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THE USE OF PLUTONIUM

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INTRODUCTION

In all nuclear reactors currently in operation, the production of electricity entails formation of plutonium. Part of this plutonium undergoes nuclear fission and contributes to the production of power. In a pressurized water reactor of the type used in France, about one-third of the power output is the result of plutonium fission.

Even though nuclear power plant construction forecasts,i.e. plutonium production levels, were reduced in the free market countries , they remain high because more than 700 GWe are expected to be operating by 1990, rising to 2000 GWe in the year 2000 (a more modest figure of 1600 GWe will be used in this paper). These figures correspond to significant quantities of fissile plutonium, since the cumulative production of plutonium will thus reach at least 650 t in 1990 and 2000 t in the year 2000. For France the corresponding figures amount to more than 60 and 150 t respectively. The energy liberated by the fission of one ton of plutonium is equivalent to that produced by the combustion of 2 MTOE, so that 2000 tons represent the same energy potential as 4000 MTOE, i.e.5% of known world oil reserves. For France, the 60 t in 1990 could replace 120 MTOE.
(These equivalences are concerned with energy directly produced by plutonium fission, and do not account for the additional advantages of breeding or even efficient conversion and represent minimum values).

What use can be made of the plutonium thus formed in uranium loaded converters ?

IS THE INDEFINITE STORAGE OF IRRADIATED FUELS FEASIBLE ?

The final storage of irradiated fuels without prior reprocessing has been considered : doubts are ra sed nowadays.

For a period of several years, the residual power excludes the possibility of storing the fuel in a permanent storage facility. It will therefore have to be cooled, either in a storage pool, or in special containers subsequently assigned to permanent storage. Thse containers are to be designed. Hence storage pools will be needed : those of the reactors are obviously not large enough, thus we should build specific temporary storage facilities for which the safety problems are far from being solved (or even assessed). Then the fuel assemblies would be put into containers, which would be stored in conditions similar to those planned today for high activity wastes.

This scheme pratically calls for storage of burnt fuel in pools for several years, raising this several problems, which are not impossible to solve but which are not yet investigated. Fuel claddings are mainly designed to operate three years in a reactor and a few others in storage pools. There, fuel is subject to milder conditions but corrosion is still possible. But, to shift to permanent storage, it is convenient to deal with undamaged pins. In addition radio-active contamination of storage pools would raise problems (approach, handling, safety...) and instrumentation for clad failure detection would be difficult to designe and costly to implement.

The mixture of radionuclides and fissile materials makes the problems more difficult and increases residual power. Owing to the radioactivity and to the large amount of plutonium thus stored, the storage facilities must show considerable resistance to external aggression. In short, the safety problems set by potential interim storage facilities are not less formidable than those of reprocessing plants, and this leaves the problem of final storage unsolved (whereas the vitrification of fission products provides a satisfactory transitory solution).

From a philosophical point of view it should also be noted that fission products have a much shorter half-life than plutonium, and consequently true plutonium mines would be created for the future.

PLUTONIUM STORAGE

In our opinion, despite the continuing debate on economic aspects, reprocessing will prove necessary. In this case, a new alternative will become available : whether or not to use plutonium to feed nuclear reactors. To simply store the plutonium after taking the trouble to reprocess the irradiated fuel does not appear to be a very attractive policy. All the costs and problems of reprocessing have te be faced, together with those of storing plutonium. Some comfort is gained in terms of fission products, since the latter can be vitrified and then placed in indefinite storage according to already established procedures. On the other hand, it is necessary to define, plan and finance the procedures and operations designed to eliminate any risk of accidental spread and any possibility of plutonium theft. There will be still doubts as to the total effectiveness of these measures if the plutonium remains separate; to overcome this, it will perhaps be necessary.

as it has been suggested, to mix plutonium with radioactive material to discourage any approach and to dilute it in another material, such as depleted uranium, to make its military use impossible. This would almost amount to cancelling the effects of reprocessing, in other words, to partly undo what has been achieved after considerable trouble and expense.

USES OF PLUTONIUM

Logically one must therefore realize that if the fuel is reprocessed, this will be for the subsequent use of plutonium in nuclear reactors. When plutonium is recycled in a light water reactor, the energy drawn from uranium is only increased by about 50% ; with more efficient converters a better gain is achieved, perhaps by a factor of 2 or 3. On the other hand, the use of fast breeder reactors makes it possible to increase the energy output by a factor of roughly 100. The policy of recycling plutonium only in converters is not very wise from the point of view of worldwide resource management,especially since a plutonium industry will have to be created.

This shows how attractive are breeder reactors : France has thus decided to assign priority to these reactors for the use of plutonium and is practically getting ready to use plutonium in breeder reactors as soon as it becomes available. This strategy was not adopted by all countries. Thus we should wonder how to manage plutonium. Should it be temporarily stored awaiting to be loaded in fast breeders or should it be used for a while in thermal converters.

RECYCLING PLUTONIUM IN THERMAL CONVERTERS

This is technically feasible. From the neutron point of view, plutonium is distinguished from uranium 235 by a smaller fraction of delayed neutrons and a higher ratio of capture to fission cross sections. These two differences give rise to changes in the reactor control system, notably to a larger number of control rods (with correspondingly slightly higher investment). The fuel behavior raises no particulier problem but fabrication will evidently have to be carried out in special facilities, featuring higher investment and operating costs because of the need for shielding and the very small scale. Hence the fuel fabrication cost will be higher; this also applies to reprocessing. Technically, this is an intermediate case between the reprocessing of light water reactor fuels and that of fast reactor fuels, so that no special problems should arise. Nevertheless, the higher plutonium content will require at least some dilution, thus increasing costs.

RECYCLING STRATEGIES

Several strategies may be considered to recycle in thermal plutonium converters. Some reactors may be specialized and loaded entirely with plutonium fuel (mixture of natural uranium and plutonium); this strategy maximizes problems of reactor control and has been discarded. It appears preferable to make partial loads (30 to 40%) of plutonium fuel. Two ways are possible, depending on whether the fuel elements consist entirely of pins loaded with plutonium, or they contain a mixed load : uranium pins on the outside, plutonium pins inside. The latter strategy has the drawback of mixing, in the reprocessing stage, the fuel pins loaded with plutonium and those originally loaded with enriched uranium.

One could go a step farther and mix plutonium and enriched uranium within each pin.

If, as has been suggested, the uranium and plutonium are not separated at the end of the reprocessing stage, a U-Pu mixture becomes available, approximately equivalent to uranium enriched to 1.4%. By mixing this material with uranium enriched more than 3.25%, a suitable fuel can be obtained for use in the core. However, with 1 kg of U-Pu from reprocessing, (1 + a) kg of fuel are produced, so that an enrichment level will have to be selected, consistent with the demand growth rate, in other words, with the expansion of the nuclear power plant system (a p value of 10% corresponds to a growth rate of 4% per year). Such a process presents one drawkack : one will be obliged to handle with all the care required by the presence of plutonium, greater quantities of fuel, that means more risk and highercosts.

ECONOMIC AND PRATICAL CONSIDERATIONS

Costs will obviously have to be taken into consideration, but economic analyses are problematic (and debatable), because they involve extra costs and savings which are difficult to assess, and because they depend on the strategy selected. Only a few indicative values may be suggested. For instance, in the case of plutonium + natural uranium fuel pins, if the fabrication and reprocessing costs treble, plutonium must have a null value. On the other and, the absence of extra cost would lead to allocating a value of 70 to 80 F to plutonium (depending on the penalty for isotopic degradation). Hence the usual plutonium values are obtained for probable extra cost figures.

In the case of composite pins, the economic analysis requires the allocation of a price to reprocessed U-Pu, together with consideration of the gain achieved by eliminating U-Pu separation and of the extra cost due to the higher plutonium concentration.

In every case, it is necessary to follow the gradual evolution of the amounts of plutonium and its concentrations, and to set up fuel management schemes accordingly (concentrations and positions).

The perpetual recycling of plutonium in thermal reactors has been considered, but it is improbable that more than two recylings will be carried out, owing to the production of higher isotopes.

The different alternatives suggested thus represent provisionnal solutions which would allow countries that decide to delay the introduction of fast reactors to use their plutonium. However this delay should not last over years and would result in a slo   penetration of fast breeders. Furthermore, it will be necessary to make a detailed examination of the industrial repercussions of such a policy (special fabrication installations used for a relatively short period), together with their influence on costs.

BREEDER REACTORS : A GOOD SOLUTION

Use of plutonium in fast breeders received special attention because the effect of plutonium for the nuclear consumption of uranium 238 is somewhat similar to the action of a catalyst in a chemical reaction. Indeed the overall operational balance of a breeder reactor is the production of energy in exchange for the consumption of uranium 238. An additional benefit is derived as an excess of this pseudo-catalist is produced allowing a faster penetration of breeder reactors into the nuclear power plant system, together with the possibility of total substitution of breeder reactors for converters, even if power capacity goes increasing. For this, it is sufficient for the doubling time of the plutonium inventory to be less than the doubling time of the reactor plant system (in other words, the doubling time of electric power demand). In fact, since the breeding rate can be lowered at will, plutonium production can be reduced to the strict minimum, even in the case of cutbacks in nuclear plant installations, since a breeder reactor can always be converted into a plutonium consuming reactor.

The breeder reactor cycle includes only two operations : fabrication and reprocessing.

Fuel fabrication does not raise any special technical problems, but is mereley a matter of organization. Two factors must be considered : the optimum plant size, namely, the facility which minimises fabrication cost at full capacity; and the adequation of the plant size and the reactor program. At present the EDF plans the progressive commissioning of breeder reactors to reach an overall capacity of 8 GWe in 1990. This corresponds to annual supplies ranging from 100 to 150 t of fuel, only slightly less than the optimum capacity estimates of the fabrication plant (roughly 200 t).

Secondary reprocessing, namely, the reprocessing of fuels irradiated in fast reactors, is absolutely essential for the viability and economy of the system, and shows significant differences with the reprocessing of PWR reactor fuels.

Great plutonium content and high burn up create special problems of criticality and solvent degradation, leading to modifications in plant design in the following areas :

- plant head (cutting and dissolution),
- packaging of active wastes,
- processing and packaging of plutonium.

Reprocessing can be performed in plants designed to reprocess light water reactor fuels :

- by diluting the fuel with uranium or with fuels far poorer in fissile materials,
- by making change in the plant, enabling it to process either type of fuel.

These solutions will entail penalties in capacity and costs.

Present day technological expertise allows to plan the construction of a plant specifically designed to reprocess fast reactor fuels. This alternative is the most suitable, the economics depend on size, and here again a balance must be achieved between economy of scale and fit to demand. In 1990, about 100 t of fuel will be reprocessed, 200 to 300 t in the year 2000. This forecast corresponds to optimum plant economy. Obviously, a modular solution would be extremely interesting, and is presently investigated.

Thus two strategies may be envisaged : either the commissioning of an optimum size plant, say 200 t, or the commissioning of a 100 t plant followed five years later by another 100 t plant. Assuming a 10% penalty in operating cost, and by restricting the calculation to a period of 20 years, a simple calculation shows that an extra investment cost of 39% may be allowed for the smaller plant.

According to current assumptions fast reactors are rapidly becoming competitive with light water reactors. After commissioning of early plants, the extra investment will be limited to 30%, and will hence be offset by lower fuel cycle costs.

	PWR data January 1976	FBR estimate
investment	3.7	4.8 - 5.1
operation	1.5	1.5 - 1.6
fuel	2.2	0.8 - 0.9
TOTAL	7.4	7.3 - 7.6

CONCLUSION

In the present state of technology and research, it is difficult to accept the indefinite storage of irradiated fuels. Consequently reprocessing is mandatory, implying the availability of plutonium, that a sound reasoning and economic considerations assign to energy production in nuclear reactors. The best ones are fast breeder reactors, which make it possible to draw 50 to 100 times more energy from the same quantity of uranium. These reactors are technologically mature.

Breeder reactor models which will follow Super-Phénix will achieve a economic competition with light water reactors, and will even prove advantageous if uranium prices continue to rise. Recycling in pressurized water reactors is feasible, various strategies have been considered, but this merely represents an provisionnal solution, the economics of which is difficult to assess. Only countries wishing to delay the use of fast neutron reactors might resort to this solution, the drawback of which is a slower penetration of breeders.