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PU UTILIZATION IN FAST-BREEDER AND IN LIGHT-WATER REACTORS IN ITALY

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PLUTONIUM UTILIZATION IN FAST-BREEDER AND LIGHT-WATER REACTORS IN ITALY

Plutonium utilization for a better exploitation of natural resources is generally a very important aim, especially for Italy which lacks of endogenous resources.

Consequently Italy has pursued this aim utilizing parallely the two instruments of the most short-term commercialization of fast breeder reactors and Plutonium recycle in thermal reactors

ENTERPRISES ON FAST BREEDER REACTORS

As regards the first aim, ENEL has been one of the most active promotors together with Electricité de France and RWE of the enterprise which brought to the establishment of NERSA and ESK companies for the construction in Europe of two demonstrative ~ 1000 MWe fast breeder power plants.
The construction of the first one, a 1200 MWe power plant equipped with a Super Phenix reactor type, will take place at Creys-Malville in France and has substantially begun at the end of 1976 with the formal decision of NERSA.

The firm bid for the nuclear steam supply system is foreseen for March 1977.

The utilities decision as regards the construction of Creys Malville plant has constituted the reference framework of Italian nuclear strategy for the industrial development of fast breeder reactors.

This strategy pursues, on the one hand, a short-term commercialization of fast breeder reactors and, on the other hand, the adoption of the prototype Phenix reactor technology which will be later on developed, within the framework of agreements between CNEN, NIRA and manufacturing Italian industries and CEA and the most important French industries.

ITALIAN PARTICIPATION TO THE CREYS-MALVILLE PLANT CONSTRUCTION

Within the framework of the above-all mentioned agreements, NIRA - NOVATOME provide for design development, bid formulation and construction of Super Phenix nuclear steam supply system.

NIRA - NOVATOME operate as main contractor and industrial architect, selecting the various systems and components by means of tenders and choosing among the various offerers according to the lower cost criterion under the same technical qualification.

NIRA role is that of Italian industry file-leader.

In accordance with specific agreements with manufacturing industries NIRA sells and plans, taking upon itself all the functional responsibilities, while manufacturing industries co--operate to the executive plans and carryes out the components.

As regards the most important components for the system operation some cooperation agreements have been defined with the most qualified French industries. These agreements provide for a full knowledge exchange among the interested partners.

The design of the core and of its elements is CEA responsibility within a mixed CEA - NIRA group set up at "Centre d'Etudes Nucléaires de Cadarache".

Supplies distribution of nuclear steam supply system components assignes NIRA and joined Italian industries the 34% of the business.

Italian intervention is particularly important for the nuclear boiler, the intermediate heat exchangers and in-reactor fuel handling supplies.

ITALIAN ENGAGEMENT AS TO SUPER PHENIX FAST BREEDER LINE

CNEN, ENEL and NIRA are tending their efforts towards Super Phenix fast breeder reactor industrialization.

It is necessary to work for the optimisation of system and its main components in order to achieve a Super Phenix power station rating more than 1500 MWe which will be able to compete economically with the thermal nuclear power plants.

As to this aim NIRA, NOVATOME and CEA are defining the formalities of their further cooperation in the field of LMFBR development.

Further-more, CNEN and NIRA are going to form a consortium for the coordination of all the activities wich will be carried out by Italy.

The three main activities are :

- Support tests to the Creys-Malville power station construction.
- Super Phenix line development.
- Construction of the PEC fuel element testing reactor.

As to the first one, we point out :

- Shaft and rotating primary pumps test, under different working conditions in CP-1 loop realized at Brasimone.
- Trials of Sodium-water interaction on a steam generator prototype utilizing I SA-1 loop.

As to the second one, the main activities concern :

- The technology and development of Sodium components and particularly of steam generators.
- Fuel development
- Safety evaluations.
- Core development.
- Technical and economic evaluations.
- Codes and standards activities.
- Physics reactor studies.

CNEN employs an important set of experimental facilities in this activity.

One can mention among these FNA1 and FNA2 Sodium loops at Casaccia for trials on fuel pins and bundles in deformed and nominal configurations and ESPRESSO and CEDI Sodium loops at Brasimone, which are able to perform some "indurance" and thermal shock tests on complete fuel bundles.

Also the new OPEC - 2 hot cells facility and the Plutonium Laboratory can be mentioned.

At present CNEN and CEA are supporting an agreement between French and Italian industries on steam generators for fast breeder reactors.

Within this framework, Italian developing activity will lead in 1978 to check a 45 MWth straight tubes steam generator prototype in "Les Renardiers" testing facility.

CNEN, NIRA, CEA and CIRNA have re-evaluated the original design of the PEC fuel elements testing reactor, whose construction was committed to NIRA in order to adopt largely the French

technology and to simplify the design consistently with experimental performances defined by CEA and CNEN.
At present the civil works in the container building are carrying on.
Further-more the first detailed plans have been submitted to the Control Authority and also the orders have been remitted for the main components of the reactor boiler.

At CNEN some technological tests in support to the construction of the reactor and of the experimental channel are carrying on.

In the near future CPC-1 facility at BRASIMONE and CPC-2 and IPM at CASACCIA will be utilized for Sodium tests of PEC components.

FUEL MANUFACTURE FOR FAST BREEDER REACTORS

In 1974 AGIP NUCLEARE had signed a cooperation agreement with CEA in order to achieve the necessary knowlegde for the realization in Italy of a plant for the production of mixed Uranium and Plutonium oxides fuel for Super Phenix fast breeder reactors

So, while NIRA was starting with CEA in the field of the core and fuel design, AGIP NUCLEARE was starting with the same CEA the conceptual design of the production plant.

In summer 1976 the preliminary design of the plant was completed.

Afterwards an Italian and French team has collaborated to the development of process flowsheet and equipments.

We can consider this second phase accomplished and look at future developments with reasonable optimism.

AGIP NUCLEARE aim is to begin its fuel production in 1982 and to secure the possibility of supplying a third of the fuel needs for Creys-Malville power station as well as for PEC research reactor and the future fuel needs for the fast breeder reactor development in Italy.

The present incertitude about the estimate of future market development have induced AGIP NUCLEARE to design a plant wich derives from the French concept but wich is different as to the initial capacity and layout philosophy. The initial capacity is of about 7 T/A of mixed oxides with the possibility of attaining a final capacity of 21 T/A of mixed oxides, with two subsequent increases, each one of 7 T/A.

The incertitude about Plutonium characteristics which will have to be worked have induced to foresee the production line fully authomised. For particular production a manual manufacture production-line which has a limited capacity has been foreseen.

The plant has been conceived as a self-consistent unit equipped with all those nuclear services which are necessary for Plutonium handling i.e : purification facility for chemical Plutonium recovery, Plutonium reprocessing by separation of Americium, solid waste disposal system.

PLUTONIUM RECYCLE IN LIGHT WATER REACTORS

As is known, since 1968 ENEL has loaded sixteen prototype Plutonium assemblies into the Garigliano reactor, which permitted a host of data to be acquired on the bahaviour of this type of fuel. In 1975 a whole reload batch of forty-six Plutonium island assemblies was loaded again in the Garigliano reactor and in 1976 eight all-Plutonium assemblies were loaded into the Trino Vercellese reactor. Depleted uranium (with a 0.5-0.6 % U-235 enrichment) was used for the Plutonium fuel assemblies of both reactors.

The Plutonium fuel assembly of the Garigliano reactor was designed for a reactivity lifetime similar to that of the enriched uranium assembly. Since it was a Plutonium-island assembly, special care was taken in the choice of the four enrichments in order to reduce the power density of the central rods that are liable to develop a highest clad temperature rise in the event of a LOCA (loss-of-coolant accident).

The insertion into the core of the forty-six Plutonium - island assemblies required the performance of a new safety evaluation for the Garigliano nuclear power station. The procedure entailed the revision of the plant licensing bases in order to define which events were still bounded by the original analysis and which had to be re-analyzed. To this purpose, the parameters that significantly affect the evolution of the transients and accidents were evaluated and a check was made to ascertain whether their values fell within the range provided for the original safety analysis.

It was observed that some values exceeded the boundary ones, such as the scram reactivity function versus time, mainly owing the improvements in the calculation models since the issuance of the original analysis.

This particular aspect, especially due to the backfitting requirements, entailed the revision of a certain number of transients and accidents that demonstrated the compliance of the reload batch with the safety limits.

The same analysis was performed for eight Plutonium assemblies loaded into the Trino Vercellese reactor. Also in this case, the availability of more updated methods that were conformant with the latest safety criteria led to the re-evaluation of a few events, including the classes of steam line breack accidents.

An analysis with highly sophisticated methods was made of steam line break accidents since they represent a limiting condition for Plutonium recycle in PWRs. It was ascertained that the reactor may house ut to one third of a core of Plutonium fuel assemblies without exceeding the limits provided for this type of accidents

The fresh Plutonium assemblies did not entail more trouble in handling at Garigliano site than fresh uranium assemblies. The intensity of the total dose in contact with the fresh fuel assembly, that had already been measured at the FN factory, proved lower than the highest expected dose of 10 mrem/h.

The presence of plutonium required special procedures in the event of an assumed accidental break (fall or corrosion) of the fuel rods. All the lifting facilities and equipment used in fuel handling were subjected to accurate non - destructive tests (with dye penetrants, ultrasonics and gamma radiography).

As regards the mechanical behaviour of the assemblies, the off-gas trend during the present cycle is indicative of the excellent behaviour of all the assemblies in the core.

Also the operation of the reactor, whose core is loaded by one fourth with Plutonium assemblies, did not show any substantial difference attributable to Plutonium, except for the presence of gadolinia that was used in the Garigliano reactor for the first time and led to the modification of the control rods inserted as a function of burnup.

The radial power distribution underwent no significant modification in respect to the previous cycle and the cycle lenghts was as expected.

An extensive post-irradiation program is being implemented on the Garigliano mixed-oxide fuel assemblies. The following table summarizes the program, which includes fourteen PuO_2 and five UO_2 rods irradiated at different burn-up levels from 7,000 to 25,000 MWd/t. At present, phase PPU 1-2 is completed, while PPU 3 is in progress. Both programs have been performed in the hot cells at Risø (Denmark) under a contract between CNEN-ENEL and DAEC. Results are given only for the five rods of the PPU

1-2. As regards the comparison between $(U-Pu)O_2$ and UO_2 rods related to the general behaviour, il has been noticed that (1) the only difference between the uranium rod and the mixed-oxide rods is in the fuel structure; this seemed not to have influenced the general behaviour of the rods; (2) the rods behaved well during irradiation, also one $(U-Pu)O_2$ rod with localized hydride attacks showed no immediate risk of failure. It was concluded that the $(U-Pu)O_2$ rods, with the above-mentioned few exceprions, behaved just as well as the UO_2 rod. Details of the rods, the cladding and the fuel behaviour are given below.

a) Rods

- The thickness of the rather spongy crud la er varied from 0 to 26 m.
  The crud consisted mainly of a Fe with small amounts of Cr and Ni.
- The diameter of the rods varied from 15.05 to 15.14 mm, wich falls within the specified fabrication limits (14.87-15.24 mm). No marks of ridging or of fretting corrosion were observed at the spacer locations.
- The rod lenght increased by 0.15% in SA-58 and 0.23% in SA-56.
- The getter material present in the $(U-Pu)O_2$ rods acted well as a getter and picked up from about 100 to 300 ppm of hydrogen, which was much more than the hydrogen content in the cladding (10 ppm).
- By piercing the rods, the pressure was found to be above 2 ata (SA-58) and above 4 ata (SA-56) in the $(U-Pu)O_2$ rods, and 1.26 ata in the UO_2 rod. The pressure and gas composition proved that the rods were leaktight upon completion of the irradiation.

b) Cladding

- The oxide layers were up to 19.4 m thick on the outer surface and up to 6 m thick on the inner surface.
- Localized hydrogen attacks were found in the cladding of one $(U-Pu)O_2$ rod of SA-56 in the form of cavities with a maximum diameter of 4.5 mm and a maximum depth of 0.3 mm.

The electron microprobe analysis carried out in this region showed that the cavities contained carbon, chlorine and traces of oxygen. No fission products were detected in the cavities; coesium was found in localized parches at the surface where it was associated with the oxide film. The cavities were presumably due to localized cladding hydriding.

- Apart from the localized hydrogen attacks mentioned above, the content of hydrides in the cladding of all the five rods of PPU 1-2 was low and evenly distribuited with random orientation.

c) Fuel pellets

- The Plutonium was found to be distributed in the pellets very homogeneously.
- Local grain growth was observed around the Plutonium particles, but there was no evidence of "bridge formation",which could result in a hot spot in the cladding.
- The metallic inclusions detected in the pellets by the electron microprobe analysis consisted mainly of Mo, Tc, Ru, Rh and Pd. In one $(U\text{-}Pu)O_2$ rod, Sn was also found.
- The maximum fuel temperature was estimated to be on the order of $1600^{o}C$.
- The pellet stacks shortened by at least 11-19 mm, but this value could not be determined exactly because the fuel was generally rather loose and moved easily when the rods were handled.

The activities carried out at CNEN aimed at the verification, in operating conditions, of the know-how acquired during the past years in the framework of the CNEN Plutonium Program for the design and fabrication of Plutonium fuel assemblies. To this purpose, the following prototype fuel assemblies were fabricated at CNEN's Plutonium plant to a CNEN design, and have been operating in the following reactors :

a) The plutonium-island (4x4 rods) assembly operating in BWR conditions in the Agesta reactor (Sweden). At the final shutdown of the plant in summer 1974 this assembly had reached an average burnup of 16,200 MWd/t, with a peak value of 28,400 MWd/t, with a peack value of 28,400 MWd/t.

b) Two all-Plutonium assemblies (each consisting of 6x6 rods) operaiting in the Kahl BWR plant (Federal Republic of Germany) The first (P-22) has now reached an average burnup of 6,000 MWd/t. In the second (P-41), which has reached an average burnup of 3,500 MWd/t, Gd_2O_3 has been used as a burnable poison in two rods: one an enriched UO_2 rod and the other a $(U-Pu)O_2$ rod.

c) A Plutonium fuel assembly (IFA-170) operating in the Halden reactor has now reached an average burnup of 22,500 MWd/t.

To support the design and performance evaluation activities additional experiments were carried out at CNEN to caracterize the behaviour of Plutonium fuel assemblies from the thermohydraulic and mechanical standpoints, as well as from the neutronic viewpoint which is peculiar of plutonium fuel.

With regard to the latter aspect, a particular effort was recently devoted to the oprimization of the calculation methods for Gd treatment also in plutonium assemblies. The development of such methods in bases on ad-hoc experimental data, among which one could mention first the reactivity values and power distributions measured in the RITMO and ROSPO critical facilities at the Casaccia Nuclear Center in both Uranium and Plutonium fuels, as well as criticality and power distributions measured in the Grosswelzheim critical facility for the P-41 assembly at beginning of life.

Irradiation experiments are under way in the high - flux SILOE reactor (CEA, Grenoble) on fuel rods containing either 1% or 2% Gd_2O_3 in either enriched - Uranium - oxide or mixed-oxide matrices, totalling four types of rods. For each rod type, irradiations are performed up to three different levels to check the Gd evolution at different stages. The results obtained so far are in good agreement with the calculated data.

Although the reprocessing crisis has postponed the times for subs ıtial Plutonium recycle in LWRs, it is deemed advisable to continue the evaluation of the performance of the Plutonium fuel already loaded in the reactors and to explore the potential far higher Plutonium loadings with minor plant modifications in order to acquire sufficient knowledge for a better exploitation of this back-up fissile material.

In the light of the foregoing, Italy has an active participation in the research program of Plutonium recycle in LWRs, launched by the European Community. Whthin this framework ENEL and CNEN were entrusted with a study to broaden the knowledge of fuel behaviour in BWRs and PWRs during transients and accidents up to the attainment of the conditions at equilibrium of the Plutonium recycle.

TABLE PIE PROGRAM ON GARIGLIANO BWR PLUTONIUM RECYCLE

Phase and Schedule	Assembly Type	Rod Type	Enrichment	Manufacturer	Assembly Burnup
PPU 1-2 1975-76	"Plutonium-Island" (assembly SA-58 and SA-56)	$(U-Pu)O_2$ $(U-PuO)_2$ $(U-PuO)_2$ $(U-Pu)O_2$ UO_2	2.0 2.0 2.0 3.2 2.4	GE GE GE GE KRT	2 Cycles 15;000 MWd/t
PPU 3 1976-77	"Plutonium-Island" (assembly SA-58)	$(U-Pu)O_2$ $(U-Pu)O_2$ UO_2	2.0 2.0 2.4	GE GE KRT	3 Cycles 21,000 MWd/t
	"All-Plutonium" (assembly SA-63)	$(U-Pu)O_2$ $(U-Pu)O_2$	3.1 0.82	BNFL BNFL	
PPU 4 1977-78	"Plutonium-Island" (assembly SA-58 and SA-57)	UO_2 $(U-Pu)O_2$ $(U-Pu)O_2$	1.83 2.0 3.2	KRT GE GE	4 Cycles 25,000 MWd/t
PPU 5 1977-78	"All-Plutonium"	$(U-Pu)O_2$ $(U-Pu)O_2$	1.55 3.1	BNFL BNFL	4 Cycles 25,000 MWd/t
PPU 6 1977-78	"Reload Plutonium Island"	$(U-Pu)O_2$ $(U-Pu)O_2$ UO_2 UO_2	6.0 3.35 1.44 2.3 (+2%Gd_2O_3)	BN BN FN GE	1 Cycle 7,000 MWd/t