditions of the repository, this waste is disposed of in the repository at Dukovany.
- **Very low level waste** is cleared into the conventional sector, insofar as the inventory falls below the limits specified.
- **Waste generated through uranium exploration** is stored in above-ground deposits of its own (tips and settling basins). This waste is not subject to Atomic Law in the Czech Republic.

Status repository

The set-up of a repository in granite is planned for spent fuel and all waste not suitable for storage in the near-surface repository. First of all, 30 potential locations had been proposed for selection in accordance with the geological data available. Due to protests at the locations, a moratorium has been enacted in 2009. A geological investigation of 7 locations shall be commenced from 2010. This search shall be focussed on two locations in 2015. A commissioning is planed after 2065 upon completion of the final definition of the location.

A repository for low and intermediate level waste is in operation. But it is not allowed to store certain parts of the intermediate level waste in this repository. A site for such a repository must still be determined.

Waste-Management facilities and existing waste volumes:

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Dukovany	in operation	284 tHM
	Interim storage (dry)	Dukovany	full	603 tHM

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Interim storage (dry)	Dukovany	in operation, will be extended	80 tHM
Spent fuel	Reactor storage pool	Temelin	in operation	204 tHM
	Interim storage (dry)	Temelin	Commissioning	-
Spent fuel from research	Reactor storage pool	Řež	in operation	32 spent fuel elements
	Storage pool	Řež	in operation	No spent fuel elements
HLW	Reactor storage pool	Řež	in operation	empty
BE / HLW	Repository	Location not defined	Commissioning after 2065	-
LILW liquid	Reactor storage tanks	Dukovany	in operation	2,111 m3
	Reactor storage tanks	Temelin	in operation	309 m3
	Reactor storage tanks	Řež	in operation	210.5 m3
LILW solid	Reactor storage facility	Dukovany	in operation	507 Mg * 40 drums *
	Reactor storage facility	Temelin	in operation	119 Mg * 2.6 m3
	Reactor storage facility	Řež	in operation	837 m3
	Near-surface repository	Dukovany	in operation	5,930 m3
	Near-surface repository	Litoměřice	not for waste from nuclear facilities anymore	7,300 m3
	Near-surface repository	Beroun	shut	330 m3

Nuclear waste	Type of storage	Storage site	Status	Volume stored
VLLW	No data on volume and whereabouts of the waste released			
U-holding waste	Tips + slurry settling facility	Stráž,Dolní Rožínka	in recultivation	? m^3

All figures for 31.12.2007 from Joint Convention Report 2009.

* No volume can be allocated from the information available.

Particular problems for Waste Management

The spent fuel must be stored in an interim storage facility for a very long period of time, because the final disposal in a repository is only planned after 2065. The condition of the nuclear waste or the level of the hazard potential of the waste at that stage is unforeseeable.

Finland

Nuclear power plants and other causers of primary waste:

In Finland, two power reactors are in operation, one at Loviisa and one at Olkiluoto. One reactor is under construction. One research reactor is in operation at Espoo.

Waste-Management Concept:

- **Spent fuel** from power reactors is radioactive waste in accordance with the Act of 1994. That means that a reprocessing is not allowed.
- Interim storage of the spent fuel at the reactor sites in a separate storage facility.
- Final disposal of spent fuel from power reactors in hard rock at a depth of roughly 500 m.
- A retrieval option is considered for the repository.
- **Spent fuel from research reactors** is stored in an interim storage on site.
- A decision, whether or not this spent fuel shall be directly finally disposed of or returned to the USA (country of origin) has not been made yet.
- Conditioning of **low and intermediate level waste** at the location of generation.

- After buffer storage the final disposal follows in near-surface repository (caverns with a depth of roughly 60 m) at the respective site of the nuclear power plant if the requirements for this repository are fulfilled.
- In case of no fulfilment of repository requirements, prolonged interim storage at the locations and disposal in deep formations afterwards.
- **Very low level waste** is disposed of into the sea (liquid waste) or onto conventional disposal sites or is reused. A respective dump is located at Olkiluoto on the premises of the power plant. At Loviisa, the waste is disposed of on an external waste dump.

Status repository

The repository site for spent fuel and for other high level waste at Olkiluoto has been finally determined in 2001. A geological exploration mine is in operation on site for the compilation of site-specific data. This mine shall become a part of the complete repository. An approval for erection for the complete repository is expected for 2012 and the repository shall be commissioned in 2020.

Near-surface repositories for low and intermediate waste are in operation at the sites of the nuclear power plants.

Waste-Management facilities and existing waste volumes:

Until 1996 some of the spent fuel (330 tHM) has been reprocessed in the Russian Federation.

Until 1961, two pilot plants for the exploration and shredding of uranium ore had been in operation, Eno (31,000 t) and Askola (1,000 t).

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Interim storage pool	Loviisa	in operation	428 tHM
	Interim storage pool	Olkiluoto	in operation	1,142 tHM
Spent fuel from research	Reactor storage pool	Espoo	in operation	4.2 kgSM

Nuclear waste	Type of storage	Storage site	Status	Volume stored
BE / HLW	Repository	Near Olkiluoto	Commissioning 2020	-
LILW liquid	Interim storage	Loviisa	in operation	1,290 m^3
LILW	Interim storage	Loviisa	in operation	239 m^3
	Interim storage	Olkiluoto	in operation	1,334 m^3
	Interim storage	Espoo	in operation	6 m^3
	Near-surface repository	Loviisa	in operation	1,475 m^3
	Near-surface repository	Olkiluoto	in operation	4,790 m^3
VLLW	Interim storage	Olkiluoto	in operation	51 m^3
	Dump site	Olkiluoto	in operation	no data
U-holding waste	Tips + slurry setting facility	Eno Askola	Recultivation	no data

All figures for 31.12.2007 from Joint Convention Report 2009.

Particular problems for Waste Management

The most important element in the repository concept is the efficiency of technical barriers for several hundred thousand years. A final disposal will only be possible in hard rock due to the geological situation in Scandinavia. Hard rock is fractured, however, and is thus aquiferous. The retention of the radionuclides from the radioactive waste can thus only be guaranteed for a long period of time using a material extremely resistant against corrosion. Copper had been regarded as very corrosion-proof so far, from which the container for the repository shall be made.

In 2009, in the Royal Technical Highschool of Stockholm research results were published indicating a much faster corrosion progress in view of the geo-chemical conditions in a sealed repository than known up to now. This means releases within period of time, during which also less long-life radionuclides have not decayed to a large extent.

France

Nuclear power plants and other causers of primary waste:

58 power reactors at 19 locations are in operation in France. One reactor is under construction.

9 research reactors are in operation at 4 locations.

Four plants for the production of fuel elements or pellets are in operation at 3 locations, two conversion plants at two locations and one enrichment plant.

Two reprocessing plants are in operation at one site.

14 power- and research reactors at 11 locations as well as 10 other nuclear facilities at 5 locations are in the process of decommissioning.

In France there are a lot of facilities in operation for the handling of radioactive waste generated through military activities. Because of a lack of information, this waste is not considered in this study.

Waste-Management Concept:

- The valid Waste-Management Concept is based on a law dating back to 2006.[6]
- **Spent fuel** is first of all stored in the reactor storage pool.
- Mainly reprocessing of spent fuel (until 2009 approx. 850 tHM per year, from 2010 approx. 1,050 tHM of 1,150 MgSM annually generated spent fuel in France).
- Spent fuel with MOX or with reprocessed uranium have only been reprocessed for demonstration purposes in small volume. Instead, interim storage is carried out until use supposedly becomes possible in reactors developed in the future (GenIV).
- With respect to non-reprocessed spent fuel, to high level waste generated during reprocessing as well as to intermediate level waste with longer half-life periods, three fields of research- and development complementary to each other are being

[6] Planning Act No. 2006-739 of 28 June 2006 Concerning the Sustainable Management of Radioactive Materials and Waste

pursued at the moment:
a) Partitioning and transmutation. In 2012, a status report shall make a statement regarding the various different technologies. The construction of pilot plants shall be started in 2020 and it is planned to set industrial-scale plants into operation in 2040. It is planned to closely intermesh this development with the development of new reactor technologies.
b) Repository in deep geological formations. The disposal shall be retrievable for at least 100 years. This is the reference solution for all radioactive waste, which cannot be stored in an above-ground final repository for safety reasons.
c) Further development of interim storage- and conditioning technologies, which shall be realized by 2015 at the latest.

- **Spent fuel from research reactors** is partially reprocessed and partially stored in an interim storage until reprocessing.
- **Low and intermediate level waste with long-lived radionuclides** is mostly stored at the locations, where the waste had been generated
- There has no Waste-Management Concept been developed yet for some part of this waste (e.g. graphite waste from research and from the operation of gas-cooled and heavy-water reactors, certain slurries from reprocessing, tritium-holding waste) and the conditioning processes have not been tested yet for some other waste (sodium-holding waste from fast breeder research, uranium-molybdenum solutions from reprocessing).
- **Low and intermediate level waste with short-lived radionuclides** is conditioned at the sites, where the waste had been generated.
- Depositing as soon as possible into above-ground final deposits.
- Each storage section of the repository will be completely filled up and the complete repository will be covered with several layers of different materials upon utilization of the capacity.
- The above-ground repositories will be monitored for a period of approx. 300 years after closure.
- **Very low level waste** is finally stored in France in an above-ground repository with reduced safety requirements. In exceptional cases, a clearance of very low

level waste is possible. A release, however, shall – under no circumstances – result in a recycling in consumer products or buildings. In most cases, this will only be allowed for nuclear applications.

- **Uranium-holding waste** generated through enrichment and through the manufacturing of fuel elements will be stored – depending on the radioactivity inventory – in the repository for very low level waste or in the repository for low and intermediate level waste.
- The approx. 50 million tons generated through uranium ore processing and the roughly 200 million tons of rock and ore residue from the uranium mining, which cannot be used anymore, are stored on site.

There are some materials, where the further handling has only partially been clarified. Examples are the depleted uranium from the enrichment process, fuel elements, which are not reprocessed and uranium from reprocessing. Also the stock of non-radiated plutonium has steadily increased and has amounted to 56 t (+26 t, which are the property of foreign operating companies) at the end of 2009.

Status repository

It is planned to set up the repository for high level and long-lived radioactive waste close to the underground laboratory operated at Bure. It shall be commissioned in 2025.

A near-surface repository for long-lived low level waste shall be put into operation in 2019.

An above-ground repository (CSM) is closed since 1994 and is in the follow-up status for at least 300 years since 2003 (monitoring).

An above-ground repository for very low level waste is located at Morvilliers and a repository for short-lived low and intermediate level waste is in operation at Soulaines (CSA).

Waste-Management facilities and existing waste volumes:

Until 2010 about 16,000 tHM of French spent fuel was reprocessed in La Hague.

200 uranium mines and 20 facilities for uranium ore exploration and processing are all shut down.

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Nuclear power plant sites	in operation	3,923 tHM
	4 storage pools	La Hague	in operation, is extended	9,421 tHM *
	Storage pool	Creys-Malville	in operation	no data
HLW	3 interim storage facilities	La Hague	in operation, is extended	1,650 m^3 **
	Interim storage	Marcoule	in operation	558 m^3 **
	Interim storage	CEA-sites	in operation	85 m^3 **
Spent fuel from research	Interim storage (dry)	Cadarache	in operation	120 tHM
BE / HLW / ILW long-life / spent fuel from research react.	Repository	District around Bure	Commissioning 2025	-
ILW long-lived	Interim storage	Nuclear power plant sites	in operation	966 m3
	Interim storage	La Hague	in operation	19,171 m3 **
	Interim storage	Marcoule	in operation	10,684 m3 **
	Interim storage	CEA-sites	in operation	10,727 m3 **
	Interim storage	Research centres	in operation	2 m3 **
	Interim storage	Bouches-du-Rhone	in operation	8,043 m3 **
	Near-surface repository	No site defined yet	Commissioning 2019	-
Radium-holding waste	Interim storage	Charente-Maritime	in operation	25,726 m3 **
	Interim storage	Isère	shut down	1,929 m3 **

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Radium-holding waste	Interim storage	Vaucluse	in operation	384 m^3 **
	Interim storage	Bouches-du-Rhône	in operation	5,950 m^3 **
LLW long-lived	Interim storage	Le Bouchet	in operation	11,867 m^3 **
	Interim storage	Nuclear power plant sites	in operation	9,061 m^3 **
	Interim storage	La Hague	in operation	4,952 m^3 **
	Interim storage	Marcoule	in operation	37,874 m^3 **
	Interim storage	CEA-sites	in operation	4 m^3 **
	Interim storage	Research centres	in operation	63 m^3 **
Tritium-holding waste	Interim storage	Côte d'Or	in operation	2,368 m3 **
LILW short-lived	Reactor storage	Nuclear power plant sites	in operation	13,696 m3 **
	Interim storage	Conditioning plants	in operation	1,819 m3 **
	Interim storage	CEA-sites	in operation	8,037 m3 **
	Interim storage	Research centres	in operation	852 m3 **
	Interim storage	Uranium plants	in operation	849 m3 **
	Above-ground repository (CSM)	La Hague, Manche	shut down	527,225 m3
	Above-ground repository (CSA)	Soulaines, Aube	in operation	208,053 m3

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Waste without classification	Interim storage	Site not named	in operation	1,564 m^3 **
VLLW	Reactor storage	Nuclear power plant sites	in operation	16,752 m^3 **
	Interim storage	CEA-sites	in operation	32,570 m^3 **
	Interim storage	Research centres	in operation	1,364 m^3 **
	Interim storage	Uranium plants	in operation	28,637 m^3 **
VLLW	Interim storage	Conditioning plants	in operation	4,251 m3 **
	Above-ground repository	Morvilliers	in operation	89,331 m3
U-holding waste	Tips + slurry settling facilities	20 locations	shut down	33 million m3 **

All figures for 31.12.2007 from Joint Convention Report 2009., except for

* Figures for 31.12.2009 (of which approx. 45 tHM from foreign sources)[7]

** Figures for 31.12.2007 from National Inventory[8]

Particular problems for Waste Management

As of the end of 2007, 1,121 sites had been registered, at which radioactive waste is stored.

Altogether radioactive waste in a volume of 1,152,533 m^3 has been generated until 31.12.2007. In addition, 33,000,000 m^3 of waste have been generated through uranium mining distributed to 20 facilities.

[7] Mycle Schneider: Reflections about Disposal Strategies of a Raw Material with a Negative Market Value, Lecture, University of Hamburg, July 1, 2010

[8] National Inventory of Radioactive Material and Waste 2009, Synthesis Report, Andra

Despite this way of power generation not sustainable under environmental aspects, nuclear energy shall be used in France also in the future.

The reprocessing of the spent fuel and the use of the fuel separated this way in new fuel elements require a manifold handling of radioactive materials. The consequences are:

- Exposure of personnel to radiation,
- Extensive release of radionuclides and thus increased exposure to radiation of population and environment,
- High risk of incidents and accidents,
- High risk of proliferation.

The comparison of sites with different geological formations originally required by law for the repository in deep geologic formations has failed. Bure is now planned as the repository region, where an underground laboratory for tests for final depositing in clay is in operation.

For a part of low and intermediate level waste in France there is no handling concept developed until now.

In the past, large volumes of depleted uranium from the enrichment plant have been transported into the Russian Federation as UF_6 for re-enrichment. Roughly 4/5 of the UF_6 which is further depleted will remain in Russia. The contracts concluded between the licensees of the plants in France and in Russia do not contain any binding safety-relevant requirements for the further handling. Concepts for the long-term handling are obviously not available in the Russian Federation. A long-term storage in the open in containers not fulfilling safety-relevant requirements can be assumed.

Germany

Nuclear power plants and other causers of primary waste:

17 power reactors are in operation at 12 locations in Germany.

17 power and prototype reactors are in the process of decommissioning at 12 locations.

3 research reactors are in operation and 8 are in the process of decommissioning.

Four research centres have an extensive nuclear infrastructure.

In addition, a uranium-enrichment facility and a fuel element plant are in operation.

In addition to the reactors, also a pilot reprocessing plant and some research facilities are in the decommission state.

Waste-Management Concept:

- **Spent fuel** is stored, first of all, in the reactor storage pools for a few years.
- Transhipment of fuel elements into transport and storage casks and interim storage in buildings at the nuclear power plant locations.
- Final disposal without retrieval option in deep geological formation.
- Conditioning and interim storage of **low and intermediate level waste** at the locations of generation or centrally.
- Final disposal in deep geological formation.
- For re-enrichment the majority of the **depleted uranium** from the enrichment plant has been transported into the Russian Federation in the past.
- It will be converted to uranium-oxide in Southern France in the future.
- After returned transportation to Germany it will be stored in Gronau. There is no concept developed for further handling.
- **Very low level waste** is cleared for disposal, incineration or for further use.

Status repository

No repository site has been determined for spent fuel, high level waste and some part of the intermediate level waste. At the location Gorleben, the salt mine is in the process of tests and analyses for its suitability by way of underground exploration works.

An approved final repository exists at Salzgitter for low and intermediate level waste, where a commissioning is scheduled for 2019.

At the locations of Asse and Morsleben, repositories for low and intermediate level waste exist, which have been closed some times ago which are in danger of collapsing.

Waste-Management facilities and existing waste volumes:

Until 2005, 6,258 tHM had been transported for reprocessing to France, Great Britain and Belgium as well as 90 tHM for a domestic reprocessing to Karlsruhe.

In addition, 327 tHM had been transported to other foreign facilities and remain there.

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool + interim storage (dry)	Brunsbüttel	in operation	76 tHM
	Reactor storage pool + interim storage (dry)	Krümmel	in operation	125 tHM
	Reactor storage pool + interim storage (dry)	Brokdorf	in operation	322 tHM
	Reactor storage pool + interim storage (dry)	Unterweser	in operation	217 tHM
	Reactor storage pool + interim storage (dry)	Grohnde	in operation	425 tHM
	Reactor storage pool + interim storage (dry)	Emsland	in operation	435 tHM
	Reactor storage pool + interim storage (dry)	Biblis	in operation	704 tHM
	Reactor storage pool + interim storage (dry)	Philippsburg	in operation	510 tHM

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool + interim storage (dry)	Neckarwest-heim	in operation	527 tHM
	Reactor storage pool + interim storage (dry)	Gundremmin-gen	in operation	860 tHM
	Reactor storage pool + interim storage (dry)	Isar	in operation	556 tHM
	Interim storage (dry)	Greifswald	in operation	583 tHM
	Interim storage (dry)	Ahaus	in operation	55 tHM
	Interim storage (dry)	Gorleben	in operation	37 tHM
HLW	Interim storage	Karlsruhe	in operation	56 m^3
	Interim storage	Gorleben	in operation	433 m^3
	Interim storage	Ahaus	in operation	1,252 m^3
	Interim storage	Research facilities	in operation	97 m^3
BE / HLW	Geological repository	not defined yet	Commissioning ?	-
LILW	Reactor storage	Nuclear power plant in operation	in operation	11,495 m^3
	Reactor storage	Nuclear power plant in process of shut-down	in operation	8,702 m^3
	Interim storage	Unterweser	in operation	1,148 m^3
	Interim storage	Gorleben	in operation	6,201 m^3
	Interim storage	Mitterteich	in operation	4,925 m^3

Nuclear waste	Type of storage	Storage site	Status	Volume stored
LILW	Interim storage	Hanau	in operation	6,588 m^3
	Interim storage	Greifswald	in operation	3,644 m^3
	Interim storage	Karlsruhe	in operation	16,196 m^3
	Interim storage	Research facilities	in operation	49,187 m^3
	Geological repository	Asse	in process of shut-down	47,000 m^3
	Geological repository	Morsleben	in process of shut-down	36,753 m^3 6,617 sources
	Geological repository	Salzgitter	Commissioning 2019	-
VLLW	No data on volumes and whereabouts of the waste released			
U-holding waste	Tips + slurry settling facility	Wismut in Thuringia + Saxony	in process of recultivation	No data

All data 31.12.2007 from Joint Convention Report 2009.

<u>Particular problems for Waste Management</u>

The mines Asse and Morsleben used as repositories for low and intermediate level waste are unstable. In addition, a massive water inrush is threatening for the Asse site. The ground floors of storage chambers are already soaked with water. A long-term safety proof cannot be presented. For this reason, the waste shall be retrieved from the Asse mine.

The location of Gorleben had been selected without geo-scientific criteria. Fears exist that the location will be enforced due to external frame conditions and not because of safety-relevant characteristics.

In the past, large volumes of depleted uranium from the enrichment plant at Gronau have been transported into the Russian Federation as UF_6 for re-enrichment. Roughly 4/5 of the UF_6 (further depleted) will remain in Russia. The contracts concluded between the plant licensees in Germany and in Russia do not contain any binding safety-relevant requirements for the further handling. Concepts for the long-term handling are obviously not available in the Russian Federation. A long-term storage in the open in containers not fulfilling safety-relevant requirements can be assumed. Any release from a container may cause catastrophic consequences for the environment.

Great Britain

Nuclear power plants and other causers of primary waste:

19 power reactors are in operation in Great Britain at 9 locations.

Two reprocessing plants and one MOX fuel element plant are in operation at the location Sellafield.

One uranium-enrichment plant is in operation at Capenhurst and one fuel element plant is in operation at Springfield.

Waste is also generated in the JET fusion experiment.

9 power reactors, 5 research reactors, 2 reprocessing plants and on uranium plant are in the stage of decommissioning.

In Great Britain there are a lot of facilities in operation for the handling of radioactive waste generated through military activities. Because of a lack of information, this waste is not considered in this study.

Waste-Management Concept:

- The **spent fuel** from the Magnox- and from the Advanced Gas-Cooled Reactors (AGR) are transported to Sellafied after a short period of cooling down in the reactor storage pool and are stored in an interim storage until reprocessing.
- The spent fuel from the light-water reactor is stored in an interim storage at the site of the nuclear power plant.
- With respect to the spent fuel from the reactors in operation now, the operating companies shall make a decision, whether to reprocess the waste or to pass it into a repository without further processing. The operation of the reprocessing plant THORP shall be prolonged until 2020 in any case, in order to mainly pro-

cess the spent fuel from the AGR. The direct disposal into a repository is assumed so far for the spent fuel from the new reactors planned.

- Interim storage of **high level waste** at the location of generation for 50 years.
- Higher radioactive waste (including fuel elements defined as waste) shall be disposed of into a repository in a deep geological formation.
- Interim storage of **intermediate level waste** at the locations of generation.
- Final disposal of intermediate level waste in a deep geological formation.
- Interim storage of **low level waste** at the location of generation or at Sellafield, respectively.
- Final disposal of radioactive waste with low activity level in an above-ground repository.
- **Very low level waste** is disposed of on conventional dump sites, which are either monitored or not monitored depending on the volume of the waste.

<u>Status repository</u>

The commissioning of a repository for higher radioactive waste (including spent fuel) is planned for 2075. At the moment the procedure for a selection of the site has commenced. One favourite region for the repository is West Cumbria.

The commissioning of a repository for intermediate level waste is planned for 2040.

A repository for low level waste is in operation at Drigg.

A repository for low and intermediate level waste at Dounray must be cleared for safety reasons. The commissioning of a new repository is planned for 2013.

<u>Waste-Management facilities and existing waste volumes:</u>

In the past, almost all of the spent fuel has been reprocessed in Great Britain. No data had been available for the MAGNOX reprocessing plant for this study. About 1,700 tHM Britain spent fuel has been reprocessed until 2009 in the other reprocessing plant (THORP).

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Nuclear power plant	in operation	620 tHM
	Interim storage	Sellafield	in operation	5,220 tHM*
HLW	Interim storage	Sellafield	in operation	1,730 m^3
Spent fuel from research	Reactor storage pool	Dounreay and other sites	in operation	21 tHM
BE / HLW	Repository	No site selected	Commissioning 2075	-
ILW	Interim storage	Sellafield	in operation	63,900 m^3
	Interim storage	Aldermaston Dounreay Harwell nuclear power plant sites	in operation	28,600 m^3
LLW	Interim storage	Sellafield	in operation	11,200 m^3
	Interim storage	Capenhurst	in operation	10,700 m^3
	Interim storage	Dounreay	in operation	6,860 m^3
	Near-surface repository	Dounreay	shut down	33,600 m^3
	Near-surface repository	Drigg	in operation, will be extended	905,000 m^3
VLLW	Dump sites	No data on volumes and sites		

Figures for 01.04.2007[9]

* Of which 750 tHM fuel elements of foreign origin

**Of which 0.7 tHM fuel elements of foreign origin

[9] NDA + defra: The 2007 UK Radioactive Waste Inventory, Main Report, March 2008

Particular problems for Waste Management

The reprocessing of the spent fuel and the use of the fuel separated this way in new fuel elements require a manifold handling of radioactive substances. The consequences are:

- Exposure of personnel to radiation,
- Extensive release of radioactive substances and thus increased exposure to radiation of population and environment,
- High risk of incidents and accidents,
- High risk of proliferation.

An increased level of contamination has been detected in the sea water and on the beach at the Sellafield site. This has resulted in relatively high activities in plants and animals. Scientific publications point out to an increased number of diseases of children of employees of Sellafield in the neighbourhood of Sellafield. For years now, vehement discussions are under way, whether or not the facilities are the reason for this. It had been impossible so far to unambiguously prove causality but it can also not be excluded.

High radioactivity concentration levels have been detected in the neighbouring coastal waters at Dounray. This is the reason for retrieval of radioactive waste from the disposal and a new treatment of the waste.

Due to the low level of environmental precautions, 13,000,000 m^3 of contaminated soil are expected at the sites of nuclear facilities in the UK.

Hungary

Nuclear power plants and other causers of primary waste:

4 reactors blocks are in operation at Paks.

In addition, one research and one training reactor are in operation at Budapest.

Waste-Management Concept:

- Cooling-down storage of **spent fuel** in the reactor storage pools.
- Interim storage close to location in a modular dry storage facility.

- No decision has been made, whether or not this spent fuel shall be reprocessed or directly disposed of in a repository. The direct final disposal is the reference scenario, however.
- Interim storage of **spent fuel from research** on site.
- At the moment, there are three options under discussion: the return to the country of origin (Russian Federation), the joint handling of the Paks spent fuel or the long-time storage on site at Budapest.
- Liquid **low and intermediate level waste** is stored in storage tanks at the site of generation. The necessity for conditioning will depend on the storage capacity required. At least some part of the waste shall be conditioned as late as within the scope of the shut-down of the reactors.
- Solid low and intermediate level waste is treated at the location of generation and stored in an interim storage facility as long as the capacity is sufficient.
- Very low level waste is cleared for the conventional sector.

Status repository

Since 1995, a program for the final disposal of high level waste (including spent fuel) and long-lived radioactive waste in deep geological formations is being pursued. The Boda clay formation in the Mecsek mountain range has been identified as a possible region for a repository. First of all, it is planned to set up an underground laboratory at that site. The commissioning of the repository is planned for 2064.

In 1976, an above-ground repository for low and intermediate waste has been commissioned at Püspökszilágy. Some of the operating waste from Paks has been disposed of to a minor extent. This repository has actually been designed for radioactive waste generated through other sectors of nuclear energy use. At the moment, a near-surface repository for low and intermediate level waste from the use of nuclear energy is set up in hard rock close to Bátaapáti and shall be commissioned in 2012.

Waste-Management facilities and existing waste volumes:

Until 1998, 2,331 spent fuel elements with 273 tHM had been transported into the Russian Federation / Soviet Union for reprocessing. A returning of the radioactive waste generated through this reprocessing of this spent fuel is not planned.

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Paks	in operation	223.2 tHM
	Interim storage (dry)	Paks	in operation, will be extended	719.7 MgSM
HLW	Reactor storage facility	Paks	in operation	92.4 m^3
Spent fuel research reactor	Reactor storage pool	Budapest	in operation	0.24 tHM
BE / HLW	Repository	Mecsek mountain range	Commissioning 2064	-
LILW long-life, liquid	Reactor storage tanks	Paks	in operation	975 m^3
LIHLW liquid	Reactor storage tanks	Paks	in operation	150 m^3
LILW liquid	Reactor storage tanks	Paks	in operation	5,826 m^3
LILW	Reactor storage facility	Paks	in operation	1,687 m^3
	Interim storage	Bátaapáti	in operation	320 m^3
	Near-surface repository	Püspökszilágy	in operation for institutional waste	5,040 m^3
	Near-surface repository	Bátaapáti	Commissioning 2012	-

Nuclear waste	Type of storage	Storage site	Status	Volume stored
VLLW	No data on volumes and whereabouts of the waste released			
U-holding waste	Tips + slurry settling facility	Pecs	in recultivation	$29.6 \cdot 10^6$ m³

Volume data for liquid waste 31.12.2007 from Joint Convention Report 2009.

Volume data of all other waste 01.01.2010[10]

Particular problems for Waste Management

There are 30 destroyed fuel elements resulting from serious accident at Paks in 2003 in 68 storage casks.

The safety requirements (e.g. for interim storage) are significantly lower than those of Western countries (e.g. floods, long-term storage of liquid waste).

At least during the first years, waste without any acceptance conditions had been disposed of in the above-ground repository in operation but nearly filled up. Thus, some of the repository sections have been re-opened

Lithuania

Nuclear power plants and other causers of primary waste:

Two reactors decommissioned recently exist at Ignalina/Lithuania.

Waste-Management Concept:

- **Spent fuel** is stored in the reactor storage pool.
- Upon commissioning, transport into dry interim storage for 50 years.
- Analyses are planned for the further handling of the spent fuel. There are three options being investigated: repository in Lithuania, repository or reprocessing abroad.

[10] Public Limited Company for Radioactive Waste Management: 10th Medium and Long-Term Plan of Public Limited Company for Radioactive Waste Management (RHK Kft., May 2010)

- **Intermediate level waste** with a **long-lived** inventory shall be disposed of in a repository in a deep geological formation.
- Liquid **low and intermediate level waste** is bitumised or cemented.
- **Very low level waste** can be clearanced or deposited on a conventional dump site.

Status repository

No decision has been made regarding the further handling of the spent fuel. At the moment, a feasibility study is prepared, which shall be the basis for a political decision for an option.

It is reviewed with respect to the bitumised waste, whether – as has been planned originally – the disposal facility at the nuclear power plant site used at the moment may be used as a repository. A decision shall be made in 2011. A near-surface repository shall be set up for all of the other low and intermediate level waste. The site has been determined (Stabatiškė) and is located a few kilometres away from Ignalina. At the moment, safety analyses are carried out.

Waste-Management facilities and existing waste volumes:

No interim storage for radioactive waste had been set up as has been the case for the majority of the Russian-type nuclear power plants, but the waste had been – after various different conditioning processes (vaporisation and bitumination plant, cementing plant) – immediately moved into a repository located on site. Tanks for the liquid waste have been buried into the ground, which have been hermetically sealed after upon completion of filling. Solid radioactive waste has been deposited in concrete bunkers set up underground or above-ground. According to the description of the construction, the constructions named interim deposits right now are actually those constructions originally designed as repositories. The use as a repository is – at least partially – reviewed.

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Ignalina	in operation	1,502 tHM
	Interim storage (dry)	near Ignalina	in operation, will be extended	541.7 tHM

Nuclear waste	Type of storage	Storage site	Status	Volume stored
LILW long-lived	Interim storage	Ignalina	no information	760 m^3 **
LILW liquid	Interim storage tanks	Ignalina	in operation	3,746 m^3
LILW	2 storage buildings	Ignalina	partially in operation	25,625 m^3 *
	Deposit for bitumised waste	Ignalina	in operation; review for conversion to above-ground repository	13,963 m^3 *
	Deposit for cemented waste	Ignalina	in operation	1,198.4 m^3
	Near-surface repository	Stabatiškė	Commissioning 2015 ?	-
VLLW	Dump site	no information		26,000 m^3 **

Figures for 01.03.2008 from Joint Convention Report 2009, except for:

* Figures for 01.01.2010 from VATESI[11]

** Figures for 31.12.2004 from 6th Situation Report[12]

Particular problems for Waste Management

There is no concept and no time schedule for the drafting of such concept available for the further handling of the spent fuel. A decision for reprocessing would mean to shift off the hazard potential to a country outside the EU with lower safety requirements (Russian Federation). When deciding upon a direct disposal in a repository, a period of time of an above-ground interim storage for the spent fuel exceeding 50 years must be assumed.

The storage situation for the majority of the low and intermediate level waste from the operation of the nuclear plant is desolate. The kind of today's depositing of the waste does not guarantee the retention of radionuclides for a longer period of time.

[11] VATESI: Nuclear Energy in Lithuania, Annual Report 2009

[12] Commission of the European Communities: Sixth Situation Report Radioactive Waste and Spent Fuel Management in the European Union, COM(2008)542 Final, September 2008

In some cases, the approvals for the interim storage will terminate at the end of 2010. The waste must be retrieved and re-conditioned. For this purpose, the set-up of a new waste treatment- and interim storage facility is planned.

Netherlands

Nuclear power plants and other causers of primary waste:

One reactor is in operation in Borssele in the Netherlands. The approval procedure to build a further reactor has commenced in October 2010.

In addition, three research reactors are in operation at Petten and Delft.

One uranium-enrichment plant is in operation at Almelo.

One power reactor is decommissioned and is in the state of a so-called “Safe Containment”. This stage is planned for 40 years.

Waste-Management Concept:

- Reprocessing of all **spent fuel** generated until 2015 at Sellafield and La Hague. With respect to the handling of spent fuel generated after 2015, a new contract has been concluded with AREVA NC on the reprocessing at La Hague. The waste generated from this reprocessing shall be delivered to the Netherlands until 2034.
- Any highly active, vitrified and long-lived intermediate level waste generated through reprocessing and to be accepted by the Netherlands shall be stored in an interim storage facility for up to 100 years.
- If a repository concept will be chosen, it shall include a retrieval option.
- Long-term interim storage of the majority of the **spent fuel from research reactors**. Some of the spent fuel from the high-flux reactor at Petten has been returned to the USA.
- **Low and intermediate level waste** is transported to the central conditioning plant at the interim storage site and is treated there.
- Interim storage for approx. 100 years.

- A research program has been initiated with respect to the final disposal of this waste. Due to the high ground water level and the height of the sea water level, which cannot be forecasted over a longer period of time, no above-ground- or near-surface repositories can be considered. Thus, all radioactive waste shall be stored for a long period of time in deep geological layers.
- The majority of the **depleted uranium** from the enrichment plant has been transported into the Russian Federation in the past.
- It will be converted to uranium-oxide in Southern France in the future.
- Afterwards interim storage at Vlissingen. No further handling concept has been developed.
- **Very low level waste** will be cleared.

There is an overall assumption of an option of an international or regional repository for all kinds of radioactive waste.

Status repository

No site for a repository has been searched for until now. It has been determined, however, that there are sufficient salt and clay deposits available for a repository in the Netherlands. The results of a research program completed in 2001 showed that a final disposal under radiation protection aspects is possible and implementable including the option of retrieval of the waste from salt or clay. There are various different research programs under way with respect to the different options of final disposal, inter alia with a participation in international projects.

Waste-Management facilities and existing waste volumes:

The spent fuel generated in The Netherlands was and will be reprocessed in La Hague and Sellafield. No data on this concept are supplied in the Joint Convention Report 2009. It had been researched for this study that the reprocessing in Sellafield amounts to just 53 tHM. In La Hague 326 tHM were reprocessed until the end of 2009.

A waste treatment plant is in operation for all kinds of waste at the site of the long-term interim storage at Borsele.

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Borssele	in operation	561.6 tHM
Spent fuel from research	Reactor storage pool	Petten, Delft	in operation	0.14 tHM
HLW / spent fuel	Long-term interim storage (dry)	Borsele	in operation	29.6 m^3
	Interim storage	Petten	in operation	no information
LILW	Reactor storage	Borsele	in operation	1,687 m^3
	Long-term interim storage	Borsele	in operation	9,078 m^3
VLLW	No information on the volume and whereabouts of the waste cleared			
Depleted uranium-oxide	Long-term interim storage	Borsele	in operation	1.845 m^3

All figures for 31.12.2007 from Joint Convention Report 2009.

Particular problems for Waste Management

Despite the non-existing perspective for the final handling of the radioactive waste, the time to operate the nuclear power plant at Borssele had been drastically prolonged and it is planned to build a further nuclear power plant.

The reprocessing of the spent fuel and the use of the fuel separated this way in new fuel elements require a manifold handling of radioactive substances. The consequences are:

- Exposure of personnel to radiation,
- Extensive release of radioactive substances and thus increased exposure to radiation of population and environment,
- High risk of incidents and accidents,
- High risk of proliferation.

The reports from the Netherlands do not contain any information on the experience made with the condition of waste containers after a long-term storage. Examples from other EU Member States show that severe corrosion- or other detrimental events occurred after storage periods of only 20 years – even earlier in some cases. It will thus be expected in case of a storage period of 100 years that extensive maintenance- and repair works will be required, again connected to an exposure to radiation of the personnel and – to a lower degree – of the population.

In the past, large volumes of depleted uranium from the enrichment plant at Almelo have been transported into the Russian Federation as UF_6 for re-enrichment. Roughly 4/5 of the UF_6 (further depleted) will remain in Russia. The contracts concluded between the plant licensees in The Netherlands and in Russia do not contain any binding safety-relevant requirements for the further handling. Concepts for the long-term handling are obviously not available in the Russian Federation. A long-term storage in the open in containers not fulfilling safety-relevant requirements can be assumed. Any release from a container may cause catastrophic consequences for the environment.

The extensive use of the clearance of very low level waste into the conventional sector may result in an increase of the background radiation for the population, especially in a small country like the Netherlands.

Romania

<u>Nuclear power plants and other causers of primary waste:</u>

Two power reactors are in operation in Romania, a further one is in the planning stage (all at Cernavoda).

In addition, one research reactor is in operation and one is decommissioned.

One uranium mine is in operation, one is planned and one is shut down.

<u>Waste-Management Concept:</u>

- Interim storage of **spent fuel** in storage pools of power reactors for 6 years.
- After that, interim storage of the spent fuel in a dry storage facility for at least 50 years.
- Final disposal in deep geological formation at the earliest from 2050.

- **Spent fuel from research reactors** will also be moved into the repository after the interim storage or will be returned to the country of origin.
- Conditioning and interim storage for at least 50 years of long-lived **low and intermediate level waste.**
- Repository in deep geological formation at the earliest from 2050.
- Interim storage of short-lived low and intermediate level waste.
- Final disposal in a near-surface repository.

Status repository

The documents available (Joint Convention Report 2005 und Sixth Situation Report Radioactive Waste and Spent Fuel Management in the European Union) do not contain any remarkable activities on a repository for spent fuel.

The near-surface repository for short-lived low and intermediate level waste shall be put into operation in 2014. The documents available do not state, however, any decision on the location.

Waste-Management facilities and existing waste volumes:

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Cernavoda	in operation	603 tHM
	Interim storage (dry)		in operation, will be extended	159 tHM
Spent fuel from research	Reactor storage pool	Pitesti	in operation	< 1 tHM
	Interim storage (dry)		in operation	
	Reactor storage pool	Magurele	in operation	< 1 tHM
BE / HLW	Repository	Location not yet defined	Commissioning ?	-

Nuclear waste	Type of storage	Storage site	Status	Volume stored
LILW	Reactor storage site	Cernavoda	in operation	179 m^3
	Interim storage	Cernavoda Pitesti Magurele	in operation	304 m^3
	Near-surface repository	Location not yet defined	Commissioning 2014	-
U-holding waste	Tips + slurry settling facility	Brasov	shut down	4.5 million t

All data taken from Joint Convention Report for 2004

Particular problems for Waste Management

No serious efforts are noticeable with respect to a search for a location and for a set-up of a repository for spent fuel and high level waste as soon as possible.

Sweden

Nuclear power plants and other causers of primary waste:

10 power reactors are in operation at 3 locations and two research reactors are in operation at two locations.

In addition, a fuel element plant and a uranium residue recycling plant are in operation.

Three power reactors and two research reactors are in the process of decommissioning.

Waste-Management Concept:

- Storage of **spent fuel** in the reactors storage pools.
- After a sufficient period of cooling down, transport and storage for at least 30 years in the central underground interim storage facility (CLAB) in hard rock at a depth of 25 to 30 m.

- Packaging suitable for a repository in a plant on the site of a repository to be set up yet.
- Repository in hard rock at a depth of 400 to 700 m.
- Despite a back-filling and sealing of the repository, a retrieval of the waste shall still be possible.
- **Spent fuel from research** is partially transported into the USA as a destination (country of origin).
- Conditioning of **low and intermediate level waste** from operations at the locations of generation or combustible and metallic waste at Studsvik.
- Final disposal of all low and intermediate waste with short-lived radioactivity inventory in the repository SFR-1 set up in hard rock.
- All waste generated through decommissioning shall be finally deposited in an extension building of the SFR from 2020 onwards.
- Interim storage of long-lived low and intermediate level waste at the locations of generation. This waste shall be moved into a central interim deposit and into a separate repository later on. At the moment, a repository is assumed not before 2045.
- **Very low level waste** will be either finally deposited in above-ground repository at the sites of the nuclear power plants or at the conditioning plant at Studsvik or will be released for any given further use as well as for the depositing on a conventional dump site.

<u>Status repository</u>

The location of Östhammar close to the nuclear power plant Forsmark has been determined for disposal of spent fuel in 2009. It is planned to put the repository into operation at a depth of 500 m in 2025. Extensive research- and development works have been carried out in an underground laboratory at a different location with a very similar surrounding rock.

No specific plans are available with respect to long-lived, low and intermediate level waste. A commissioning of a respective repository is planned after 2045.

Repositories are in operation for the short-lived, low and intermediate level waste.

Waste-Management facilities and existing waste volumes:

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Oskarshamn	in operation	157 tHM
	Reactor storage pool	Forsmark	in operation	191 tHM
	Reactor storage pool	Ringhals	in operation	308 tHM
	Central near-surface interim storage pool	Oskarshamn (CLAB)	in operation, will be extended	4,676 tHM
	Repository	Östhammar	Commissioning 2025	-
Spent fuel from research	Reactor storage pool	Studsvik	in operation	0.08 tHM
LILW long-lived	Interim storage	Studsvik, Simpevarp/Oskarshamn	in operation	>1,100 m^3
	Repository	Site not determined	Commissioning 2045	-
LILW short-lived	Reactor storage facility	Oskarshamn, Forsmark, Ringhals, Barsebäck	in operation	? m^3
	Near-surface interim storage	Studsvik	in operation	1,708 m^3
	Near-surface repository	Forsmark	in operation	31,768 m^3

Nuclear waste	Type of storage	Storage site	Status	Volume stored
VLLW	Dump site	Forsmark	in operation	3,929 m^3
	Dump site	Oskarshamn	in operation	7,346 m^3
	Dump site	Forsmark	in operation	2,410 m^3
	Dump site	Studsvik	in operation	1,151 m^3

All figures for 31.12.2007 from Joint Convention Report 2009

Particular problems for Waste Management

The most important element in the repository concept is the efficiency of technical barriers for several hundred thousand years. A final disposal will only be possible in hard rock due to the geological situation in Scandinavia. Hard rock is fractured, however, and is thus aquiferous. The retention of the radionuclides from the radio-active waste can thus only be guaranteed for a long period of time using a material extremely resistant against corrosion. Copper had been regarded as very corrosion-proof so far, from which the container for the spent fuel for the repository shall be made.

In 2009, in the Royal Technical Highschool of Stockholm research results were published indicating a much faster corrosion progress in view of the geo-chemical conditions in a sealed repository than known up to now. This means releases within periods of time, during which also less long-lived radionuclides have not decayed to a large extent.

Slovak Republic

Nuclear power plants and other causers of primary waste:

There are two reactors in operation at Bohunice and two at Mochovce in the Slovak Republic.

Three reactors at Bohunice are in the process of decommissioning.

One experimental-type bituminisation plant and one incineration facility are also in the process of decommissioning.

Waste-Management Concept:

- Storage of **spent fuel** in reactor storage pools up to 7 years.
- After that 40 – 50 years of interim storage in containers at the nuclear power plant site.
- The reference scenario is a repository in deep geological formations. But also the options to transport the spent fuel abroad for a final disposal or reprocessing (without taking back the waste) and for a use of international or regional repository are checked, however.
- Buffer storage of **low and intermediate level waste** in the buildings of the reactor blocks.
- Conditioning depending on kind of waste.
- Near-surface repository. Waste exceeding the safety-related requirements for acceptance of this repository will be stored in an interim storage facility at the locations of the reactors. It is planned to dispose of this waste in a deep geological formation.
- **Very low level waste** shall be stored in a near-surface repository or shall be released for the conventional sector.

Status repository

Within the scope of a research program, three regions with five potentially suitable locations for a deep geological repository have been determined quite some time ago. The research program had been stopped in 2001, however, and a new strategy had been specified by the government. This also includes a final disposal. There is no definition, whether the five locations shall be further explored in case of a decision for a Slovak repository. A time schedule for the further procedure is not stipulated as far as publicly known.

A near-surface repository for low and intermediate level waste is in operation at Mochovce.

Waste-Management facilities and existing waste volumes:

In the past, a minor portion of the spent fuel had been transported into the Russian Federation for reprocessing. The volume is not specified in the Joint Vention Report 2009. No radioactive waste generated through this reprocessing will be delivered into the Slovak Republic.

Nuclear waste	**Type of storage**	**Storage site**	**Status**	**Volume stored**
Spent fuel	Reactor storage pool	Bohunice, Mochovce	in operation	No data available
	Interim storage pool	Bohunice	in operation	996 tHM
HLW	Reactor storage facility	Bohunice	in operation	167 cells *
LILW long-lived	Interim storage	no information		50 m^3 ***
LILW liquid	Reactor storage tanks	Bohunice V-1, V-2, A-1	in operation	5,087 m^3
	Reactor storage tanks	Mochovce	in operation	2,003 m^3
LILW solid	Reactor storage facility	Bohunice V-1, V-2, A-1	in operation	5,712 m3 + 389 pcs *
	Reactor storage facility	Mochovce	in operation	449 m3
	Deposit of contaminated soil	Bohunice A-1	in operation	6,819 m3
	Above-ground repository	near Mochovce	in operation	4,800 m3 **
Nuclear waste	Type of storage	Storage site	Status	Volume stored
VLLW	Storage facility	no information		4,000 m^3 ***

* The information available does not allow any classification of volumes.

** This is the waste generated through nuclear power plants and treated in the conditioning plant at Bohunice before final depositing. The information available does not show whether or not any other waste from nuclear power plants are finally deposited at Mochovce.

All figures for 31.12.2007, except for

*** From the 6th Situation Report for 31.12.2004

Particular problems for Waste Management

The handling of spent fuel after interim storage has not been defined in the Slovak Republic. It can be assumed that this will hamper the determined search for a location for a repository and for the development of a repository concept. The date originally planned for the commissioning of a geological repository had been 2037. This has now been postponed for an indefinite period of time. A repository for highly active radioactive waste would also be necessary in case of reprocessing due to the radioactive waste generated through this process.

The confusion of the Slovak situation with respect to the handling of spent fuel is also significantly indicated by the number and type of questions of other countries within the scope of the Third Review Conference on the Joint Convention 2009.

If the Slovak government should incorporate the reprocessing in the Russian Federation into the Waste-Management Concept, not only the basic safety-relevant problems explained in Chapter 3.1.1 of this study will become relevant but also the relatively low safety level of nuclear facilities in the Russian Federation.

The decommissioning of the reactor A-1 at Bohunice has been realised after two serious accidents (INES 4). The contamination through radionuclides generated by these accidents has resulted in a severe contamination of structural components, structures and environment.

Slovenia

Nuclear power plants and other causers of primary waste:

One power reactor is in operation in Slovenia (Krško) jointly together with Croatia and one research reactor is in operation (Brinje).

The uranium mine Žirovski has been shut down in 1990.

Waste-Management Concept:

- Interim storage of **spent fuel** in storage pool at the nuclear power plant site.
- After the shut-down of the reactor, transfer into a dry interim storage for 35 years.
- Final disposal in deep geological formations in Slovenia, Croatia or in a third country.
- **Spent fuel from the research reactor** shall be returned to the country of origin (USA).
- Treatment of **low and intermediate level waste** and packaging into steel containers at the locations of the reactors as well as externally abroad to a low extent.
- Interim storage of the waste in a facility at the location of generation.
- Repository
- **Very low level waste** is cleared upon the stipulation of use.

Status repository

The decision on the concept for a final disposal of spent fuel shall be made in 2020. A repository shall be commissioned in 2065. In case of an export, this shall be 2066 to 2070.

Waste-Management facilities and existing waste volumes:

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Krško	in operation	323 tHM
Spent fuel	Interim storage (dry)	Krško	in planning stage	-
Spent fuel from research	Reactor storage pool	Brinje	in operation	none
BE / HLW	Repository	Location not defined	Commissioning 2065	-

Nuclear waste	Type of storage	Storage site	Status	Volume stored
LILW	Reactor storage facility	Krško	in operation	2,209 m^3 [1)]
	Interim storage	Brinje	in operation	85 m^3
LILW short-life	Near-surface repository	Krško	Commissioning 2014	-
U-holding waste	Waste dump of uranium mine	Žirovski	in recultivation	$1.9 \cdot 10^6$ m^3 [1)]
	Deposit for residue from uranium ore processing			$7.21 \cdot 10^6$ m^3 [1)]

[1)] Data as of 31.12.2009 from Annual Report 2009[13]

Particular problems for Waste Management

The reactor at Krško is operated jointly together with Croatia. Differing interests and responsibilities of the two countries may lead to problems when developing a Waste-Management Concept, or with respect to the financing of the Waste Management and to the determination of a location for the repository.

The final disposal of the spent fuel is planned, however no efforts are visible regarding the realisation.

Spain

Nuclear power plants and other causers of primary waste:

8 power reactors at 6 locations are in operation in Spain.

A fuel element plant at Salamanca and the research centre CIEMAT near Madrid are in operation.

[13] Slovenian Nuclear Safety Administration: Annual Report 2009 on the Radiation and Nuclear Safety in the Republic of Slovenia

Two power reactors and two research reactors are in the process of decommissioning.

Waste-Management Concept:

- Long-term storage of **spent fuel** in the external storage pools or container storage facilities of the nuclear power plants.
- Transfer into a central interim storage and depositing for more than 60 years.
- Disposal in deep geological formations. The option of retrieval shall be possible for a certain period of time.
- Interim storage of long-lived **low and intermediate level waste** in a central above-ground deposit provided for that purpose and final disposal in deep geological formations later on.
- Conditioning of short-lived low and intermediate level waste at the reactor sites or at the site of the repository.
- Final disposal in the above-ground repository at El Cabril near Córdoba. The repository site shall be released from the monitoring after 300 years after closure.
- Final disposal of short-lived **very low level waste** in an above-ground repository with lower safety requirements.
- In-situ storage of long-lived very low level waste in mines.

Status repository

The decision for a repository for spent fuel, highly radioactive waste and long-lived intermediate level waste has been postponed. The slow international development is stated as the reason.

In the past, conclusions from investigations made had been drawn that deep geological formations existed in Spain generally suitable for a repository. At the moment, solely investigations about the possibilities of a characterisation of granite- and clay formations are carried out above ground. Generic repository concepts shall be developed for both rock types.

A repository for short-lived, low and intermediate level waste and for very low level waste is in operation.

Waste-Management facilities and existing waste volumes:

Until 1983, spent fuel from the reactor Santa Maria de Garońa had been shipped to Great Britain (145 tHM) and until 1994, from the reactor Vandellŏs I to France (1.913 tHM)[14] for reprocessing.

The plutonium separated remained in France, the ownership of the uranium had been transferred to the reprocessing company. From 2014 onwards, the return of vitrified waste generated in France is planned. But the technical specifications of these waste containers have not yet been accepted by the Spanish authorities. Also a transporting-/storage cask has not yet been approved and the construction of a storage site in France has been delayed. The situation for Plutonium and waste generated through reprocessing in Great Britain is unknown.

There are three uranium facilities shut down in Spain. One uranium mill and one uranium ore processing plant are in the process of decommissioning at the moment, the decommissioning of another uranium ore processing plant has been completed.

Nuclear waste	**Type of storage**	**Storage site**	**Status**	**Volume stored**
Spent fuel	Reactor storage pool	Cáceres	in operation	994 tHM
	Reactor storage pool	Tarragona	in operation	1,312 tHM
	Reactor storage pool	Valencia	in operation	598 tHM
	Reactor storage pool	Burgos	in operation	326 tHM

[14] Bernard Bigot, Administrateur Général, CEA, Brief an Henri Revol, Haut Comité pour la Transparence et l'Information sur la Sécurité Nucléaire, datiert vom 10. November 2003

Nuclear waste	Type of storage	Storage site	Status	Volume stored
Spent fuel	Reactor storage pool	Guadalajara	in operation	296 tHM
	Container storage facility	Guadalajara	in operation	923 tHM
BE / HLW /ILW long-lived	Interim storage (dry)	Valencia	Commissioning 2012	-
	Repository	Location not defined	Commissioning 2050 ?	-
LILW	Reactor storage facility	Cáceres	in operation	1,684 m^3
	Reactor storage facility	Tarragona	in operation	3,981 m^3
	Reactor storage facility	Valencia	in operation	1.784 m^3
	Reactor storage facility	Burgos	in operation	1,061 m^3
	Reactor storage facility	Guadalajara	in operation	690 m^3
	Storage facility	Juzbado	in operation	491 m^3
	Storage facility	Madrid	in operation	10 m^3
	Interim storage	Córdoba	in operation	? m3
	Near-surface repository	Córdoba	in operation	55,988 m3
VLLW	Near-surface repository	Córdoba	in operation	? m3
Uranium-holding waste	Mines + tips + slurry settling facilities	Salamanca	in recultivation	80.3 million t
		Badajoz	shut-down and monitored	6.6 million t
		Jaén		1.2 million t

All figures for 31.12.2007 from Joint Convention Report 2009.

Particular problems for Waste Management

The search for a repository location and the decisions on the final disposal of spent fuel and high level waste have been postponed in Spain. For this reason, only the long-term, above-ground interim storage option is available for the handling of this waste.

The long-term handling of the radioactive graphite waste from the decommissioning of Vandellos I is not clarified.

4.2 Strategies in the Russian Federation and in the USA

Russian Federation

Nuclear power plants and other causers of primary waste:

32 power reactors and a number of facilities for the supply of these reactors are in operation in the Russian Federation. The nuclear power capacity as well as the uranium exploration and uranium processing capacities shall be increased in the course of the following years.

The operation of reprocessing plants with more than 90 facilities provides for a generation of large quantities of radioactive waste.

23 research reactors are in operation.

Waste-Management Concept:

The spent fuel is stored, first of all, in reactor storage pools for 3 to 5 years. Depending on the reactor type, the fuel elements will then be transported to reprocessing or into an interim storage facility. Interim storage facilities are operated centrally and at the reactor sites. These are storage pools. In the future, a dry interim storage shall be increasingly used.

A final disposal of spent fuel is not planned. No intensive research is known in this respect. This also applies, however, to high level and other waste from reprocessing.

Status repository

In the past, radioactive waste has been pressed into boreholes in Russia. After an increasing amount of public protests as well as criticism offered by the IAEA with respect to the non-existing step-by-step barrier system, this technology had been stopped.

Particular problems for Waste Management

The reprocessing of Russian and foreign spent fuel from power reactors is carried out at Mayak. This is a plant originally used for mainly military purposes. The plutonium for the first Russian atom bomb has been produced here, for example. Also today, certain parts of the plant or facilities still have military tasks. This way, there is no distinct separation between military and civil operations.

A scientific research program carried out by the Russian and Norwegian governments in 1997 arrives at the conclusion that altogether $8.9 \cdot 10^{18}$ Bq of the radioactive isotopes Sr-90 and Cs-137 have been emitted into the environment at Mayak.

Several serious accidents occurred in the facility resulting in a severe contamination of the environment:

- In 1957 a storage tank holding reprocessing waste exploded after the cooling had failed for a longer period of time. This has been an accident classified with 6 on the INES scale.
- In 1967, a lake situated on the premises of the plant dried out during a period of drought, which had been used as an open-air waste deposit (through feeding liquid waste into the lake). The radioactively contaminated sediment of the lake had been carried away by a tornado and had been transported into the environment.
- In 2007, a storage tank for radioactive waste of the reprocessing plant began to leak. The liquid waste penetrated from the storage tank obviously located in the open air and spread out on a road. This incident shows that even the most elementary safety precautions, like a floor tray, are missing at Mayak.
- In August 2010, large-scale forest- and turf fires came close to the plant, so that the authorities had to declare a state of emergency. Luckily, the plant itself had not been involved, but again radioactive substances due to the relatively serious

contamination of the environment as a result of the accidents and other releases of substances have probably been mobilised by the fire.

Over all it must be noted, that there is no sustainable concept for a disposal of high level waste. It seems that safety requirements for the operation of nuclear facilities are still insufficient.

USA

Nuclear power plants and other causers of primary waste:

104 power reactors and a large number of facilities for the supply of these reactors are in operation in the USA.

A further large-scale generator of waste is the civil reprocessing plant shut-down at West Valley.

In addition, large civil and military research facilities are in operation.

Waste-Management Concept:

The Waste Management for the civil and the military use of nuclear energy are mostly separated from each other. This section only describes the mainly civil Waste Management.

Spent fuel from power reactors is deposited in storage pools of the nuclear power plants. In addition, half of the reactors are equipped with interim storage facilities independent from the operation of the reactor. A future extension of the storage capacity shall preferably be carried out by way of a dry storage in cans, which are – in turn – stored in concrete silos or containers.

Spent fuel from research reactors in the USA and from overseas (also from EU Member States) is stored in central interim storage facilities at the locations of Savannah River Site and Idaho National Laboratory.

It is planned to store the spent fuel from power reactors (also MOX fuel elements with weapons-grade plutonium from the disarmament agreements concluded with the Russian Federation) and from research reactors in a repository in deep geological formations. Thus, no civil reprocessing of spent fuel is planned. The current US government has installed a commission (Blue Ribbon Panel) to newly assess the various different Waste-Management options and to supply a respective report in 2011.

The high level waste previously generated from civil reprocessing shall be disposed of in the same repository as the spent fuel.

The repository shall stay open for more than 100 years from the start of the disposal. That means, a depositing shall be carried out for roughly 50 years and the storage areas shall be accessible for a further 50 years.

There is no radioactive waste in the USA classified as intermediate level waste but four different categories for radioactive waste with a low activity level. The waste is usually stored in an interim storage facility at the site of generation until compiling a sufficient volume for transport to the repository. At the moment, the category waste with the largest and also long-lived radionuclide inventory is stored in an interim storage facility for a longer, undefined period of time. The other radioactive waste with a low activity level is disposed of in near-surface repositories up to 30 m below the surface of the earth. Very low level waste is also deposited on other disposal sites for hazardous substances.

Status repository

Since 1987, Yucca Mountain has been explored and expanded upon a resolution passed by the US-American Congress as a location for a repository for spent fuel and high-activity radioactive waste. In the spring of 2010, the US government decided to stop the program and to backfill Yucca Mountain.

Transuranium-holding waste (TRU) generated through the research, development and production of nuclear weapons is disposed of in a depth of 655 m in the Waste Isolation Pilot Plant (WIPP).

At the moment, three near-surface repositories for low level waste categories are in operation in the USA.

Particular problems for Waste Management

The search for a location for a repository for high level waste must be started up again. The authorities have stuck to the location of Yucca Mountain for decades despite the doubts of the safety-relevant suitability of the site, of the integrally very long transporting routes and of the socio-political problems.

New discussions are held in recent years with respect to the stability of the salt formation or of the retention capacities in case of a release of radionuclides regarding the final disposal of the military nuclear waste carried out in the WIPP for a longer period of time.

Since July 2008, one of the companies operating the repository for low-activity radioactive waste rejects the acceptance of waste from three US States. The companies generating the waste in these three States have to establish methods for a long-term depositing. One new, near-surface repository is in the process of licensing at the moment. Four near-surface repositories have been shut down already, because it had been impossible to fulfil the environmental requirements and conditions.

5. Summary

More than 2,000,000 m^3 of radioactive waste (without residues from uranium mining and processing) have been finally disposed of in the 27 EU Member States until 2007. The EU Member States with the largest volumes of radioactive waste are Great Britain and France.

One or more than one repository for low level or low and intermediate level waste are in operation in only 7 out of the 16 countries of the EU using nuclear energy:

- In two countries for waste generated through nuclear power plants (Finland, Czech Republic)
- In one country for low level waste (Great Britain)
- In four countries for low and intermediate level waste with short half-life periods (France, Sweden, Spain, Slovak Republic).

In no country a repository for high level waste and spent fuel exists.

The following volumes have been stored in interim storages in the EU Member States as of the end of 2009:[15]

[15] Estimated on the basis of data available for 2009 and the data given in the Joint Convention Reports for 2007

- Approx. 250,000 m^3 of very low level waste (on which many countries do not supply any information),
- More than 550,000 m^3 of low and intermediate level waste (according to the European Commission, a large portion without any perspective for a final disposal),
- Approx. 35,000 m^3 of high-activity radioactive waste (according to the European Commission without any actual perspective for a final disposal),
- Approx. 48,000 tHM of spent fuel.

Until 2020, an additional volume of roughly 2,000,000 m^3 of waste is expected in the EU.

Most of this waste must be stored in interim storage facilities for many decades. In many cases, the safety-related requirements are doubtful. In addition to the risks caused by the radioactivity, risks of acts of terrorism and extreme weather conditions are an additional contribution to the overall risk.

As becomes increasingly apparent the final disposal in geological formations (up to now considered to be the most reliable disposition) is also associated with problems. The hazards detected in the German repository Asse, namely those of a potential release of the radioactive materials stored in the repository into the biosphere are only one example. In this case, the asserted long-term safety has already expired after only 40 years.

Technologies such as reprocessing or transmutation do not offer a way out. According to our current state of knowledge, a repository, for which a long-term safety proof is required, will nevertheless be necessary. The manifold handling of the radioactive waste will, however, increase the risks for incidents and accidents, the exposure of personnel and population to radiation and the chances for a military misuse. Transmutation will be applicable in 50 years at the earliest, if it all. By that time, more than 1,000,000 m^3 of nuclear waste which would have to be transmuted will have been accumulated, as well as large volumes of high level waste that is already conditioned and non-treatable (e.g. vitrified waste). Therefore it seems impossible that transmutation will be a solution for the problem.

In addition, most of the countries with reprocessing as a part of the Waste-Management Concept actually do not carry out the reprocessing at home but export the risks. In particular the reprocessing outside the European Union, in the Russian Federation, has to be stopped immediately. The safety requirements are to some extent even more insufficient than those in France and Great Britain.

Result:

Even after more than 50 years of using nuclear energy, no country has developed an implemented and functioning Waste Management Strategy for all kinds of radioactive waste. A solution of the problems associated with the handling of radioactive waste in the EU is also impossible by way of a respective Directive.