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Fuel Cycle Centres

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1) Introduction

It is one of the characteristics of the present status of peaceful nuclear power utilization in almost all countries that there is a striking difference in the maturity and capacity of reactor industry and fuel cycle industry.

Despite major setbacks in the optimistic nuclear power growth projections made under the impression of the oil crisis in 1973/4, especially in the last year and in full apprehension of enormous difficulties coming from politic, public opinion and environmental questions there is no doubt that an increasing number of countries will have to utilize nuclear power in order to satisfy their future enrgy demand.
It is generally accepted that the light water reactor (LWR) is industrially developed as far as manufacturing capacity, operational reliability and environmental safety are concerned so that the required number of LWR power plants can be built.

On the other hand operation of nuclear power plants indispensibly requires availability of respective fuel cycle services.

Whereas the front end of the nuclear fuel cycle can be regarded as being far enough advanced, that no major problems in the stage of industrial implementation are expected, the real weak point with respect to this is to be seen in the back end. Therefore, the following discussion is concentrating mainly on the back end fuel cycle activities i.e. interim storage of spent fuel, reprocessing and recycling, treatment, storage and disposal of radioactive wastes. It is necessary to come to a clearer understanding of this somewhat disturbing situation which could severely prohibit future exploitation in order to find ways and concepts to get out.

2) Development of fuel cycle activities in the last years

The back end of the fuel cycle, in contrast to the front part fresh Uranium fuel procurement, has suffered strongly from changing attitudes of governments, nuclear industry, utilities and - most important - the public.

To give an example, six years ago, a paper on the 4th Geneva Conference on the Peaceful Uses of Atomic Energy stressing the need for concentrating all efforts on closing the fuel cycle in order not to endanger prospects and growth of nuclear power would have met mild astonishment and raised eyebrows. Some crucial arguments which enlighten the development of this situation are summarized below.

- in the past utilities were only interested in reprocessing of spent fuel as a means to recover valuable fissile material, the re-use of which would allow the electricity generating cost to be reduced. The value of the recovered material had to be in excess of any prices to be paid for the takeover of spent fuel assemblies by a reprocessor;

- excessive economic arguments and strong competition at a very early stage have discouraged further development work and investments to meet future requirements;

- until recently reprocessing and recycling of Plutonium was the domain of Government sponsored institutions. Industries were considered to take over successfully developed processes with operating experience for many years;

- those engaged in reprocessing and recycling, both in the research and development field and in plant construction or operation, missed to point to the tremendous efforts still required for adapting the technology to new nuclear fuels (the oxide fuel with its high burn-up and consequently higher fission product/and plutonium contents) and for up-scaling facilities to economic sizes;

- besides, people realized in the meantime that reprocessing is not the final problem to be solved when producing nuclear energy. Reprocessing itself produces end-products, the treatment of which requires established procedures and regulations. Since then, solutions for reprocessing are tied intimately to solutions for the re-use of plutonium and the final treatment and storage of wastes;

- in parallel to all these mainly economic and technical reasons, discouraging industrial initiative, came along the very recent, sharp increase of public debate in many countries with major nuclear power programmes on risks and benefits of nuclear power, including specifically the questions of safeguarding Plutonium, Non-proliferation of nuclear weapons capability, terrorism and sabotage;

- this, in turn, added to the already existing indecision of governments to set up the necessary system of rules and regulations for activities in the back end of the fuel cycle.

This short explanation of a development that finds nuclear power programmes trapped in the bottleneck of non-existing industrial solutions for the management of spent fuel also indicates how to find a way out.

A viable concept for the back end of the fuel cycle, in order to be acceptable to all, governments, nuclear industry and the public, must assess and acceptably solve the following problems for industrial scale reprocessing, recycling, waste management:

- technology
- economics
- safety, safeguards and regulations
- non-proliferation of nuclear weapons capability
- interim solutions
- alternatives
- clear definition of respective rôles of governments and industries
- international acceptability, multination use

3) Fuel Cycle Centre Concept

Since especially throughout the last year the political issues of non-proliferation and diversion of Plutonium in reprocessing and recycling became prevailing over technical economic and even safety problems it is clear that industries expect government to take the lead in finding fuel cycle solutions.
Though this might imply a certain draw back of tendencies to commercialize and industrialize all fields of peaceful nuclear technology it must not necessarily lead to a withdrawal of industry from these activities. It only needs a clear definition of the respective roles of governments and industries and adjustment to the specific conditions under which the energy programmes are brought forward.

It seems that the concept of co-locating and integrating all relevant fuel cycle facilities on one property/selected site is the most attractive solution for countries with substantial nuclear electric generating capacity just embarking on the construction of industrial size fuel cycle-especially back end-facilities.
These centres could serve either political or economic, technical and environmental conditions. When specified to the back end operations a centre will contain an integrated system of

- spent fuel storage facility
- reprocessing plant
- Uranium product buffer storage
- Plutonium/Uranium mixed oxide (MOX) fuel fabrication facility (for LWR or FBR)

- Waste treatment and interim storage facilities
- terminal storage facility for conditioned waste products
- infrastructure

First observation to be made is a substantial reduction of the amount of radioactive material to be transported. The material flow between the dispersed installations in a nuclear power economy will only consist of

- spent fuel and low activity reactor waste going from the power stations to the fuel cycle centre
- fresh Uranium or MOX fuel going from the centre to the reactors
- eventually additional transports of Uranium product for conversion and enrichment

This is of superior importance either for safeguarding special nuclear material or for reducing safety risks from transportation accidents with breach of containment and release of radioactivity. Plutonium will not be transported in refined pure and easily accessible form, but either contained in spent fuel i.e. well protected or strongly diluted with Uranium in fresh MOX fuel.
More that 99 % of all the radioactivity generated through nuclear fission is only transported once, contained in spent fuel, from the reactor to the Centre, where it undergoes final conditioning and disposal.

Secondly safeguarding the nuclear material flow throughout the back end operations is facilitated, in particular if safeguardability was one of the pertinent criteria, e.g. in designing properly transition points between different processing areas, optimizing in line buffer capacities and applying instrumented material control at critical points.
Co-location alone offers the advantage of reducing handling steps. (Preparation for transport, loading, unloading) and providing for a much safer product leaving the centre.

Thirdly one centre will profit from the economy of scale and integrations. E.g. the overall common infrastructure is notably cheaper for each facility in the centre than for dispersed installations. This includes e.g. transportation connections, supply of process media, social services and environmental surveillance.

Fourth physical protection measures can be designed and applied uniformly for the different facilities.
Some specifically critical transportation acts will be avoided. The absolute protection effort for the centre can be increased considerably without bringing too much of a burder for the single process steps.

Fifth environmental protection measures will even be stricter for the individual facility inside the centre than for dispersed ones because radioactive release criteria are uniform and unchangeable at the fence regardless whether there are one or ten sources of radioactivity.

Sixth politically the centre concept turns out to be favourably in essentially two aspects

- being externally much more transparent than many small and dispersed facilites
- and internally by allowing to concentrate the inevitable public debate on one site (though this helps the intervenors, too)

Seventh the integration of facilities will help in case of operational incidents where adjacent process areas can easily and quickly continue on an interim basis material from the area concerned and can strengthen considerably the number of skilled personnel to cope with the incident.

Besides these more or less positive features of fuel cycle centres one should be aware of the fact that this concept imposes restrictions on the responsible industrial partners for the different process areas. E.g. because of the necessary integration there is a strong mutual capacity interdependance which forecloses essentially free competition of capacities and prices.
It must be recognized that some countries already have industrial size facilities in the fuel cycle business that voriginate mainly from military programmes and have been transformed, partially or totally to civil use.

They normally will have to continue with dispersed facilities, because site selection then did not follow explicitly fuel cycle centre requirements, though they might be interested to concentrate at least some essential operations, e.g. storage, reprocessing and MOX fabrication.

It is by no means impossible also, to combine front end and back end fuel cycle operations in one centre. This depends mainly on practical considerations like combined siting requirements, adjustment of capacities, harmonization of saftey and licensing requirements.

4) The Fuel Cycle Centre in the Federal Republic of Germany

With regard to the above mentioned lack of industrial decisions to provide sufficient back end fuel cycle capacity in the F.R.G., the government therefore, in the last years, has taken the lead in developping and promoting a concept that satisfied the above mentioned criteria and which, after long discussions, in the meantime has been generally accepted by industry. At present, it is in the process of materialization.

4.1 The concept

According to this concept:

1. Spent fuel interim storage, reprocessing of irradiated fuel, recycling of recovered fissile material, waste handling, treatment, storage and disposal have to be seen as an integrated system to be co-located at one site. This system will be appropriate to a nuclear power capacity of 4o - 5o GWe, and has to be in full operation at the end of the 8o'ies to allow for the growth of the German nuclear power programme.

2. Low and medium level radioactive waste has to be treated and disposed of at the reprocessing site without undue delay. This means, that the selection of a suitable site depends on its waste disposal potential.

3. High level waste (HLW) will be solidified and, if necessary, stored for an adjustable period in engineered storage facilities in retrievable form to allow for the time to develop, demonstrate and optimize a disposal system.

4. Disposal of LHW is anticipated to take place in stable geologicl formations, i.e. under the German gelogic conditions, especially in a large salt dome on site. This very promising concept still needs development and demonstration to make sure that any conceivable risk for the environment will be avoided.

Government and industry will each be responsible for certain parts of operations in the centre:

- Industry builds and operates spent fuel storages reprocessing and recycle facilities, waste conditioning plants and waste interim storage facilities.

- The government builds and operates disposal facilities according to its legal obligation (Atomic Energy Law). Besides, it takes care especially in its nuclear research centres, of major parts of the necessary research and development, including construction and operation of pilot facilities, in the whole area of the "back end of the fuel cycle".

- All costs arising from the construction and operation of the centre have to be born by the utilities which are delivering the spent fuel, following the principle "polluter pays". In turn they will pass it on to the consumer, the ultimate "polluter".

4.2 Site selection

The Federal Government's responsability for on-site disposal of radioactive waste arisings, consequently, charges the government with selecting and owning the site, leasing part of the land to the industrial facilities.

In the last years, extensive site selection studies in the whole F.R.G. territory have been made. Several sites on top of large and extremely old salt domes have been identified. Thorough site investigations, starting with bore hole drilling operations have been started to verify the waste disposal potential.

The site selection is still continuing. The state government of Lower Saxony and the Federal Government have agreed to make a preliminary selection of one or possibly two alternative sites with regard to the already existing data and to start the licensing procedure. Throughout the licensing process, before issuance of the first construction permit, the final qualification of the site has to be examined.
That means among others

- establishment of the suitability of the underlying salt dome by extensive deep drillings to locate large enough portions of rock salt
- long term observation of regional hydrology in order to exclude any risk for the drinking water supply
- long term observation of meteorology
- verification of minimum earthquake frequency and intensity
- complete data collection of agricultural infrastructure, population density, regional interdependance etc.

It is anticipated to conclude this site examination within the next 2 - 3 years.

4.3 Implementation

4.3.1 Reprocessing

The first step in realisation of the project will be the construction of large scale storage ponds, with a capacity of about 3.ooo tons of spent fuel at the first stage. The first module of these ponds has to be in operation about 1985.

Partly in parallel, construction of a reprocessing plant of 1.5oo tons annual capacity to serve a 5o GWe LWR economy will follow. The main problem to overcome is the financing of such a capital intensive investment.

After a period of studies during several years it became clear, that German chemical industry, initially starting the reprocessing business in Federal Republic of Germany and being shareholder of

Kernbrennstoffwiederaufarbeitungs GmbH, was not at all prepared to carry the burden of investing 2 - 3 billion DM in a system with completely different economic conditions as compared to typical chemical investments. In addition, the risk of delays during start-up and plant operation, furthermore possible breakdowns due to new technology are of a magnitude which surpass all conventional practices. Since the government had stated clearly that it was not prepared to invest in the plant, utilities had to be convinced that it was in their own vital interest to raise the necessary funds. The necessary motivation was mainly induced by two factors:

- no sufficient capacity outside Germany, available under favourable financial conditions on an assured long term basis,
- a federal guidance to licensing authorities to include provision for proper management of spent fuel in the licensing requirements for nuclear power stations.

This finally led to the creation of a utility company Deutsche Gesellschaft zur Wiederaufarbeitung von Kernbrennstoffen (DWK), financed by all German utilities operating or building nuclear power plants. DWK will finance the reprocessing plant.

At present, DWK has concluded a contract with KEWA for the preparation of a detailed project for the 1.5oo ton/a plant. The construction of the plant is expected to start with issuance of the first license, in about 2 - 3 years. DWK submitted its license application end of March and filed the safety report. At this stage the project is estimated to cost about 2.5 billion DM, without taking into account interest rates during construction and escalation.

Technology presents no principal uncertainty for the execution of the project. The Purex process, as demonstrated for LWR-fuel in our own pilot plant in Karlsruhe (WAK, 4o t, LWR fuel/a) and the EUROCHEMIC in Mol, together with the know-how created by our French and British partners in United Reprocessors, provides us with a sound technological basis. Besides, a large scale development program for components and, especially, the waste treatment and handling is under way.

In addition, a high amount of redundancy, built-in into the reprocessing plant will guarantee to have the ncessary capacity on stream, even in case of low availability factors of certain components during the first years of operation. If, after the first years of operation, everything runs smoothly, this redundancy means a relatively large capacity reserve.

As far as licensing requirements are concerned, the German plant will be required to follow a "near zero release" concept, including high degree retention of rare gases, iodine and tritium.

In general, it has to be protected against earthquake, plane crash and forceful attack from outside.

4.3.2 Plutonium Recycling

In connection with the operation of reprocessing plants, the extracted plutonium has to be taken care of. The German Fuel Cycle Concept aims at solving the problems of:

- protecting the environment
- using all fissile material to a maximum extent
- avoiding any diversion of nuclear material to other than peaceful purposes, and
- converting plutonium into other less dangerous materials.

The optimal solution to all these questions is the immediate recycle into nuclear power stations, primarily into light water reactors and later on into breeder reactors.

The feasibility of Pu-recycle has been successfully demonstrated in our demonstration plants at Obrigheim, Gundremmingen and Kahl during the last six years.

When the equilibrium is reached, U/Pu-recycle in thermal reactors i.e. LWR will substitute 3o % of the necessary feed material for nuclear power plants and up to 2o % of enriching services. At the same time it will guarantee optimum physical protection against diversion.

Therefore only a buffer storage capacity for plutonium is foreseen, sufficient to bridge the relatively short periods of time between extraction from the spent fuel elements and refabrication of fresh fuel.

The material will be recycled as MOX fuel into LWR as soon as it is available from reprocessing plants. Transports of plutonium in any refined form will be avoided completely.

4.3.3 Waste Management

Since the problem of safe handling, treatment and disposal of radioactive wastes has become one of the focal points in public discussions, sound and realistic answers will haveto be given to convince licencing authorities and to get the necessary public acceptance. This is one of the necessary prerequisites for the successful realization of the fuel cycle centre and the execution of the nuclear power program, respectively.

Low and medium level waste

During the past 2o years, systems have been developed to incorporate medium and low level waste, i.e. non heat generating waste, into bitumen or concrete. These processes have been used very seccessfully for presently generated wastes which then were transferred to the disposal site. The products have a sufficiently good stability and relatively good leaching resistance.

Since a few years, both in France and in Germany, promising experiments have been initiated to incorporate radioactive materials into organo-plastic substances. This process seems to be especially suitable for wastes coming from the primary loop cleaning systems of LWR's. The results of these investigations will show, whether this attractive and simple process can be used in large scale operations.

An other alternative to processes used so far, could be the vitrivication of low and medium level wastes in phosphate glasses. The result will be a very stable product with a high potential for process salt incorporation. Development work is under way in this area.

Presently, salt caverns in the ASSE salt mine are being excavated to house solidified low and medium level wastes in containers. The industrial disposal operations on site the nuclear fuel cycle centre will proceed with a conventional salt mine concept. Later on also advanced disposal techniques, presently under consideration, e.g. in-situ-solidification in caverns, could also be applied in the salt formation underlying the centre.

High level waste

In order to have the best conceivable solution for the storage, solidification and disposal of highly radioactive waste solutions, when the reprocessing plant in the centre is taken into operation, development of several alternate processes has been started many years ago. The general decision to be taken according to present knowledge is that vitrified waste products will be safe and reliable for disposal into rock salt.

The behaviour of rock salt under the influence of realistic temperatures, as compared to HLW disposal has been simulated in heating experiments. The promising results that have been obtained so far justify the concept of disposing HLW in the salt dome underlying the centre.

If there are better solutions for disposing of high level waste than salt, this is no real questioning of the centre concept. The relatively small amounts of HLW (about 1oo - 15o m^3 glass product, annually from the 15oo t/y reprocessing plant) could, if necessary, be transported to another site, but leaving co-location of the other "back end fuel cycle" activities justified.

4.4 Economics

Because of increasing prices for natural Uranium and enrichment services the value of fissile Plutonium and residual Uranium recovered by reprocessing and thermal recycling is increasing in parallel, thus leaving only a relatively small residual penalty for the whole back end fuel cycle operations. This penalty was evaluated for the German facilities in the range of 1-2 mills/kwh. This is by no means prohibitive for nuclear electricity generation. But, even if situation were not developping that favourably for these services, one strongly had to take into account their ecological advantages, amongst others especially the possibility of proper, safe and adequate Waste management which is only possible after separating the reusable fissile material.

It goes without saying that reprocessing and recycle are indispensible for fast breeder reactors.

5) <u>International Aspects</u>

With a view to present international discussions on non-proliferation large fuel cycle centres for multinational use seem to be especially attractive. The result of a thorough, very detailed analysis of merits and problems of such an approach have been presented by the IAEA.

Only some aspects with regard to multinational use of a fuel cycle centre should be mentioned:

- pushed by public debate, moste countries at present are not prepared to accept large amounts of spent fuel from other countries, on a e.g. 30 years contract basis;

- may be that an option of sending HLW products back, even though not logical from a technical and safety point of view, will help some countries in offering reprocessing services to others;

- a real change of public opinion can only be accomplished after successful demonstration of back and fuel cycle technology over extended periods of time;

- even after such demonstration a reanimation of free commercial competition in the field of back end fuel cycle services is doubtful. The common environmental safety aspect and the political issue of Plutonium will remain dominant for all countries.
