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NEW SYSTEMS FORUM

THE FRENCH MOLTEN SALT REACTOR PROGRAMME

(Notes on a visit to Fontenay-aux-Roses, May 15th 1973)

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INTRODUCTION

Discussions are being held between interested parties concerning the possibility of setting up collaborative arrangements in Europe for the further development of a molten salt fuelled reactor. Although the prospects for such systems received a set-back when the American A.E.C. announced that the ORNL programme is to be stopped, this may well be counterbalanced by funding from the American Utilities. An enthusiastic report is being presented by an Ebasco Services Study Group (comprising Ebasco, five industrial companies and nine Utilities) to the Edison Electric Institute which may be very influential in determining the level of future support in the USA.

Meanwhile efforts are being made from within Euratom to establish a European Study Group and there is very active interest both at Wurenlingen, Switzerland, and in France.

The French interest was aroused at a special informal meeting at the 1971 Geneva Conference, and during 1972 one chemist (M. Faujeras) and one physicist (M. Lecocq) surveyed the work elsewhere in order to decide which type of molten salt system would best suit French conditions. They are now beginning a considerable expansion of their assessment studies (up to 12 pmy?) and have established a close collaboration with Pechiney-Ugine-Kuhlmann. The latter is the largest chemical company in France and consumes about 10 per cent of the EDF output. Industrial interest of this type adds a new dimension to the thinking about the prospects of molten salt systems and PUK show both enthusiasm and some advanced ideas concerning design.

Faujeras and Lecocq visited Harwell in December, 1972, and were told about the AEA study of the MSFR. On May 15th, we visited Fontenay-aux-Roses to learn more about the plans of both CEA and PUK.

STRUCTURE OF THE CEA PROGRAMME

The programme is being set up as a project, co-ordinated by Faujeras (Chemistry Division), which spreads through several Divisions at Fontenay. The principle staff involved are:

Materials and Nuclear Fuels Division (under M. Grison)

(a) Graphite Studies; M. Rappeneau (DT/SPCM)

(b) Structural Materials; Mme. Laniesse (DT/SRMA)

Chemistry Division (under M. Frejacques)

(c) Corrosion; M. Jarny (DCA/SECE)

(d) Tritium; M. Dollé (DRA/SAECNI)

(e) Chemistry; Mme. Brigaudeau (DRA/SEA)

Reactor Studies and Development Division (under M. Vendryes)

(g) Neutronics; (M. Luffin, not present)

(h) Components; M. Gollion

Economic studies are the responsibility of M. Bendell.

The morning of the visit was devoted to presentations by the French of variou aspects of their programme, and the afternoon to a two-hour open discussion and a brief tour of laboratories.

M. Lecocq emphasised that the starting-point of their programme was the ORNL/Ebasco molten fluoride, thorium-cycle, thermal system. This decision had been reached on the basis of the large amount of technology already available from the US, and not on an appraisal of the relative merits of, e.g. thermal fluoride, epithermal fluoride and fast chloride systems. The present "limited studies" at Fontenay were aimed at what the French identified as the more uncertain aspects of the ORNL/Ebasco design (TID-26156). These are primarily concerned with compatibility and component life in the core. No reprocessing work was at present envisaged, although CEA-Fontenay has experience in the development to the pilot-plant scale of chloride and/or fluoride volatility processes for fast and PW reactor fuels. It became clear that apart from a small amount of preliminary work on corrosion most of the effort to date has been spent in paper studies of economics and neutronics and in translating experience from other relevant fields (e.g. graphite, corrosion) into the likely conditions of a molten salt reactor.

TECHNICAL DETAILS

Graphite

M. Yvors spoke of the CEA/PUK wide experience of graphite problems gained ove many years in the development of gas-cooled reactors.

In MSR, the graphite moderator suffers irradiation swelling, which for present graphites implies replacement every 4 years at a power density of 70 kw.l⁻ ORNL are developing "POCO" graphites which are much improved; irradiations of test specimens will be completed in June 1973. PUK and CEA believe that ORNL did not pay sufficient attention to graphite problems and that with their experience they can achieve significant improvements in the graphite life. They commented that the swelling problem is less severe in MSR's than in advanced HTR's since, in contrast to HTRs, the graphite temperature is fairly modest, close to that of the coolant.

Metallurgy (Mme. Laniesse)

Alternatives to the Hastelloys as structural materials are being sought since Hastelloy costs contribute 15% to the capital cost of the ORNL design of reactor. They hope to demonstrate the suitability of stainless steels, which are not only cheaper than Hastelloy but will also allow direct translation from the CEA fast reactor programme of experience on irradiation behaviour and of component design and fabrication.

A programme is planned which involves 316 Stainless Steel and a 15 Ni/15 Cr steel (comparable in properties to a modified Hastelloy-N) in various metallurgic states to study:

mechanical properties,

corrosion by fuel salt (ORNL had good long-term experience with stainless steel in loops, but the details of salt chemistry were not rigorously measured). Effects of fission products (e.g. Te) will be included,

possibility of transport of carbon from moderator to steels via the salt.

ORNL had planned to investigate stainless steels if their programme had continued.

Corrosion (M. Jarny)

Techniques are being developed to provide a rapid screening test for mass transport in molten salts. An Ni tab is held in each limb of a U-tube containing LiCl/KCl eutectic with 5% $NiCl_2$ and the current flowing between the tabs in an external circuit is measured. With the limbs of the U-tube at different temperatures, mass transfer takes place:

at the high temperature electrode $Ni^{o} \longrightarrow Ni^{++}(d) + 2e$,

at the low temperature electrode $Ni^{++}(d) + 2e \longrightarrow Ni^{o}$

At 500-600°C, the current ($\sim$few ma cm^{-2}) is proportional to the temperature difference and the total charge passing correlates well with the amount of metal transported. With a stainless steel in LiCl/KCl + 2% $CrCl_2$ the current was very erratic, intergranular attack was observed at the hot specimen but no deposition occurred on the cold specimen.

M. Jarny agreed that the technique would probably not be applicable to fuel salt containing U^{3+} and U^{4+}, since corrosion would take place by local redox reactions ($Ni^{o} + 2U^{4+} \rightleftharpoons Ni^{2+} + 2U^{3+}$) and no current would pass through the external circuit.

Chemistry (Mme. Brigaudeau)

Equipment is being planned in which fuel salt ($LiF:BeF_2:ThF_4:UF_4$) will be prepared to meet the needs of the whole programme. The scale of requirements is not yet detailed.

For the determination of the U^{IV}/U^{III} ratio ORNL techniques will be used. Windowless spectrophotometry and voltametry are preferred to EMF techniques, since it is difficult to establish a reliable, absolute reference electrode.

Tritium (M. Dollé)

Tritium is produced from Li in the fuel salt in quantities in excess of the permitted release to the environment. Both containment and extraction of tritium is therefore required. Various possibilities are being considered but experiment work has not yet started. Control of tritium in the water circuits is not being considered, since results of studies for PWR's will be directly relevant. Consideration is being given to tritium control by:

retention in the fuel salt by reaction with dissolved nitrides,

extraction from the fuel as HF, if corrosion permits,

retention in the coolant circuit by forming impermeable oxide layers on the water-side of the boiler,

retention in the structure by incorporation of a H-getter (e.g. Zr) in the structural steels (not favoured by the metallurgists present).

Economics (M. Bendell)

French assessment of the relative costs of a 1000 MW(e) MSR and a PWR show that a 10% disadvantage on capital costs is more than offset by a 40% saving in fuel cycle costs giving a nett advantage to MSR of 5% in the unit cost of power sent out. However, these figures are capable of refinement: at present they are based on U.S. capital costs and French fuel cycle costs. No figures were quoted for an HTR and fast reactor costs were assumed to be the same as PWRs.

P.U.K.

M. Blum is the nuclear scientific adviser and the company employs M. Grenon as a consultant. The latter has close connections with ORNL.

Pechiney-Ugine-Kuhlmann has a turnover of $\$3.10^9$ per annum, employs some 100,000 staff (70,000 in France) and is involved in a wide range of metallurgical and chemical enterprises. The firm has close general interests in electricity production, and a particular interest in the MSR, since PUK is a major producer of graphite and fluorides and has considerable experience in such special material as refractory metals (including Mo fabrication) and the Hastelloys.

In a preliminary design study, PUK are exploring the possibility of a high temperature primary circuit, up to 1000° or even 1200°C, to improve efficiency (through a topping cycle) or to provide a source of process heat. Features of their current thoughts include:

(i) a high ΔT in the fuel (say, between 600°C and 1200°C) which gives efficient heat extraction and allows "conventional" molten salt pumps to be used in the cooler regions of the circuit.

(ii) A core and hot piping lined with graphite (incorporating layers of graphite felt for liquid tightness) so that the stainless steel container vessel would operate at $\sim$300°C, minimising corrosion, creep and loss of tritium.

(iii) A graphite heat exchanger, which is capable of approaching direct contac in its efficiency.

(iv) With a high efficiency heat exchanger, saving 1/3 on salt inventory, it is possible to consider an intermediate reactor in which the graphite moderator, with its attendant radiation damage problems, is eliminated and in which lithium is no longer a necessary salt component, so cheapening the salt and removing the tritium problem.

DISCUSSION

Role of MSR's

The French views, expressed as a result of our questioning, on the role of MSR's are:

(i) As a fuel, molten salts have characteristics very different from those of solid fuels, many of which can be turned to advantage. The problem is to define how best to exploit these potential advantages.

(ii) The U.S. estimate of fusion power by ~2010 AD was considered very optimistic. If one could indeed rely with certainty on this date, conventional fuels could cater for power requirements for at least 40 years. Since one cannot be certain, fission power is needed to bridge the gap and in this event breeding is essential.

(iii) More than one breeding system should be developed, as an insurance and to meet differing power requirements (heat and electricity).

(iv) Kasten's work at ORNL shows that in its breeding and fuel requirements an MSR meets the likely demands more closely than an LMFBR.

(v) Although total energy requirements are increasing, the proportion contributed by electricity may remain constant (M. Blum). Growth is also required in the provision of both low-grade (< 400°C) and high grade (~1000°C) process heat, where it is uneconomic to produce electricity as an intermediate. MSR's are potentially capable of providing both; LMFBR's cannot provide the high-grade heat and a fusion system, even if capable of producing the required temperatures, would be of too great an output for use as a heat source.

(vi) Experience gained in molten salt technology would be valuable in development of the thermonuclear breeder blanket. (Grimes, at ORNL, has been asked to investigate the corrosion and chemical properties of LiF up to 1200°C as a thermonuclear blanket).

(vii) In France, the environmental problems of Pu-fuelled reactors (e.g. LMFBR's) are severe and compound the economic and breeding difficulties of the LMFBR.

Prospects for MSR development

We agreed that with heavy commitment of resources to LMFBR programmes the most promising route to MSR development was by international collaboration. The French are keen to see individual agreements, outside Euratom, set up between parties with an active interest in MSR's. The extent of U.S. involvement will continue to be uncertain until the outcome of Ebasco's proposals for support from the Edison Electric Institute and the Utilities is known. If Ebasco are unsuccessful the French effort would suffer, but this could be off-set by a collaborative programme in Europe. M. Grenon pointed out that initiative in the US had passed from the AEC into industry, and believed that in Europe also industrial support should be sought.

In European collaboration, the French suggested that a UK/France agreement, based on our mutual active interest and comparable structures in the AEA/CEA, CEGB/EDF and industry, could form the nucleus of further agreements, involving for example Switzerland and Holland. The initial task would be to define and agree upon the most promising reactor type, followed by the construction of a ~250 MW(e) prototype reactor. It was suggested that under favourable circumstances the latter could start in two years. Mention was made of the deployment of over 20 staff in an Indian study of a molten salt plutonium burner.

General Impressions

(i) The French effort has not yet gone very far beyond the "paper study" stage, but they appear to be initiating assessment and experimental studies in 1973 of a size comparable to the Authority's 1971/2 deployment.

(ii) PUK, though Ms. Grenon and Blum are a strong driving force behind the French proposals.

(iii) A substantial French commitment will only be possible through international collaboration, with Ebasco (if their proposals are accepted), within Europe, or both.

(iv) CEA/PUK will be a stimulus to the MSR scene by bringing both new capabilities (in e.g., graphite) and new thinking (in, e.g. the high temperature MSR and their anxiety to replace Hastelloy by more conventional steels).

(v) Collaboration with the French, and possibly with Ebasco, could involve a considerable realignment of our thinking since they are polarised towards a fluoride thermal or intermediate breeder. A detailed examination of the role of such a system in the U.K. has not been made in recent years and should be undertaken.

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