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OECD NUCLEAR ENERGY AGENCY / 38 BD SUCHET / 75016 PARIS / FRANCE

OECD NUCLEAR ENERGY AGENCY

The OECD NUCLEAR ENERGY AGENCY (NEA) was established in 1972, taking the place of the European Nuclear Energy Agency (ENEA) which had been set up in 1958.

The 19 European Member Countries of the OECD have been joined in the NEA by Australia, Canada, Japan and the United States. The Commission of the European Communities (CEC) and the International Atomic Energy Agency (IAEA) both take part in the Agency's work.

The NEA works to promote co-operation between Member governments in the safety and regulatory aspects of nuclear power and in the development of nuclear energy as a contributor to economic progress.

This is achieved by:

- *reviewing technical and economic aspects of the nuclear fuel cycle;*
- *encouraging the harmonization of governments' regulatory policies and practices;*
- *assessing demand and supply and forecasting the potential contribution of nuclear power to energy demand;*
- *exchanging scientific and technical information; and*
- *co-ordinating and supporting research and development programmes, notably through the setting up of joint projects.*

The NEA Newsletter is published twice a year, in English and French, to inform readers about the main issues in the peaceful development of nuclear power, the NEA programme and the direction of the Agency's future activities.

The opinions expressed in the Newsletter are those of the contributors alone and do not necessarily reflect the views of the NEA Secretariat or of Member countries.

 Correspondence and requests for additional copies should be addressed to:

The Editor,
NEA Newsletter
OECD NUCLEAR ENERGY AGENCY
38, boulevard Suchet
75016 Paris, France
Telex: 630.668 AEN/NEA

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Foreword

In 1984, nuclear electricity generation in the OECD area increased by the largest rate since 1977. According to official submissions by OECD countries, the nuclear share of total electricity generation now exceeds the share of oil. Although it is by far the most economical option for a majority of countries, the economic advantage of nuclear power has nevertheless declined due to the stabilisation of current fossil fuel prices. NEA is examining in detail the economics of the entire nuclear fuel cycle in a study which reviews the various methods for determining fuel cycle costs and provides data on the costs of constituent parts of the fuel cycle. "The Economics of the Fuel Cycle", one of the featured articles in this issue, takes a look at the methodology used to calculate fuel cycle costs for PWR's and other fuel cycles.

The management of the spent fuel discharged from a reactor is clearly an essential step in the back-end of the nuclear fuel cycle and it is vital that government and industry take into consideration all of the underlying policy and technological issues and options. An NEA study which discusses the technical, economic, commercial and political aspects forms the basis of "The Management of Spent Nuclear Fuel", the second featured article in this issue.

Recently, the NEA published a collective opinion by the Radioactive Waste Management Committee which reflects agreement among international experts that there is no fundamental obstacle to the safe disposal of radioactive waste – even with currently available technology. The Summary and Conclusions of this report, which offers a technical appraisal of the current situation in the field of radioactive waste management, appear in this issue.

Health and safety issues also arise at the front-end of the fuel cycle, in activities like uranium mining. Inhalation of radon and decay products in the mine atmosphere is a primary source of internal radiation for mine workers. A similar problem arises for sizeable groups of population living in dwellings built with materials containing higher than average natural radioactivity levels. International co-operative efforts are underway, aimed at improving methods and techniques for radiation dose assessment and monitoring of environmental conditions. A review of NEA's contribution to these efforts is included.

Although at present uranium is in an over supply situation, the continued growth in nuclear power assures that new uranium developments will be needed. The NEA/IAEA-sponsored International Uranium Resources Evaluation Project (IUREP), which is reviewed in this issue, assesses existing and inferred uranium resources worldwide and is providing a solid basis for exploration activities in the future.

To assure light water reactor safety, it is vital to have confidence that no dangerous cracks develop in the reactor pressure vessel and associated piping, which together constitute the primary coolant circuit. To this end, ultrasonic inspection procedures are indispensible. This issue of the Newsletter reports on the latest developments in the NEA-sponsored Programme for the Inspection of Steel Components (PISC-II), a series of international trials of the efficiency of current inspection procedures.

The NEA's capability to provide computerized information services is highlighted in this issue with a review of the Agency's Joint Evaluated File project. JEF provides carefully selected data for use in nuclear energy calculations.

Finally, as mentioned at the outset, the latest figures received by NEA concerning the nuclear situation in OECD countries in 1984 contain some encouraging signs. The final analysis of these numbers will appear this month in the annual NEA publication "Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries", but the table in this issue of the Newsletter provides a look at some of the more interesting results of the survey.

MAJOR ISSUES IN NUCLEAR POWER DEVELOPMENT

THE ECONOMICS OF THE NUCLEAR FUEL CYCLE

M.J. Crijns

As a natural extension of an NEA Expert Group study of comparative electricity generating costs, a Working Group was assembled to explore in detail the economics of the nuclear fuel cycle. The purpose was to present a clear, unambiguous account of the separate stages of the fuel cycle, enabling the reader to see the significance of certain individual cost components in relation to the fuel cycle itself and to the overall costs of generating electricity in nuclear power stations, particularly the Pressurised Water Reactor (PWR). To this end, the Working Group reviewed the various methods of determining nuclear fuel cycle costs and gathered data on the costs of constituent parts of the fuel cycle which illustrate the derivation of overall nuclear fuel cycle costs. The data, drawn from 17 countries, were based on detailed studies of all components of the fuel cycle, ranging from the purchase of uranium to the ultimate disposal of spent fuel or wastes.

Methodology

The "present-value" method has been used to analyse costs. All fuel cycle costs incurred during a reactor's lifetime are discounted, in order to arrive at their present-value for a given base date. All costs are expressed in constant money. To arrive at the average or so-called "levelised" cost, the sum of the discounted costs of all component stages of the fuel cycle is divided by the total discounted net electrical output of the reference reactor during its assumed life. This method was also used in the above-mentioned study on comparative electricity generating costs. Since it provides the average discounted cost over the course of the reactor's lifetime, it is particularly suitable for economic comparisons of fuel cycles or alternative fuels (e.g. coal, oil) associated with new power station investment decisions.

There has been some argument as to the appropriateness of discounting for the evaluation of nuclear fuel cycle costs, since back-end costs are incurred long after benefits have been enjoyed. Having given careful consideration to these criticisms, the Working Group finds discounting a practical and appropriate approach for the whole fuel cycle, including the back-end.

Main Parameters

Table 1 summarizes the basic assumptions of fuel cycle component prices. For both the once-through and the reprocessing cycle the most significant of these assumptions is the price of uranium. As such, the effects of a range of potential uranium prices have been examined. No effort has been made to arrive at a consensus on future prices, which in any case will be affected by a variety of factors.

Enrichment and fabrication are well established processes whose costs are widely known and subject to a solid – and currently highly competitive – market. However, the prospect exists for significant reductions in enrichment costs over the long term as new technologies evolve. While the level of such potential reductions cannot be known with certainty, based on present information, overall fuel cycle costs might be reduced by 10 per cent or more.

Mr. M.J. Crijns is a member of the Nuclear Development Division, NEA.

Table 1. **LWR FUEL CYCLE UNIT PRICES**

$US at 1st January 1984

Component	Basic assumptions for PWR	
	Reference unit cost	Parameters
Uranium	83.2/kg U	–
	(32/lb U_3O_8)	–
	escalation 2 % p.a.	0 and 4 % p.a.
Conversion	6/kg U	–
Enrichment	130/SWU	100-150/SWU and 70/SWU
Fabrication	190/kg U	160-210/kg U
Interim Storage		
Transport	40/kg HM[1]	–
Storage	(40+4/y)/kg HM	20+2/y-60+6/y
Reprocessing cycle		
Reprocessing	550/kg HM	500-1 000/kg HM
Vitrification	200/kg HM	
Disposal Waste	150/kg HM	75-250/kg HM
Once-through cycle		
Conditioning	200/kg HM	150-550/kg HM
Disposal	150/kg HM	

1. Transportation within the European area.

Reprocessing of 5-year cooled fuel with its associated waste conditioning, encapsulation and storage involves a significant proportion of total fuel cycle costs for the reprocessing cycle. Prices for reprocessing services are contingent upon developments within Europe. The rise of the US dollar in real value *vis-à-vis* European currencies between 1981 and 1984 has produced a reduction in reprocessing costs relative to those of the front-end of the fuel cycle.

The value of plutonium and uranium recovered in the reprocessing cycle is dependent upon their intended use and its timing. In the reference case they are assumed to be used in mixed oxide fuel within a few years of separation.

A parameter determined independent of the nuclear industry is the discount rate. The value adopted for most OECD countries falls somewhere near the 5 per cent used for the reference case in this study, but the use of a higher or lower rate does not have an overwhelming impact on the overall fuel cycle cost.

The choice of fuel cycle – either the once-through, the reprocessing cycle or the use of mixed oxides – is a question of national or utility policy, as are decisions on the lead time for uranium purchase (and hence the effective uranium stockpile held by the utility) and the lag time prior to reprocessing and/or spent fuel or waste disposal. These choices can also affect the cost of the fuel cycle as indicated by sensitivity studies.

PWR Fuel Costs

Fuel cycle costs account for between 20 and 40 per cent of the levelised cost of electricity production in PWRs based on the earlier generation cost study. For the once-through cycle and the reprocessing cycle with 5-year cooled fuel, the reference costs are 7.8 and 8.6 mills/kWh, respectively (Table 2). The largest single component (40 to 50 per cent) of the fuel costs is the price of uranium, although fuel costs are also sensitive to major reductions in enrichment costs which could arise from the deployment of advanced

Table 2. **BREAKDOWN OF PWR FUEL CYCLE COMPONENT COSTS**

Reference cases*

	Reprocessing cycle		Once-through	
	mills/kWh	%	mills/kWh	%
Uranium	3.48	40.7	3.48	44.7
Conversion	0.17	2.0	0.17	2.0
Enrichment	2.28	26.6	2.28	29.3
Fuel fabrication	0.88	10.3	0.88	11.3
Sub-total of front-end	6.81	79.6	6.81	87.5
Transportation of spent fuel	0.14	1.6	0.14	1.8
Storage of spent fuel	0.17	2.0	0.65	8.4
Reprocessing/vitrification	2.18	25.5	–	–
SF conditioning/disposal	–	–	0.18	2.3
Waste disposal	0.08	0.9	–	–
Sub-total of back-end	2.57	30.0	0.97	12.5
Uranium credit	–0.54	–6.3	–	–
Plutonium credit	–0.28	–3.3	–	–
Sub-total of credits	–0.82	–9.6	–	–
Total costs	8.56	100	7.78	100

* For the low uranium price projection the uranium component would fall to 2.40 mills/kWh and for the high projection it would rise to 5.12 mills/kWh. Consequently, the credits for the reprocessing cycle would change to –0.61 and –1.20 mills/kWh, respectively.

enrichment technology. For the reprocessing cycle the charge for reprocessing is a significant factor. The 10 per cent difference between the costs of the two cycles (under 4 per cent of the total generating costs) arises from different back-end costs. Thus any uncertainty in the back-end cost will not have a significant impact on the cost of nuclear electricity generation. With this in mind, it is clear that the differences in cost between the once-through and the reprocessing cycle, while not insignificant in absolute terms, are sufficiently small as to indicate that national or company policy, and strategic and environmental considerations can influence fuel cycle choices without inflicting a substantial economic penalty.

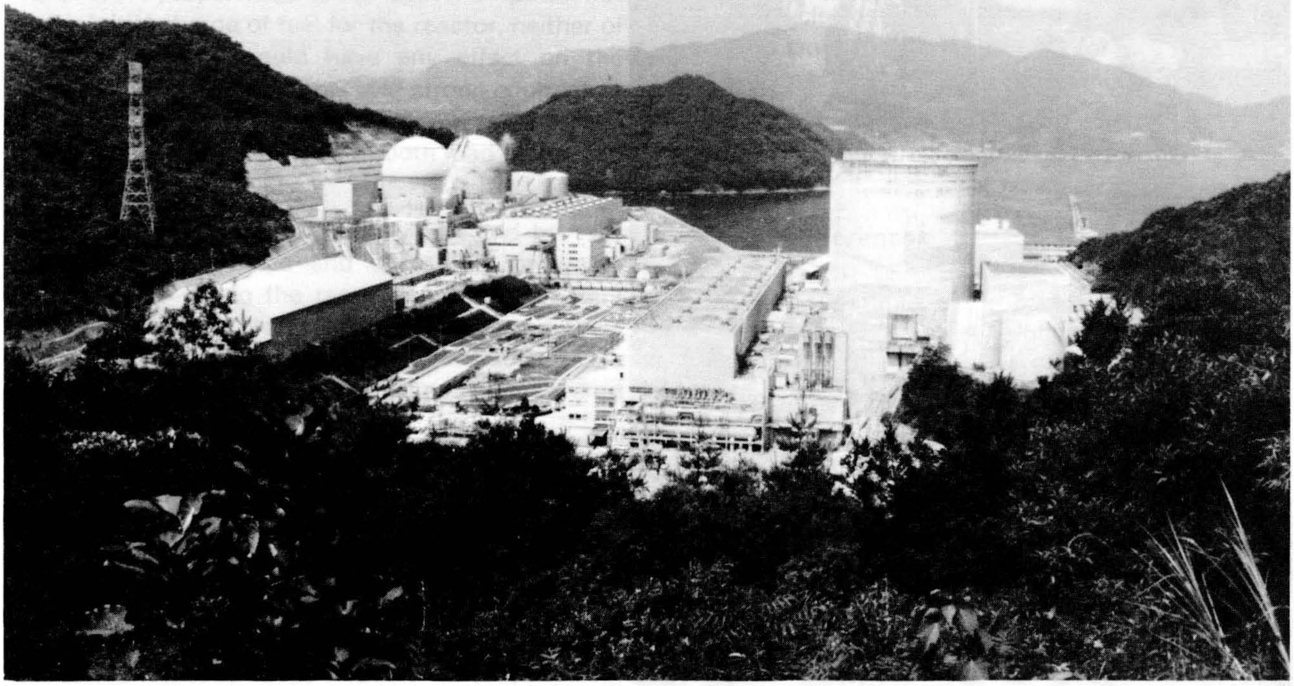
The potential economic value of a particular fuel cycle choice can only be established by analysing its impact on total electricity system generation costs, applying the economic ground rules, prices and energy supply scenarios appropriate to the specific situation or country.

The fuel cycle costs for a PWR commissioned in 1995 will lie within ±20 per cent for the central figures derived in the reference cycles. Approximately half of this variation is due to the adopted range of uranium prices and about half to other fuel cycle service cost uncertainties. This corresponds to approximately 2 and 4 per cent of overall generation costs in each case.

Increasing the discount rate results in an increase of the cost of the front end of the fuel cycle per unit of electricity produced and a decrease in the costs of the back end of the fuel cycle. These effects offset one another so that the overall cost of the nuclear fuel cycle is relatively insensitive to a discount rate in the range of 0 to 10 per cent, particularly for the reprocessing cycle. For the reference costs associated with the various stages adopted in this report the overall cost falls to a minimum, at a discount rate of approximately 3 per cent to 4 per cent per annum. At the extreme ends of the sensitivity range costs are some 5 per cent above the minimum for the reprocessing cycle and 8 per cent above for the once-through cycle.

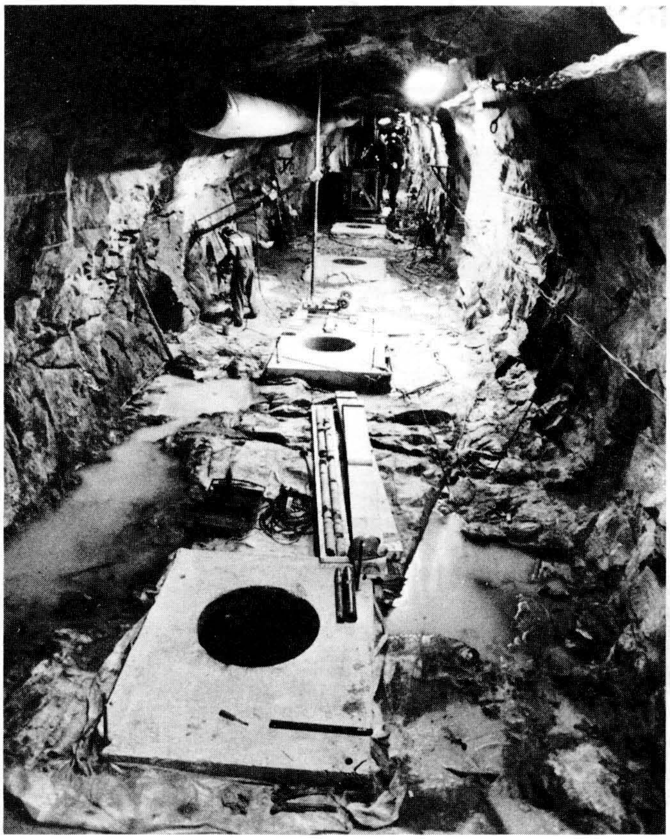
Calculations show that the levelised kWh fuel cycle costs for both the once-through and reprocessing

Some important steps in the nuclear fuel cycle:



The Takahama Nuclear Power Plant, Japan (Kansai)

The EURODIF Uranium Enrichment Plant, Tricastin, France (Eurodif).



Radioactive Waste Disposal
– R & D work carried out at the Stripa mine, Sweden, to test the suitability of granite as a host media for high level waste (Dahlin).

The Sellafield Works for the reprocessing of spent fuel, Cumbria, United Kingdom (BNFL).

cycles are not sensitive to the assumed reactor life and its load factor. This is not surprising since the quantity of fuel used, and the fuel cycle services required, are proportional to the reactor output. If not for the initial charge of fuel for the reactor, neither of these parameters would have any effect on the levelised fuel cycle cost. This is in strong contrast to their effect on the capital component of the levelised kWh cost, which is sensitive to both load factor and reactor life assumptions.

Fuel cycle costs are only slightly affected by tails assay, fabrication price and spent fuel or waste disposal price within the ranges of the parameters that seem likely to prevail. The reprocessing cycle cost is also relatively insensitive to the discount rate adopted and to the value attached to recovered plutonium and uranium.

Other Fuel Cycles

The fuel cycle costs for the Boiling Water Reactor (BWR) will be similar to those of the PWR. The mixed oxide-fuelled PWR will have costs similar to those of the uranium-fuelled once-through or reprocessing cycle PWR costs considered earlier, depending on whether mixed oxide fuel is reprocessed or not. This is due to the introduction of uranium and plutonium credits and prices which are linked to the value of the products of reprocessing when they are re-used in MOX fuel. It should be noted, however, that there is no true market for plutonium and the costs of the MOX-fuelled PWR cycle – unlike the reprocessing PWR cycle – are very sensitive to plutonium price assumptions.

Plutonium, whose costs of recovery have already been met by existing reactors, may be regarded as free fuel by the utility owning it. Its use would thus "reduce" the MOX fuel cycle costs to around 30 per cent below those for the reprocessing cycle and 35 per cent for the once-through cycle for reprocessing and once-through MOX-fuelled PWRs respectively.

A 100 per cent MOX-fuelled PWR is not, however, self-sufficient and can only operate over extended periods if run in parallel with plutonium producing reactors. Alternatively, a single PWR might run with self-generating plutonium providing up to 15 to 20 per cent of its reload fuel.

The fuel cycle costs for the CANDU reactor are based on Canadian data and the costs for the Advanced Thermal Reactor (ATR), which uses mixed oxide fuels, are based on Japanese data. These are also analysed in the report.

National Differences

Differing assumptions about future developments in main cost factors, energy policy considerations, regulatory procedures and taxation regimes will cause individual countries and utilities to have their own views on the unit prices for the various stages of the fuel cycle as well as their own plans for plutonium use in thermal or fast reactors. Consequently, the relative attractiveness of the policy options will vary.

For policy reasons, some countries may prefer to use indigenous resources rather than rely on the world market. In the case of services, e.g. waste disposal, there may not be any options, since services are not yet available on an international basis. The absolute and relative prices or costs appropriate to national calculations may thus differ from those adopted here, due to differences in factor costs, exchange rate anomalies, design philosophies, geographical circumstances and scale and timing of operations.

For a small country planning to store and package waste and to build its own disposal facilities, the back-end costs will be greater than for countries with an integrated large scale reprocessing and storage capability. The effect on overall fuel costs, however, would be small. Similarly, countries constructing small scale enrichment or reprocessing plants for the first time could incur costs above the reference levels. This type of variation is encompassed in the range of unit prices adopted by the study.

The difference between the once-through and reprocessing PWR fuel cycle is sufficiently small that factors related to general energy policy and strategic and environmental considerations will also weigh heavily in any national decision.

THE MANAGEMENT OF SPENT NUCLEAR FUEL

E. Detilleux

Although the volume of spent fuel produced is remarkably small considering the amount of electricity which it has served to generate, both governments and the nuclear industry must give careful consideration to policy and technological alternatives for the handling, processing, storage and disposal – i.e., the management – of this material. Beyond technical and economic issues, spent fuel management involves important commercial and political considerations which are specific to each country.

Spent fuel is composed of unburnt uranium and a small amount of plutonium, both of which have considerable energy (and therefore economic) value, the first as primarily fertile material and the latter as fissile material. A variety of radioactive fission products and transuranium elements are also present. These radioactive fission products emit a considerable quantity of heat as they decay (approx. 5 kW per tonne of uranium after one year and 1 kW per tonne after five years) and thus necessitate temporary cooling of the spent fuel.

Following this cooling stage, there are two distinct options for the further handling of spent fuel. It can be reprocessed through a series of mechanical and chemical operations to recover the potentially reusable uranium and plutonium and to separate the radioactive fission products and transuranium elements for disposal as waste. Alternatively, it can be conditioned and disposed of directly with no intention of recovering the fissile and fertile material it contains.

The Evolution Through Time

During the early days of nuclear power one of the main incentives to the nuclear community for pursuing the reprocessing path was the widely held view that, given the prospect of rapid expansion of nuclear energy usage, the recovered uranium and plutonium would be needed to fuel fast breeder reactors or other advanced reactor systems. Consequently, between the 1950s and the 1970s, a number of reprocessing plants – either on a pilot scale or of commercial size – were developed in France, the United Kingdom, the United States, Belgium (where the Eurochemic plant was set up under an international convention as an NEA joint undertaking), and subsequently, in the Federal Republic of Germany, Italy and Japan.

However, the slow-down in electricity demand in the late 1970s and the consequent drop in the growth rate of nuclear power sharply tempered interest in reprocessing. Predictably, the price of uranium began to fall. Under the Carter Administration, the United States indefinitely postponed the reprocessing option, citing primarily non-proliferation concerns. Owing to the complexity of the technology and the difficulties of legislative approval and public acceptance, many other countries similarly suspended plans for reprocessing their spent fuel, although they agreed that fuel recycling was an essential part of their long term energy strategies.

By the middle 1970s the building of reprocessing plants had not kept pace with the building of nuclear power plants, so spent fuel was put into storage as an interim solution. This made the option of disposing of the fuel intact an increasingly attractive alternative to reprocessing and the accompanying accumulation of high-level radioactive waste and emissions from reprocessing plants.

Today, the basic reprocessing technology has been commercially demonstrated and the costs are well known. France and the United Kingdom are extending their commercial reprocessing capacities, while the Federal Republic of Germany, Japan and Belgium plan to translate their small scale plant experience into larger commercial units.

A number of countries (Belgium, the Federal Republic of Germany, Italy, Japan, the Netherlands, Spain,

Dr. E. Detilleux is Director General of ONDRAF (Organisme national des déchets radioactifs et des matières fissiles), Belgium and the Chairman of the NEA Working Group on Spent Fuel Management. He was formerly Director of the Eurochemic Company.

Sweden, and Switzerland), have concluded contracts for some or all of their spent fuel to be reprocessed abroad while long-term storage facilities are constructed and R&D work is undertaken on definitive management options. These contracts provide for the return of separated uranium, plutonium and the resulting conditioned waste to the country of origin.

Interim Storage

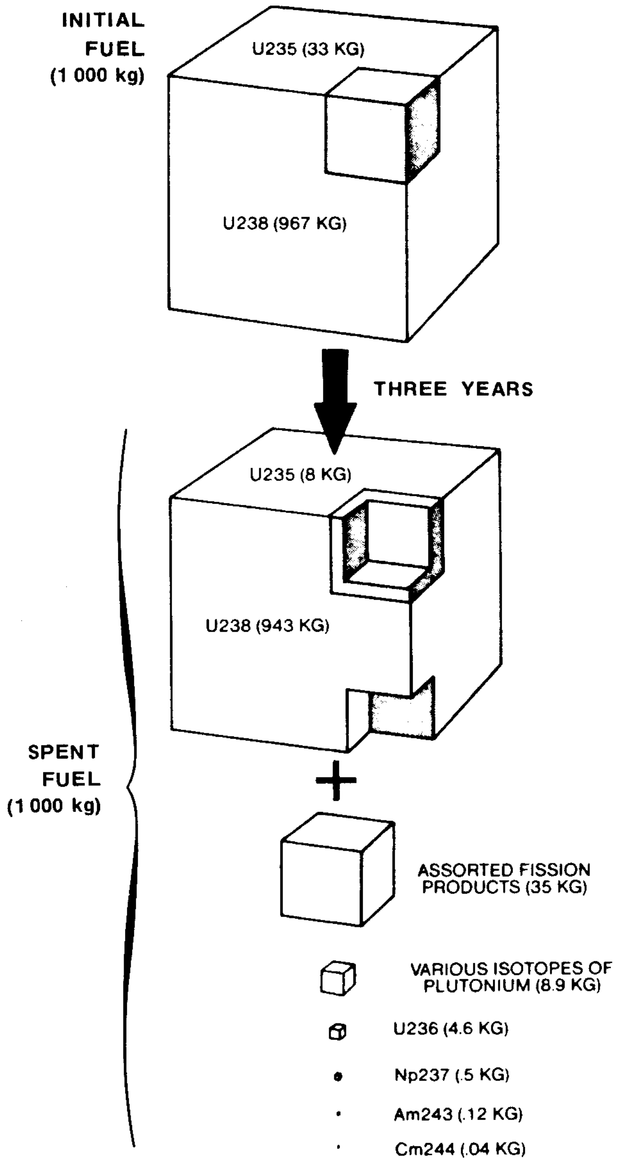
According to current projections for the growth rate of nuclear power (installed capacity), by the year 2000 nearly 160 000 tonnes of spent fuel will have accumulated in the OECD area.

Interim storage of spent fuel is defined as the period of storage between dispatch from the reactor site and reprocessing prior to disposal. In principle this storage could take place at the reactor site in the cooling pond attached to the reactor if it has sufficient capacity. Alternatively, the spent fuel could be stored at the reprocessing site. In the first instance, interim storage would be seen as a part of normal reactor operation. In the second case, it would be considered part of the reprocessing operation.

A number of different approaches have been developed for interim storage in which the fuel assemblies, either intact or processed to reduce the volume they take up, are stored in separate cooling ponds. Additionally, dry stores have been developed in which the fuel assemblies, with or without pre-treatment and special packaging, can be safely held and where cooling is accomplished using either air or inert gases.

Some countries propose to store spent fuel for extended periods prior to reprocessing or ultimately direct disposal. The criteria for a facility which has to accommodate fuel over a long period of time might differ from those for a facility designed for short term storage (e.g. different cooling arrangements). A wide range of alternative designs for this purpose now exists.

From a practical point of view, spent fuel storage can now be considered a proven technology. Moreover, there is no reason to doubt that fuel can continue to be stored under appropriate conditions for many decades. But the need for continuous scrutiny of these storage facilities precludes indefinite storage. Spent fuel storage thus cannot be considered a definitive management option and represents merely a holding position.



Change in the composition of nuclear fuel after three years in a light water reactor (Scientific American).

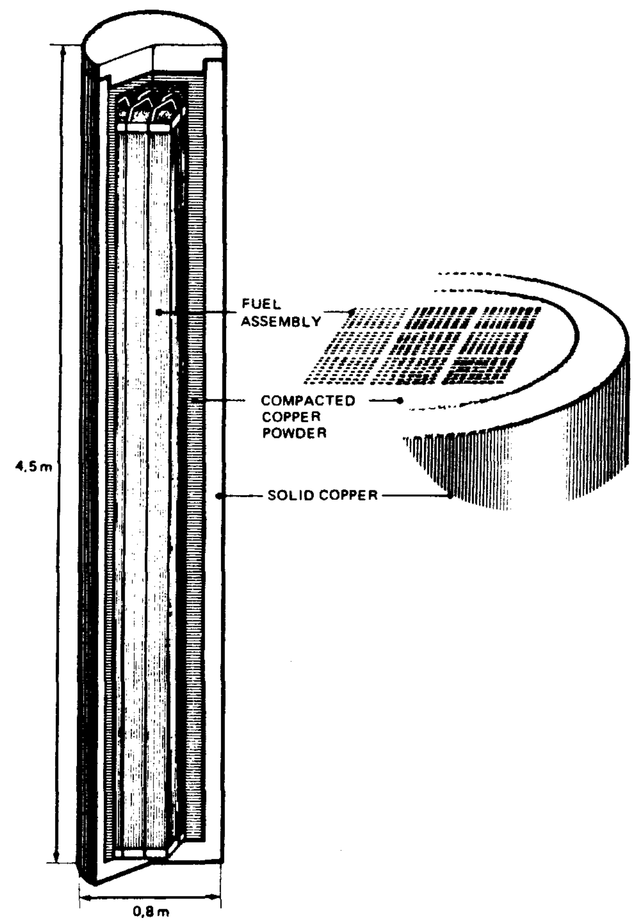
The Reprocessing Option

At the reprocessing plant, the spent fuel is dissolved in nitric acid and uranium, plutonium and fission products are then separated from the dissolved spent fuel by means of chemical extraction. That is, the solution of uranium, plutonium, other actinides and fission products is treated with solvents in a series of stages which are designed to produce solutions of plutonium nitrate and uranyl nitrate of a high chemical purity. The remainder (other actinides, fission products and unwanted impurities) is left as a highly radioactive solution, considered to be high-level radioactive waste.

The waste is stored in stainless steel tanks equipped with cooling systems which dissipate the heat generated by radioactive decay. The safety and feasibility of the storage of liquid high-level radioactive waste is well demonstrated. For longer term storage and disposal the preferred option is solidification of the waste into highly resistant glass blocks. There are several such solidification facilities now in operation or under commissioning or construction, notably in France, the United Kingdom, and Belgium. R&D work is continuing on a variety of other solidification processes.

Operations at the reprocessing plant are conducted remotely and with adequate shielding to protect the workforce from radiation exposure. The plant must be designed to restrict the emission of radioactive materials to the environment to the levels set by the regulatory authorities in the country concerned, and care has to be taken in the design of the plant to ensure that: *(a)* there is no risk of critical concentrations of fissile materials accumulating; *(b)* the risk of other damage or accident is negligible and *(c)* should either occur, the radioactivity will be contained.

Once the waste is solidified, the waste containers may then be secured and transported to disposal facilities. Most disposal schemes envisage a period of extended storage of up to 50 years, followed by deep burial in a selected geologic medium, called a repository. The disposal concept is founded on a system of multiple barriers designed to ensure that the toxic radionuclides present in the materials to be disposed remain isolated from man and his environment at least until they have decayed to levels which will not present unacceptable risks to future generations.



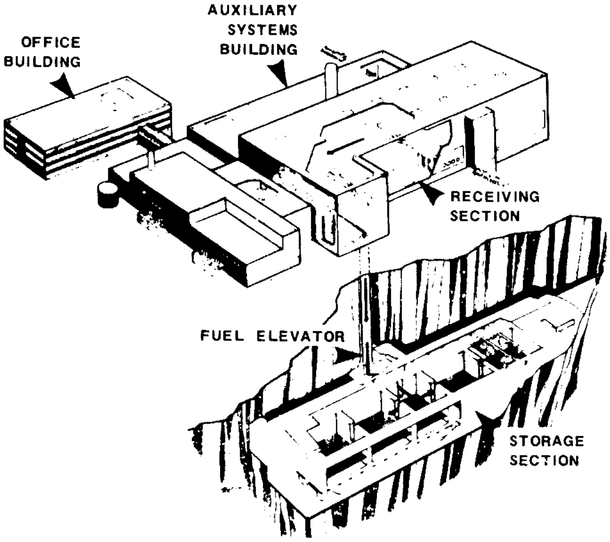
Design of a copper canister for packaging spent fuel (SKBF-KBS, Sweden)

At present there are no operational disposal facilities in OECD countries. While it is likely to be many years before a full scale repository is operating, based on extensive conceptual and pilot studies and "in-situ" tests, there is a high degree of confidence among experts that safe geological disposal systems for high-level waste can be designed and operated.

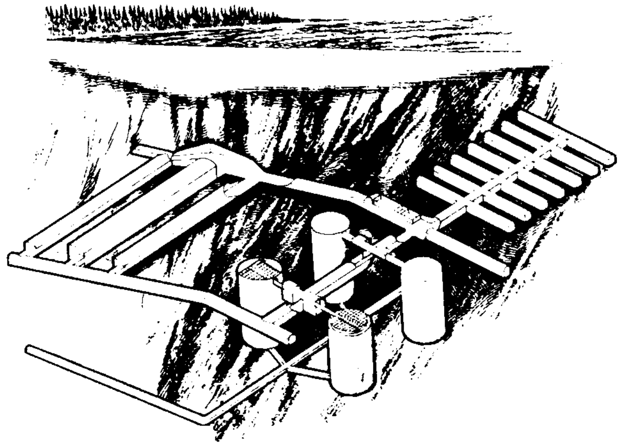
The Spent Fuel Disposal Option

After a period of cooling, the fuel assemblies may be encapsulated directly or they may be disassembled, using remote handling techniques so that the fuel pins can be packed together more closely prior to encapsulation. The problems of encapsulation are broadly similar to those for the high level waste emerging from a reprocessing plant, although the fuel itself provides an initial ceramic matrix to contain the radioactivity. The advantage of direct disposal of spent fuel is that it does not give rise to waste streams, as is the case with reprocessing. On the other hand the spent fuel contains all of the plutonium and uranium and has higher potential toxicity.

The encapsulated fuel in appropriate containers can be disposed of in a range of ways paralleling those for the vitrified high-level waste from reprocessing. The description of, and criteria for, a repository are similar to those mentioned above. Sweden has elaborated the most complete plan thus far, involving interim cooling of the spent fuel in underground water ponds and subsequent disposal of the containers in deep rock formations. There they will be embedded in a buffer material which will prevent them from coming into contact with any flowing ground water.



a) **Perspective drawing of an underground facility (CLAB) for interim storage of spent fuel using water pools (SKBF-KBS, Sweden)**



b) **An artist's impression of the planned underground disposal facility for Swedish reactor operating wastes (SKBF-KBS)**

Costing the Options

Nuclear fuel cycle costs account for approximately 30 per cent of total nuclear electricity generating costs and management of the spent fuel represents less than 10 per cent of this total. Idealized calculations conducted by NEA show that for the specific fuel cycle scenarios considered, there is only a marginal economic difference between the fuel cycle costs of the reprocessing and direct disposal options, although in absolute terms the margin can increase significantly (for further details, see "The Economics of the Nuclear Fuel Cycle" in this issue). Bearing in mind all of the variables, the reprocessing option has a slightly higher reference cost (8.6 mills/kWh) than the direct disposal option (7.8 mills/kWh).

In practice, it is the price of uranium (some 40 per cent of total nuclear fuel costs) that has the most influence on the relative economic merits of the two basic spent fuel management options. Future uranium prices will be affected by a wide range of factors influencing the fuel cycle costs. Not unexpectedly, low uranium prices tend to favour the direct disposal option, but the slight advantage would diminish with an upturn in the uranium market.

International Co-operation Prospects

The International Nuclear Fuel Cycle Evaluation (INFCE), conducted in 1977, established a basis for an international consensus on the non-proliferation aspects of various fuel cycles and associated spent fuel management options. Since then many international institutions - including the IAEA, the CEC, and the NEA - have been studying the various facets of the "back-end" of the nuclear fuel cycle, attempting to lay the foundation for active international co-operation in this field.

As far as spent fuel management is concerned, it is clear that it would be beneficial to pool the resources of several countries, not only from a technical and economic standpoint but also in relation to non-proliferation objectives. This is particularly true for smaller countries that opt to reprocess their spent fuel and wish to exert some influence over technical and economic decisions regarding reprocessing, spent fuel storage and the use of recovered materials. It is also conceivable that international co-operation could serve as a first step in the promotion of a rational joint use of waste repositories among countries sharing the same objectives and interests.

CURRENT ACTIVITIES OF THE NEA

A COLLECTIVE EXPERT OPINION ON RADIOACTIVE WASTE MANAGEMENT

In a report published in January 1985, the NEA Radioactive Waste Management Committee presents a technical appraisal of the current situation and its collective view on the main issues, particularly from the point of view of radioactive waste disposal and associated long term aspects.

The Summary and Conclusions of the report read as follows:

"Industrial activities are regarded as safe even though a small risk always exists. The philosophy of radiation protection accepts this and recognises that some level of risk will also be associated with safe radioactive waste management. Therefore the objective of radioactive waste management is to look for a strategy which, taken as a whole, is considered safe and provides an acceptable balance of all the radiological, technical, social, political and economic considerations. The RWMC's appraisal underlines the need for such a balance while concentrating on radiological and technical factors, particularly on the long term safety aspects of radioactive waste management.

The fundamental conclusion is that detailed short and long term safety assessments can now be made which give confidence that radiation protection objectives can be met with currently available technology for most waste types, and at a cost which is only a small fraction of the overall cost of nuclear-generated power. The other main conclusions on both the short and long term aspects of radioactive waste management are as follows:

On *the short term,* which covers the operational life of waste management facilities and any period of institutional control:

- Radiological protection objectives can be consistently met during the operation of a facility and for as long afterwards as controls are maintained for all currently used or envisaged radioactive waste management concepts.
- Storage can be relied upon for all waste types as an interim measure, as long as appropriate surveillance and monitoring is provided.
- While high priority is currently given to the full development and early demonstration of disposal concepts, there is no urgency to dispose of the small volumes of high level radioactive waste and spent fuel currently accumulated, as they can continue to be stored safely until disposal is judged appropriate.

On *the long term,* which covers the post-institutional control period:

- Specific long term radiation protection objectives for radioactive waste disposal have been developed to provide a basis for judging the radiological acceptability of disposal practices or developing specific criteria for individual waste types.
- Predictive risk assessment methodologies have been developed for the assessment of the long term safety of disposal systems.
- There is a high degree of confidence in the ability to design and operate disposal systems in deep geological structures which will assure long term isolation for high level waste or spent fuel and meet the relevant long term safety objectives.
- While the short term aspects of uranium mine and mill tailings can be safely managed, there remains some concern in the long term about human intrusion into tailings or their possible misuse, and long term requirements need to be established.

An overall impression of optimism and confidence prevails from the RWMC's appraisal. It results from the substantial body of scientific and technical evidence from past and ongoing studies and R-D activities as well as from the experience already available. At the same time, it is recognised that:

- R-D will have to continue, notably to fill remaining gaps for particular options, to collect site-specific data and to refine safety studies;
- periodic reassessments of waste management practices and policies will have to be made to take account of evolving knowledge; and
- quality control at all stages is an essential nuclear safety requirement and it will have to be applied throughout the whole sequence of waste management activities.

In this situation, the RWMC considers that a step by step approach to the application of waste management technologies as they become viable on an industrial scale, is both justifiable and safe."

HUMAN EXPOSURE TO RADON, THORON AND THEIR DECAY PRODUCTS

Radon and thoron are two ubiquitous natural radioactive rare gases emanating from most materials that contain traces of natural uranium and thorium, such as earth, rock, building materials, and fertilizers. The inhalation of radon and thoron, especially the inhalation of their radioactive decay products in particulate form, constitutes a primary source of internal radiation.

Approximately 10 years ago it was shown that prolonged exposure in mine atmospheres to high levels of short-lived decay products of radon and thoron could lead to an increased incidence of lung cancer in miners. Attention was thus initially focussed on the exposure of uranium miners. Over the last few years, however, understanding has gradually grown with regard to the role of radon, thoron and their decay products in the overall radiation detriment not only to uranium miners but also to workers in other types of mines and to the general population. The area of concern has thus been enlarged to include all miners and the sizeable groups of the population who live in high radiation areas or in dwellings built with materials containing higher than average natural radioactivity levels.

It is now widely recognised that the major contribution to the exposure of mankind to radiation sources of all origin – artificial and natural – comes from natural radiation. This accounts for approximately 80 % of total exposure. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) inhalation of radon, thoron and their decay products accounts for approximately half of the entire dose from natural radiation.

The following table shows a rough apportionment of the various radiation sources.

Natural radiation		Artificial radiation	
	%		%
Cosmic rays	15	Medical	20
Radon, etc.	40	Nuclear power	0.3
Other sources	25	Fallout	0.4
		Miscellaneous	0.5

The overall problem of exposure to radon, thoron and decay products is similar for workers and for members of the public. The criteria and systems for the protection of both of these groups are well established. However, their efficient application requires further improvements in the methods and techniques for the assessment of radiation doses and the monitoring of working and environmental conditions.

These considerations prompted NEA in 1979 to launch an integrated programme centred on the two major scientific and technical areas that required further development and international consensus, i.e. the dosimetry of radon, thoron and their decay products, and the metrology and monitoring of these nuclides in the workplace, the environment and individual dwellings.

In the past, dosimetric models have been developed to assess the dose to sensitive tissues in the lung after inhalation of radon and thoron decay products. However, estimates of the dose to the bronchi – generally considered the critical target for lung cancer introduction – are marked by a range of uncertainty or variability in both the aerosol characteristics and the biological parameters which influence the calculation of lung dose. Thus, Phase I of the NEA programme examined the data base needed to model the dose to the bronchial and pulmonary regions in the lung and reference mathematical models were established to cover this range of uncertainty. A report giving advanced guidance on this matter was published by the NEA in 1983.

Phase II examined the objectives of monitoring the exposure of individuals to radon and thoron and recommended a variety of techniques, procedures and methods depending on the circumstances. A detailed state-of-the-art review and guidelines for the selection and use of measurement techniques and monitoring methods will be published shortly.

In the course of this programme it became clear that in various countries the techniques and procedures for the calibration of instrumentation for measurement of radon and thoron were not always sufficiently well-developed. In addition, more homogeneous application was desirable and there was a need for intercalibration exercises within a broad framework, such as the one supplied by the OECD. An international intercalibration and intercomparison programme was launched in 1983, in close cooperation with the Commission of the European Communities Radiation Protection Research Programme, which had begun a similar exercise for the European Community area. The joint programme involves a large number of laboratories in Europe, the United States, Canada, Australia and Japan and together with the studies on radon dosimetry and monitoring, is expected to yield a significant contribution to the body of knowledge in this critical field of radiological protection.

A REVIEW OF THE INTERNATIONAL URANIUM RESOURCES EVALUATION PROJECT (IUREP)

The International Uranium Resources Evaluation Project, a programme to quantitatively assess existing and inferred uranium resources worldwide, was organised in 1976 as a joint undertaking of the NEA and the IAEA. As fossil fuel prices began to rise sharply in the early 1970s and nuclear power became an increasingly attractive alternative for large-scale electricity generation, there was concern about the capability of existing production centres to meet the anticipated increase in demand for uranium. It was therefore considered essential to not only quantitatively assess worldwide uranium resources (which has been done since 1965 on a biennial basis through the NEA/IAEA "Red Book" exercise), but also to assure that the uranium resource base was increased to a satisfactory level. This required more exploration and, in an effort to achieve greater success, an estimation of the potential for additional, as yet undiscovered, uranium resources – hence the IUREP scheme.

IUREP Phase I

The IUREP Phase I exercise sought to better define potential additional uranium resources that are exploitable at costs of less than 130 $/kg U (referred to as "Speculative Resources" in the NEA Red Book). This category encompasses uranium whose potential existence is determined primarily on the basis of indirect evidence and geological extrapolation techniques. In general, the location of potential deposits could only be identified as falling somewhere within a given region or geological trend.

For the purposes of the study ("World Uranium Geology and Resource Potential", published in 1980), data from 185 countries were collected and evaluated for a number of areas, including general geography (area, population, climate, infrastructure), laws pertinent to exploration, geology in relation to

SPECULATIVE RESOURCES LISTED BY CONTINENT

Continent	Number of countries	Speculative Resources (million tonnes U)
Africa	51	1.3 - 4.0
America, North	3	2.1 - 3.6
America, South and Central	41	0.7 - 1.9
Asia and Far East (without China and eastern USSR)	41	0.2 - 1.0
Australia and Oceania	18	2.0 - 3.0
Western Europe	22	0.3 - 1.3
Total*	176	6.6 -14.8
Eastern Europe, USSR, People's Republic of China (may include some known and inferred resources)	9	3.3 - 7.3

* A reappraisal of the Speculative Resources resulted in a revised Total of 6.6-16.2 million tonnes U.

These resources should by no means be equated with actually existing, discoverable and exploitable resources. They are, as the term implies, highly speculative.

uranium favourability, status of exploration, uranium occurences, deposits, mines, production and potential for new discoveries.

The study yielded an appraisal of the world's Speculative Resources. The data, regrouped by continent, are reproduced above.

In order to make the appraisal, the Speculative Resources were divided into seven existing uranium deposit types, according to the geological environment in which they can occur: in veins, in igneous rock (such as granites), in deposits close to major erosional very old (paleo-) surfaces now covered with younger sediments (unconformities), in very old conglomerates, in sandstones or close to today's surface. The seventh category serves as a basket for all of the remaining deposit types.

Using this breakdown of categories the theoretical resource potential of each country could be evaluated according to whether the country had all, some or none of these favourable geological environments. This allowed a favourability ranking for each country and the assignment of a broad tonnage range thought to potentially exist there. The tabulated data shown in the table are the result of the aggregation of these tonnages for entire continents.

After completion of Phase I of IUREP, in-depth studies were conducted in selected countries using resources (in cash and in kind) made available by the US, France, the Federal Republic of Germany, Japan, Italy, the Netherlands, CEC, NEA and IAEA. After consultation with the respective countries, missions usually consisting of two experts were sent to the following countries: Austria, Bolivia, Burundi, Cameroon, Columbia, Finland, Ghana, Madagascar, Morocco, Norway, Peru, Portugal, Rwanda, Somalia, Sudan, Thailand, Turkey, Uganda, Venezuela and Zambia.

The primary objectives of these in-depth studies, which were carried out during the IUREP Orientation Phase, were to review the present knowledge pertinent to the existence of uranium resources, review and evaluate the potential for the discovery of additional resources, identify areas favourable for such resources and suggest additional exploration efforts which might be carried out in promising areas. Over the course of these Missions, which were undertaken between 1979 and 1983, the experts had the opportunity to make field trips to evaluate both known uranium occurrences and the potential for unknown mineralisation in favourable geological environments on site. Discussions were held with local authorities and experts as well as with members of international organisations and exploration companies when present.

Among their findings the experts assigned high priority for Speculative Resources to the following geological environments because of the potential for uranium deposits of either high grades, high tonnages or both: faults and fractures (high grade vein deposits), sodium enrichment in host and country rocks (high tonnage) and unconformities (high grades and high tonnages).

Of the 20 countries visited, those with potential for large Speculative Resources are: Bolivia, Columbia, Morocco, Portugal, Somalia and Zambia, with an aggregate 140 000 to 830 000 tonnes of "speculative" uranium. The aggregate potential for Speculative Resources of all of the 20 countries, estimated by IUREP Phase I to be in the range of 60 000 to 550 000 tonnes uranium, is now estimated following completion of IUREP Phase II to be 230 000 to 1 350 000 tonnes uranium. This is comparable to the known resources of Australia or Canada. It should be kept in mind, however, that Speculative Resources are only a measure of the potential for as yet undiscovered resources and can by no means be equated with mineable resources.

The information gathered during the two IUREP Phases is perhaps of greatest value to the exploration industry, as it provides a company or organisation willing to do uranium exploration in a specific country with many of the data required for decision-making.

The reduction in demand for nuclear power plants and the development of new uranium deposits in some countries has altered the short and medium term need for further uranium developments. Indeed, at present, uranium is in an oversupply situation and this is expected to remain the case at least until the end of this decade. However, some growth in nuclear power continues and there inevitably will be a need in the future for new uranium developments. The key question is not *whether* uranium will be needed but *when*, and it is clear that the *when* will be measured in years not decades. IUREP will provide a solid basis for the exploration activities of the future.

INSPECTING REACTOR STEEL COMPONENTS FOR CRACKS AND OTHER DEFECTS: LATEST PROGRESS OF THE PISC-II TRIALS

In assuring light water reactor safety, it is vital to have confidence that no leaks or breaks will develop in the reactor pressure vessel and associated piping, which together constitute the primary coolant circuit. Initially small defects in these several centimetres thick steel components can grow under the stresses arising from repeated pressure and temperature changes, and the embrittlement of the metal caused by the radiation emanating from the reactor core. Ultrasonic testing is widely used for detecting, locating and sizing flaws in primary circuit elements at various stages of plant life.

A number of OECD countries joined an informal international collaborative project in the late seventies, organised in the Plate Inspection Steering Committee (the origins of PISC have already been described in some detail in NEA Newsletter Number 2). The project was a straightforward international test of an ultrasonic test procedure used in many countries. The results of the first PISC programme drew attention to the urgency of complementing this procedure and of bringing in newer techniques capable of locating all potentially significant flaws.

PISC-II – Progress to Date and Preliminary Results

A second PISC project was launched in 1980 in order to examine in more detail the performance obtainable with procedures now available. Four test blocks – two 25-centimeter thick steel plates containing butt welds and two with set-in nozzles – were provided by Member countries (Federal Republic of Germany, Italy, Japan, the United Kingdom and the Joint Research Centre of the Commission for the European Communities [JRC-CEC] at Ispra, Italy) for inspection in an international round-robin test. The plates, weighing up to 16 tonnes, had various defects implanted into the weldments. They were circulated to 50 inspection teams from 15 countries in Europe, Asia and North America.

A nozzle plate before and after destructive examination at the ISPRA laboratories (only the part of the plate containing the weld between the nozzle and flat base metal is shown below)

The JRC-CEC is co-sponsoring the project. Their Ispra Establishment is acting as Referee Laboratory for the round-robin trials and is responsible for performing destructive examination of the plates after completion of the inspections.

The inspection teams had no knowledge of the defect patterns and were encouraged to use the ultrasonic inspection techniques and procedures of their choice, as long as all the information was submitted to the Referee Laboratory along with the test results. The data were computerised for comparison with the actual flaw pattern that would be revealed when the plates were subsequently cut up. The data were also coded to preserve the anonymity of the test teams, the identities of which were known only to the Referee Laboratory.

The round-robin inspections were completed in September 1984, when all of the plates were returned to Ispra for destructive examination. This consisted of a series of repeated X-ray and ultrasonic inspections and cutting operations on each plate, so that it was possible to establish with certainty where the intended defects lay, and whether any additional unintended flaws had been introduced into the plates when they had been manufactured.

In parallel with the round-robin trials, a number of special research laboratory studies are being carried out in five Member countries. The purpose is to determine more quantitatively the effects on defect detection and sizing of a number of factors, including the presence of stainless steel cladding on the plates, the characteristics of the test equipment, and the precise nature of the defects themselves. The results of these studies are currently being combined with those from the round-robin trials to give further insights into inspection efficiency.

PISC-II – Steps to Complete the Programme

PISC-II is generating a wealth of data which calls for more evaluation than was originally foreseen in 1980. Several teams have produced parametrised information and it now appears that it may be possible to clearly identify the most efficient ultrasonic techniques. Evaluation of all the data, incorporating those from the parametric studies, will be completed by June 1986.

Under the terms of reference of PISC-II, the results of the programme are to be brought to the attention of regulatory and licensing authorities as a contribution to the development of improved codes of practice. Accordingly, the PISC-II programme will be brought to a close by a Symposium planned by the NEA and CEC for the nuclear safety community in mid-1986.

Future Studies – PISC-III

The first PISC programme was essentially aimed at establishing the capability of a specific procedure. PISC-II constitutes a more profound evaluation of the best performance obtainable by modern ultrasonic techniques under optimal conditions.

The NEA Committee on the Safety of Nuclear Installations recently decided that this evaluation should be taken an essential step further – providing validation of the capabilities of the various examination techniques when used in "real-world" conditions. This requires testing real defects in real components (possibly contaminated), and under real conditions of inspection (components under stress, restricted access, problems with decalibration, variable human efficiency, etc.). Considering the inherent limitations of ultrasonic inspection, tests should also be conducted, when feasible, with other techniques such as radiography and eddy currents, which may find application in particular instances.

Several mathematical models of ultrasonic examination have been devised in the last few years. The models have shown promising predictive ability; however, they have yet to be validated with a systematic series of measurements. More extensive parametric studies in a third PISC programme (with both artifical and real defects), as well as detailed examination of the PISC-II data bank, can be used to evaluate the significance to inspection reliability of equipment failure, calibration, automated versus manual techniques, and variability in human performance.

The Value of PISC

The PISC-II project is pointing the way to the best ultrasonic inspection procedures and establishing for the first time how results are affected by factors such as defect characteristics, equipment parameters and cladding.

The proposed PISC-III programme is intended to extend the evaluation of inspection techniques in order to establish how reliable they are in the industrial environment.

THE JOINT EVALUATED FILE PROJECT (JEF)

The engineering and physics design of reactors, their safety assessment, monitoring and fuel management are all carried out by computer through integrated systems. Over the last twenty-five years several hundreds of millions of dollars have been invested in the underlying research and development for the reliable computer programs and adequate nuclear data required for these calculations.

Evaluated data files cover a wide range of nuclides and materials and an energy scale whose end points differ by a ratio of 10^{12}. Reliable measurements are available for only parts of this range of materials and energy scale, so the gaps must be filled by reference to nuclear theory and by semi-empirical estimates based on the regularities in the behaviour of similar nuclides. When these evaluated data are tested in calculation for their ability to reproduce the experimentally measured behaviour of critical experiments and simple reactor systems, it is not surprising that discrepancies are found. In order to obtain better predictions of the behaviour of a full-scale nuclear plant, the data may then be *adjusted* to give a good fit to the observed behaviour of these simple experiments. Most of the recent evaluation projects seek to produce data which is accurate enough for general use without adjustment.

JEF: Why another evaluated file?

For reactor development work in Western Europe it is necessary to have a fully reliable file, tested as a whole, bringing together the best available evaluations, and taking into account recently measured cross-section data.

JEF (the Joint Evaluated File Project), in its JEF-2 version, is intended to provide a stable and satisfactory data base, without adjustment, for new calculations in reactor development and similar projects in NEA Data Bank Member countries.

A coordinated programme of evaluation, JEF was set up in 1982 within the framework of the Data Bank. The project is steered by the Scientific Coordinating Group which includes a nucleus of users (representing the reactor physics effort in participating countries) and a changing population of nuclear physicists from the laboratories which supply evaluated data, select data sets for JEF from existing material, and run benchmark calculations on the JEF files. The Data Bank has assembled, converted, completed and checked individual evaluations to make up the JEF-1 file.

The JEF-1 file covers more than 300 items, of which 200 are fission products. Most data are given for the separate isotopes, and in fact the neutron economy of a reactor in normal running is strongly sensitive only to a relatively small proportion of the materials for which data are stored. As is the case with its predecessors, JEF is an anthology of the best available data, with new or revised evaluations included where existing data are thought to be inadequate.

Formal validation and benchmark testing

Files included in JEF-1 have satisfied standard checking procedures and show good results in simple comparisons with other evaluations (e.g., plotting, integrals over fission and Maxwellian thermal spectra, resonance integrals). For fission products and secondary actinide isotopes, JEF-1 data are judged to be very satisfactory, although minor revisions are planned for a few fission products. Nevertheless, a common trend in the results shows the need for new or revised evaluations covering some important fissile nuclides and structural materials.

Once an evaluated file has achieved a reasonable level of accuracy overall, much of its value lies in the rigour of the benchmark testing to which it is submitted. No evaluated file can give a perfect representation of all cross-sections and it is essential to know where the inaccuracies lie. JEF-1 represents the best current knowledge of the nuclear data needed for power reactors, while the compilation and testing process of JEF-1 has pointed up the need for data improvements in important reactions of primary actinides and in the materials used in the structure of reactors.

Continued evaluation work and benchmark testing, together with extending the range of information carried in the file, will provide participants with a full programme for developing the file towards JEF-2.

THE NUCLEAR POWER SITUATION IN OECD COUNTRIES

as of 31 December 1984

Nearly all OECD countries that have nuclear programmes increased their nuclear electricity generation in 1984 by the largest rate since 1977, reaching 954 Tera Watt-hours (TWh). A more than 30 per cent increase was achieved by France, the Federal Republic of Germany, Spain and Sweden. Nuclear electricity production continued to grow steadily in OECD countries, with an accelerated annual rate of increase of 18.4 per cent, an increase of 6.8 per cent compared with the previous year. The share of total electricity generation provided by nuclear is now 18 per cent and exceeds the share of oil.

Country	Nuclear capacity (operable plants) (GWe)	Nuclear electricity generation (TWh)	Nuclear share of total electricity generated (%)
Belgium	3.5	26.4	50.8
Canada	9.5	46.6	11.2
Finland	2.3	17.8	41.1
France	33.2	181.8	58.7
F.R. Germany	16.1	87.9	23.6
Italy	1.3	6.9	3.8
Japan*	21.8	126.1	22.9
Netherlands	0.5	3.2	6.0
Spain	4.6	22.1	19.4
Sweden	7.3	48.6	40.5
Switzerland	2.9	14.9	31.8
United Kingdom*	6.5**	47.3	18.6
United States	71.1	325.2	13.5
OECD totals (rounded)	180	955	18

* Preliminary numbers

** Excludes plants (1.8 GWe) not commissioned

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A Symposium on Nuclear Third Party Liability and Insurance, organized by the NEA and the International Atomic Energy Agency in 1984, reviewed the fundamental principles of the nuclear third party liability regime and discussed the relationship of the insurance market with the international Conventions in this field. The concept of nuclear damage was examined, with particular attention given to long term radioactive waste management and decommissioning of nuclear facilities.

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Nuclear aerosol formation and release in reactor accidents receives considerable attention in safety assessments as this is one of the very few ways by which the public could be injured. Considerable progress in the understanding of nuclear aerosol phenomena has been made in recent years. This report updates the information contained in a previous publication on the same subject.

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Remote handling equipment, from a simple crane to modern robot, plays an important role in all the nuclear fuel cycle processes. These proceedings provide a review of the status of R&D in this field and application of this technology in these processes.

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For the NEA Committee on Radiation Protection and Public Health, Professor B. Lindell examines the various situations that may require an assessment of collective dose, the objective of such an assessment in the various cases, the related methodologies and the limits and difficulties of collective dose assessment in particular situations.

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