Radiation Protection

OECD
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Radiological Impact of Spent Fuel Management Options

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AEN

NEA

FOREWORD

The Nuclear Energy Agency launched a comparative study on radiological effects of spent fuel management options in 1996. Main objectives of the study are to compile data and information on radioactive releases from various steps of nuclear fuel cycles, to analyse radiological effects in a systematic manner, to present results and scientific and technological interpretations, and to contribute to informed discussion in its Member countries. The study has been carried out by an Ad Hoc Expert Group on Spent Fuel Management Options under the Committee on Radiation Protection and Public Health.

2. Two reference fuel cycles are selected to facilitate comparison of radiological impacts: simplified PWR- based fuel cycles with non-reprocessing and reprocessing of spent fuel. Actual data on radioactive releases from reference facilities are used. Reference facilities are selected taking account of their scale, duration of operation, technological characteristics, and characteristics of the installed waste management process. Radiological effects are evaluated with a generic model.

3. Since nuclear fuel cycle is still in the process of development, there remain some areas of uncertainties. Furthermore, the two reference fuel cycles are somewhat interconnected. Efforts are made to narrow uncertainties, to apply same assumptions and to include review on issues related to radiological effects.

4. The results of this study should be considered to be indicative and are not suitable for specific decision making since considerable uncertainties exist in them because of limitations in the model and data. Thus, differences in radiological effects between the two options are not significant from radiation protection viewpoint. It is hoped that this report will serve a starting point of much broader studies on nuclear power development strategy, nuclear fuel cycle strategy and sustainable development of nuclear power.

1. SCOPE OF THE STUDY

1.1 Background

5. The Steering Committee for Nuclear Energy decided to launch a comparative study on radiological impacts of spent fuel management options in 1995, following requests from the Oslo and Paris Commissions (OSPAR). The original request was centred on comparative assessment of radiological impacts from radioactive discharges into the marine environment resulting from reprocessing and non-reprocessing options. In deciding to launch the study, the Steering Committee took account of recommendations of the Committee on Radiation Protection and Public Health that narrow scope of such a study is less meaningful from radiation protection view point and that its scope should cover all steps in the fuel cycle.

6. The main purposes of the study are

- To compile scientific and technological data and information relevant to the request, and
- To analyse them and present findings with scientific and technological interpretations to assist discussions by the OSPAR Member countries.

7. The interest in revisiting results of previous studies on related subjects is also expressed. These include The IAEA International Nuclear Fuel Cycle Evaluation (INFCE 1980), the European Commission Project ExternE - Externalities of Energy (EUR 1995), and the 1983 German comparison of the safety of reprocessing and non-reprocessing options and its updated version in 1996 (HOE 1996).

1.2 Scope of the Study

8. Evaluation of radiological impacts is complex due to influence by a number of factors: plant characteristics, operating conditions, site characteristics, environmental aspects, cultural and social conditions. Furthermore, the regulatory requirements developed by national authorities also are important factors. Specifically, this study attempts to present a systematic comparison of radiological impacts arising from reprocessing and non-reprocessing options. Although stylised fuel cycles chosen for this study are significantly different from actual fuel cycles, they are comprehensive, and sufficiently detailed for realistic comparison purposes. The following equivalent parameters and conditions are used for the study:

- 1 000 MW(e) PWR, with 40 GWd/tHM burn-up
- Non-reprocessing option:
  - all waste and spent fuel are disposed of into a repository.

- Reprocessing option:
  - all U02 spent fuel is reprocessed; all Pu recovered from reprocessing of U02 spent fuel is recycled as MOX fuel only once; all waste and MOX spent fuel are disposed of into a repository.

9. In evaluating radiological impacts, a generic model and common parameters are used to facilitate systematic comparison of results. Actual radioactive release data of plants representing state-of-the-art characteristics are used as much as possible so that the results reflect current practices. When actual releases are not available, the needed information is derived from the literature.

10. Radiological impacts are evaluated in terms of individual doses and collective doses. Emphasis is placed on doses to the public, but doses to workers are also presented A short review of the radiological impacts on the environment, based mostly on previously published reviews by other international organisations, is also included in the report.

11. Production of electricity (1 GWa) has been chosen as a common basis for comparison for this study. Releases and discharges into the marine environment and the atmosphere have consequently been normalised to one unit of electricity produced. It should be noted, however, that in real situations discharges, releases, and doses are not correlated uniquely with the electricity production. For example worker doses also depend on the design, on the age of the plant, and on the amount of maintenance.

12. Only normal operation has been considered, as accident consequences are not likely to dominate. Various accident analyse have been carried out, however. This was considered to be outside the scope of this studyl.

1.3 Reference Fuel Cycles

13. Figure 1 shows the steps of the two comprehensive but simplified reference fuel cycles adopted for this study. They are defined to facilitate systematic comparison of radiological impacts by reducing uncertainty, and to make boundary conditions to the two options as equivalent as possible. They may be significantly different from the actual situation, but are sufficient to illustrate characteristic radiological impacts. A simplified description of each is given below. Details on each facility are provided in Chapter 3 and in the Annexes.

14. The once-through option (direct fuel cycle) includes the following successive steps:

- **Mining and Milling**

  Uranium is extracted from the crushed, mined uranium ore in a processing plant (mill) using chemical methods. The uranium concentrate (U3Og) produced in the ore processing plant is known as *yellowcake.*

- **Conversion and Enrichment**

  The yellowcake is purified by a complex chemical treatment and converted to readily volatile uranium hexafluoride (UF6), which is used in the enrichment process.

1 See for example the German study (ACC 19..).

Uranium occurring in nature consists largely of 238U,which acts predominantly as a neutron absorber. The fissile 235U occurs to the extent of only 0.7 % in natural uranium. Some reactors are able to function with fuel containing only the naturally occurring proportion of 235U. But PWR reactors contain a greater proportion of neutron absorbing materials, and this must be compensated for by increasing the concentration of the 235U isotope in the fuel from 0.7 per cent to around 3.6 per cent.

The process by which the concentration of the 235U isotope is increased is known as enrichment. Gaseous diffusion through porous membranes is the most widely used technique. After passing through the enrichment plant, the uranium hexafluoride has been separated into two fractions. The smaller of these is enriched in the 235U isotope and is shipped to the fuel fabrication plant. The larger fraction (enrichment tails) is depleted in 235U and is temporary stored.

- **Depleted Uranium Temporary Storage**

Part of depleted uranium may be used for the fabrication of mixed plutonium/uranium oxide (MOX) fuel (see the reprocessing option). Other possible uses, as for example in fast breeder reactors, have not been considered by the study.

- **Fuel Fabrication**

The enriched uranium hexafluoride is chemically converted to pure uranium dioxide powder, which is then pressed into pellets and sintered at high temperature to produce a dense ceramic fuel. The PWR fuel pellets are sealed in tubes put together in a lattice of fixed geometry called a fuel assembly.

- **Power Generation**

Fuel assemblies are transferred to the reactor core where they remain for about three to five years, depending on the selected refueling schedule. During this time, a proportion of the uranium atoms undergoes fission, producing energy and fission products. In addition, plutonium is also produced from uranium atoms and is, in turn, partly fissioned in the reactor.

- **Interim Storage and Conditioning of Spent Fuel**

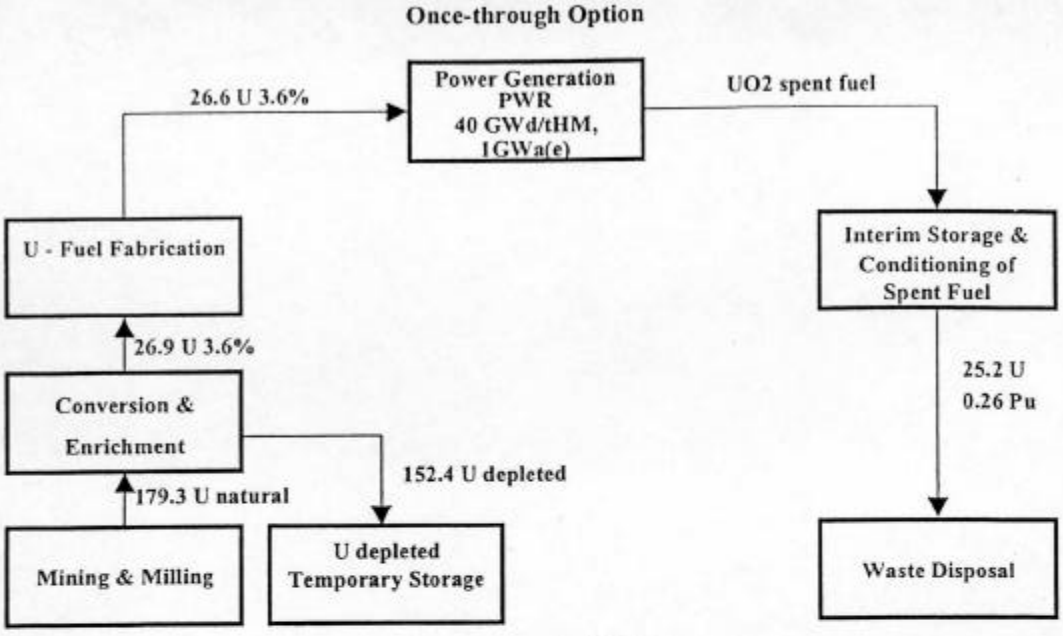
After removal from the reactor, the highly radioactive spent fuel is normally stored in pools at the reactor site and then transferred to an interim store to allow the radioactivity and residual heat to decay naturally.

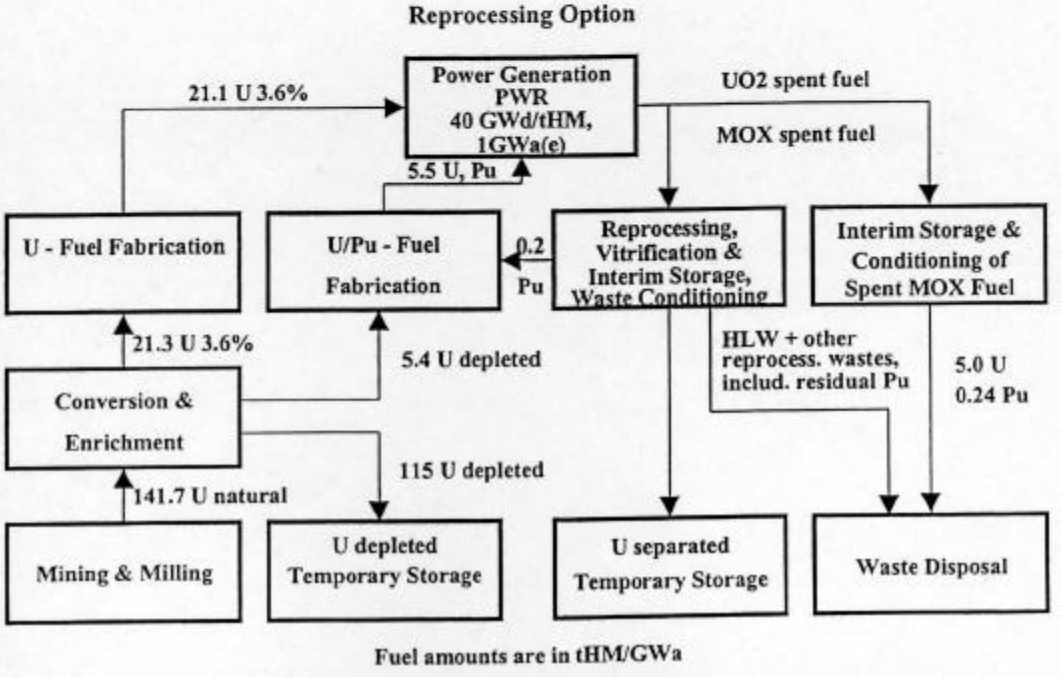
After a period of cooling, which may be 30 to 50 years, fuel assemblies are encapsulated, a process that involves placing the spent fuel in a canister of metal, such as copper, steel or titanium, or of ceramic material.

- **Waste Disposal**

Following encapsulation, the entire amount of spent fuel is treated as high level waste (HLW) and placed in deep geological repositories, possibly surrounded by a buffer material (e.g. bentonite) to prevent ground water coming into contact with the outer container forming the encapsulation.

Figure 1. **Reference fuel cycles and fuel flow charts adopted for the study**
(Flow quantities shown in tonnes of heavy metal)





15. The reprocessing option (integrated fuel cycle) includes the same steps as the direct fuel cycle with the addition of Reprocessing and U/Pu Fuel Fabrication.

- **Reprocessing, Vitrification and Interim Storage**

  Reprocessing involves dissolving the spent fuel to enable the re-usable plutonium and uranium content to be separated from the residual waste fission products and actinides.

  Fission products and actinides, which represent about 99 per cent of the total radioactivity in spent fuel, are vitrified.

- **U/Pu Fuel Fabrication**

  The recovered plutonium is recycled in the reactor with part of the depleted uranium as mixed plutonium/uranium oxide fuel (MOX).

- **Note on Waste Disposal**

  The removal of the plutonium and of the uranium via reprocessing reduces the volume of high level waste, but leads to the production of low level wastes (coming from the operation of the plant) and intermediate level wastes (essentially hulls and end fittings).

16. Reprocessing and plutonium recycling allows the production of more energy from the same initial quantity of mined uranium. Expressed from a different point of view, the same amount of energy can be produced with less mining and milling activity. Fuel amounts provided in Figure I are normalised to energy production (adapted from E. Hormann 1996). The fuel flow chart of the oncethrough option shows that the production of 1 GWa(e) requires the mining and milling of 179.3 t of natural uranium. The flow chart for the reprocessing option shows that this quantity can be reduced to 141.7 t when 0.2 t of plutonium, recovered by reprocessing, can be recycled in the production of mixed plutonium/uranium oxide fuel.