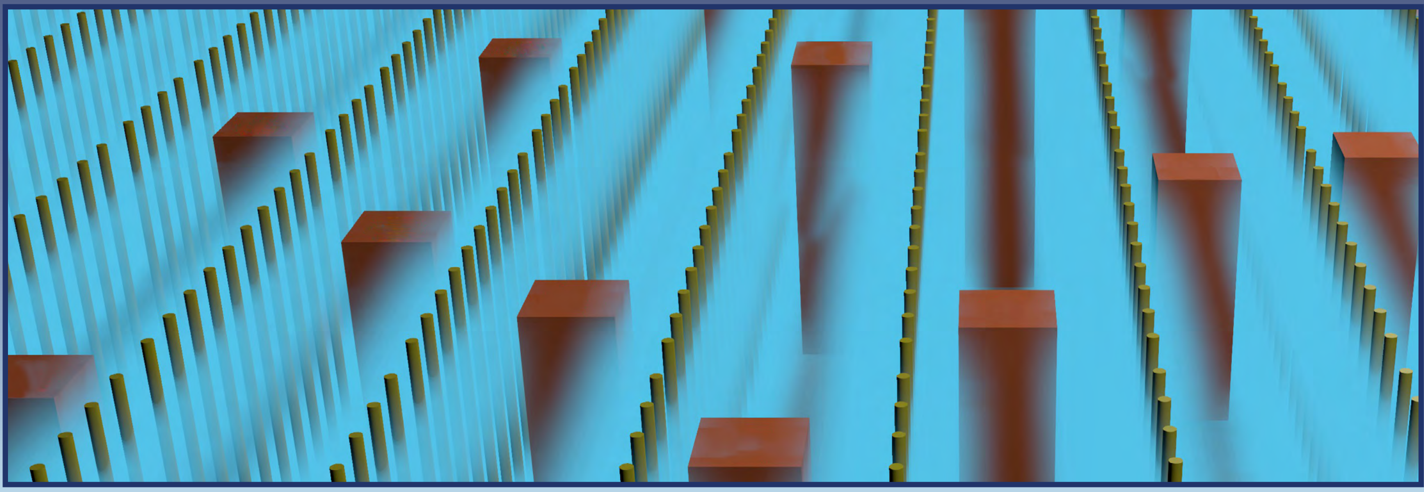
Management of spent nuclear fuel and its waste

a Joint Research Centre and EASAC Report



European Commission

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Synopsis

The European Council Directive 2011/70/EURATOM on the "responsible and safe management of spent fuel and radioactive waste" requires EU Member States to establish a dedicated policy, including the implementation of national programmes for the management of spent fuel and radioactive waste.

The report summarised here aims to inform policy makers on important issues to take into consideration in developing national programmes for the future management of spent fuel and the waste generated by fuel treatment. It describes in a concise but comprehensive way the options for spent fuel management, their present state of development, and the consequences of the choices between them.

To ensure that European policy making is informed by the best current scientific knowledge, the European Commission's Joint Research Centre (EC-JRC) and the European Academies' Science Advisory Council (EASAC) have consulted a panel of experts from Europe and the US on the challenges associated with different strategies to manage spent nuclear fuel, in respect of both open cycles and steps towards closing the nuclear fuel cycle. The resulting report integrates the conclusions on the issues raised on sustainability, safety, non-proliferation and security, economics, public involvement and on the decision-making process.

An important and inevitable by-product of nuclear energy production is the spent nuclear fuel that needs to be managed and handled in a safe, responsible and effective way. Spent fuel is highly radioactive and requires shielding and cooling. It contains components that are radioactive waste, but it also contains uranium and plutonium that can be reused as fuel in reactors. The spent fuel can thus be seen as a resource. Uranium and plutonium can be separated from the waste in a reprocessing plant and reused, while the remaining high level waste will need to be disposed of. Recycling in this way is referred to as the closed fuel cycle. Alternatively the spent fuel in its entirety may be regarded as radioactive waste that will be disposed of. This is referred to as the open fuel cycle.

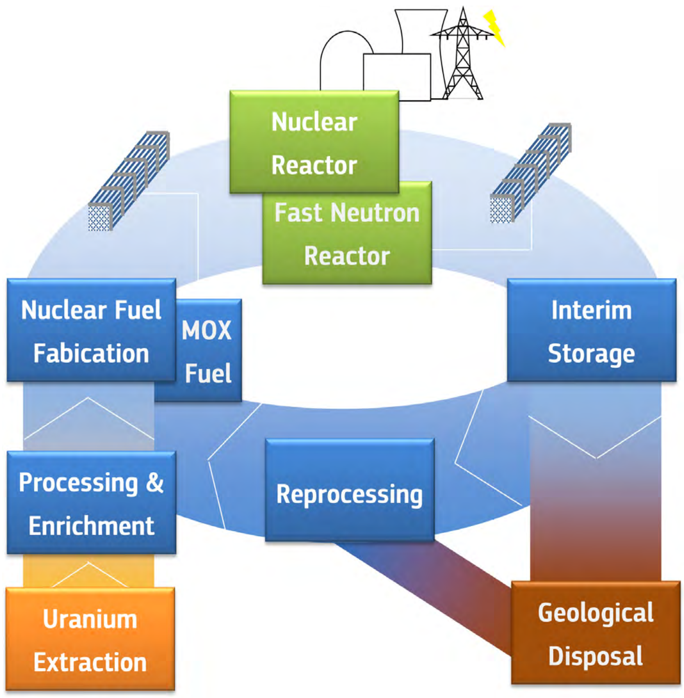

Figure 1
Fuel Cycle Steps

Open fuel cycle

In the open fuel cycle the spent nuclear fuel is considered as a waste and is encapsulated and disposed of in a deep geological repository after some decades of interim storage for heat decay. The technology for interim storage for at least 50 years is well established. The technology for encapsulation and disposal is most advanced in Finland and Sweden, where it has been developed to a stage that licence applications for construction and operation have been filed.

Closed fuel cycle

In the closed fuel cycle the spent nuclear fuel is reprocessed to separate the uranium and plutonium it contains so that they can be reused as new fuel. Fully utilising the material will require multiple reprocessing and recycling of successive generations of fuel. This cannot be done effectively in the nuclear reactors in use today, but will require the development and commercial implementation of fast neutron reactors which can enable the extraction of 50 to 100 times more energy from the originally mined uranium than in reactors currently in operation. Fast neutron reactors are, however, not yet commercially available, and the necessary development work is on-going.
At present, a partially closed fuel cycle is operated in some countries, notably in France. Spent fuel is reprocessed and the plutonium is mixed with uranium and reused in so-called MOX fuel (mixed oxide fuel) in existing thermal neutron reactors.

The spent MOX fuel is then stored, pending reprocessing for future use in fast neutron reactors. Reprocessed uranium can also be recycled after re-enrichment in nuclear reactors. Reuse of plutonium and uranium in this way improves the utilisation of the original uranium resource by about 20%. Reprocessing of spent fuel and recycling as MOX is commercially available. Processes are also operational for the conditioning and storage of the high level and long lived waste remaining after reprocessing, which will require deep geological disposal. Development work for this geological disposal is well advanced in France.

To fully utilise the energy potential of the uranium resource, through multiple recycling, a fleet of fast neutron reactors will need to be introduced. Although fast neutron reactors have been under development for many years, and fast neutron test reactors have been operated, the general view is that in Europe commercial fast neutron reactors and their associated fuel cycle facilities will not be available on a large scale before 2050. Substantial development work still remains with technical and commercial uncertainties.

The fully closed fuel cycle offers the possibility to further reduce the waste burden by separation also of some long-lived radioactive components and their subsequent transmutation (incineration) in the fast neutron reactor or in a separate transmutation facility, for example, an accelerator driven system. Commercial availability of accelerator driven systems is even more uncertain, and their implementation further in the future.

	OPEN CYCLE	FULLY CLOSED CYCLE
Uranium consumption	*- 20 ton U/TWh* *(I.e100 to 200 tonne uranium per year of reactor operation)*	*+ Consumption reduced by a factor 50 to 100*
Complexity of the techniques	*+ Few technically relatively simple management and handling steps*	*- Complexity increased by use of reprocessing and fast neutron reactor system*
Maturity of the techniques, developments required	*+ Long experience with interim storage* *- Encapsulation and disposal at the design and licensing phase*	*- Limited experience with operation of fast neutron reactors, new reactors in design phase* *- Developments for the spent fuel partitioning and transmutation techniques*
Waste disposal	*- Large repository footprint (due to waste volume and heat release)* *-Very long timescale to reach radiotoxicity of natural uranium (200,000 years)*	*+ Reduction of the footprint by a factor 1/3 (due to reduced volume and heat release for high level waste)* *+ If partitioning and transmutation is applied: significant reduction of the timescale to reach radiotoxicity of natural uranium (theoretically less than1000 years)*
Safety	*+ Fewer handling steps* *- More complicated long term safety*	*- More operations and transports* *+ Potential for simpler long term safety*
Security	*+ Fewer handling steps* *+ No separated sensitive (fissile) material*	*- More operations and transports* *- Sensitive material separated*
Proliferation	*+ No free sensitive material* *- Long-term safeguards of the repository*	*+ Less or no enrichment needs* *- Significant amount of sensitive material separated in the processes* *+ No sensitive material in repository*

Figure 2
Summary of main comparative advantages (+) and disadvantages (-) of the open and fully closed fuel cycle

Factors influencing the choice of fuel cycle

The choice of fuel cycle in a specific country will be based on several factors, for example national energy policy, technical maturity, sustainability (resources and waste), safety, proliferation resistance, and strategic and economic factors.

None of the fuel cycles are fully available today and will thus require further development work, particularly for closed cycles. It is anticipated that this development work will enable both open and closed cycles to be implemented with due regard to safety, security and non-proliferation, but any choice today is not guaranteed success. It will therefore be important to ensure flexibility in planning and implementation. Since geological disposal will be required, irrespective of the fuel cycle choice, continued R&D on disposal is a priority.

The main advantages and disadvantages of the open and fully closed fuel cycle are summarised in *Figure 2*. It is noted that a partially closed fuel cycle, if it is not followed by further recycling, will have no major advantage and should thus be seen only as an intermediary step towards the fully closed fuel cycle.

In the end the choice will also be based on economic factors. Most studies so far have indicated that the open fuel cycle is cheaper than the fully closed fuel cycle. Such calculations are, however, quite sensitive to the future costs of uranium, reprocessing, fast neutron reactors and repositories and future discounting rates; all of which have substantial uncertainties. Given the uncertainties, it is not possible at present to conclude whether open or closed nuclear fuel cycles will prove to be cheaper in the longer term. Alongside the economics, the drivers for future use of nuclear energy in the country and issues of energy self-sufficiency at an affordable cost will have to be considered.

Any choice of fuel cycle cannot only be based on technical and economic considerations but will also have to factor in political and public acceptance issues. It will thus be important to ensure sufficient public involvement in the various decision-making steps and in the siting of the facilities needed.

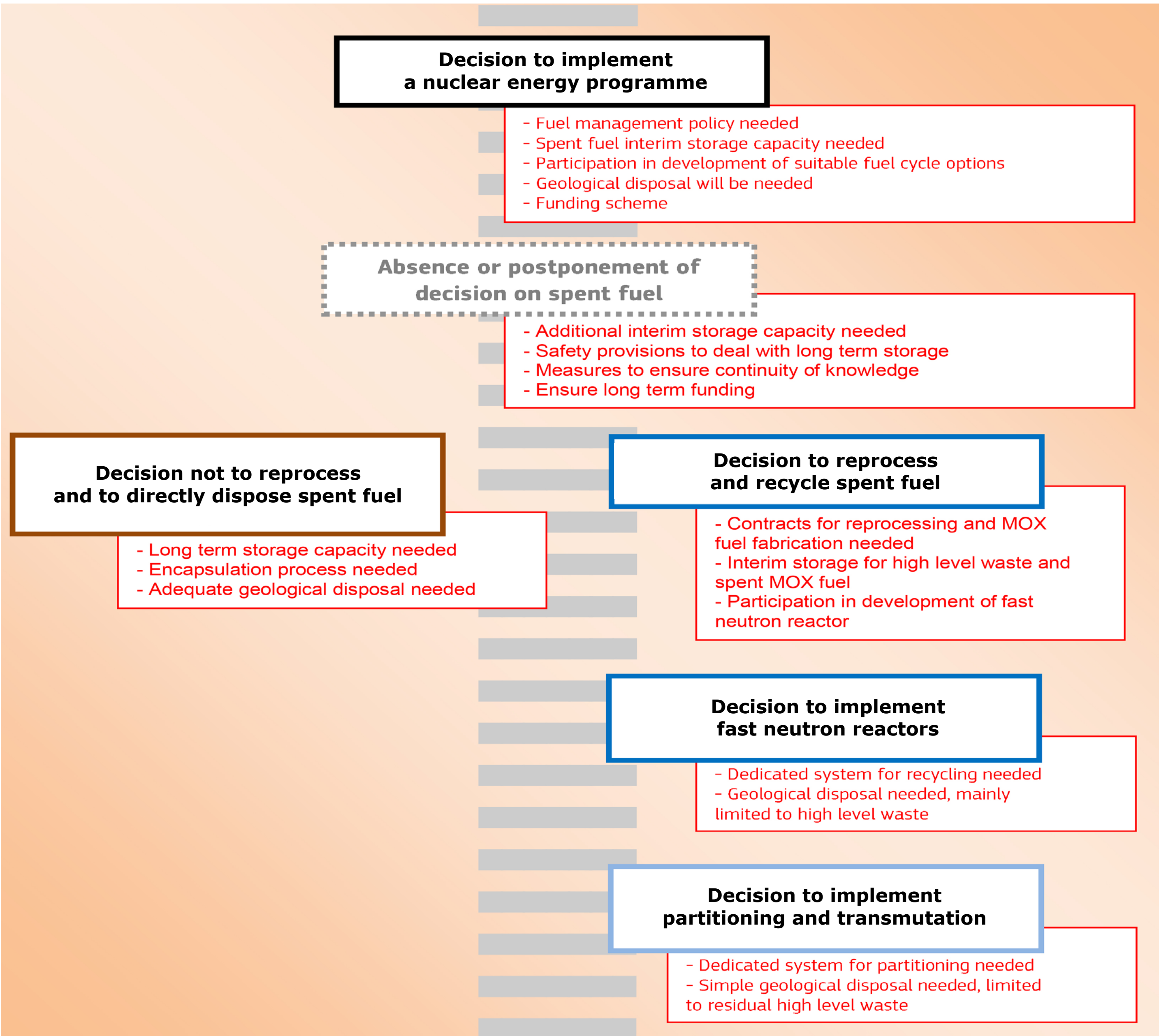

Figure 3
Key decisions and main consequences with respect to spent fuel

Decision points for determination and implementation of fuel management strategy *(Figure 3)*

Completion of an open fuel cycle, from a decision to build a repository to closure of the repository for the spent fuel will take at least a hundred years. The fully closed fuel cycle will require several hundred years, given the need to iterate recycling many times in order to fully realise the benefits of this approach. It can be foreseen that the boundary conditions will change during such long periods. The strategy should thus be able to accommodate such changes and keep an appropriate level of flexibility. As implementation proceeds, the degrees of flexibility will diminish.

A decision to build and operate one or more nuclear power plants in a country means that spent fuel will be generated, and that decisions will have to be taken on its safe management.
A decision to reprocess and recycle, or to store the fuel for direct disposal, can be taken at any time after the fuel has been removed from the reactor. Ample storage capacity should be provided to ensure flexibility, but should not be an excuse to delay development work. The value of reprocessing lies in the re-use of spent fuel in fast reactors. Hence, a decision to reprocess should be accompanied by engagement in the development of a fast neutron reactor system and related fuel cycle facilities, either directly or in association with other countries.

Irrespective of which choice is made for spent fuel management, it will be necessary from the outset to plan for sufficient spent fuel storage capacity and for disposal in a deep geological repository (for spent fuel and/or high level waste). At the same time a system for collecting funding for the future waste management should be developed.

European cooperation

Continued cooperation, at the European level, multi-laterally and bilaterally, in the scientific and technical development of both fast neutron reactors and their fuel cycles, and of deep geological repositories, is necessary to provide a real choice of options. Such cooperation includes sharing of skills, education and training, R&D, and development of joint facilities. Although politically sensitive at present, this could also include studies of joint or regional geological repositories, especially involving countries with small nuclear programmes and small volumes of radioactive waste.

Key considerations for a fuel cycle policy

Defining a spent fuel management policy is an essential step. Each country must implement a programme and ensure that the necessary technical and financial resources are available now and in the future for the safe and responsible management of spent fuel.

The policy will support continuity in the necessary developments and in the related investments, and continuity of knowledge and competence.

The fuel cycle policy should take account of the following considerations:

- Given the long timeframes of all fuel cycles, it is advantageous to generate robust technical solutions, covering the whole process, but keeping alternatives available to accommodate changes in future policies and plans.
- To ensure this flexibility in future choices, it is important that research is conducted on both open and closed fuel cycles. Cooperation bilaterally or at the European level is very useful for this purpose, including also the common development of fuel cycle and reactor facilities.
- The potential improvement in uranium utilisation from recycling in fast neutron reactors merits continuing their development.
- Further work on national or regional solutions for deep geological disposal is essential and urgent to ensure that spent fuel or high level waste can be safely disposed of at the appropriate time.
- Education and training are necessary to support the long term safe management of spent nuclear fuel and should be carefully considered. EU level initiatives to enable sharing of training materials and access to research facilities would be of value.

In the end the policy will not only be based on technical and organisational factors, but will also have to consider political aspects in general, and public acceptance issues in particular. It will thus be important to ensure sufficient public involvement and communication in the different steps of decision-making.

Contact information

European Commission
Joint Research Centre
https://ec.europa.eu/jrc
European Commission
Joint Research Centre (JRC)
CDMA Rue du Champ de Mars, 21
B-1050 – Brussels - Belgium

EASAC
the European Academies' Science Advisory Council
http://www.easac.eu
EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Jägerberg 1
D-06108 Halle (Saale)
Germany

EASAC Brussels Office
Royal Academies for Science and the Arts of Belgium (RASAB)
Hertogsstraat 1 Rue Ducale
B-1000 Brussels
Belgium

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