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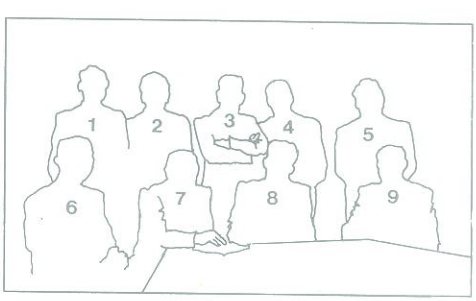
# THE PHEBUS-CSD PROJECT AND THE PHEBUS-SPAIN CONSORTIUM

**THE CONSORTIUM'S STEERING COMMITTEE (*)**

The peaceful uses of nuclear energy, and in particular the production of electricity by means of fission reactors, has passed through several stages since December 2, 1942, the day on which Enrico Fermi within the Manhattan Project succeeded for the first time in setting off a fission reaction in a self-sustaining, controlled chain with the Chicago Pile (internationally known as CP-1) in the University of Chicago. On that occasion, the moderator was a pile of graphite blocks with cylindrical perforations housing natural uranium rods - the fuel. Its power was only 0.5 watts, and thus cooling was achieved by natural convection of the surrounding air.




*In the photograph*
*1) Emilio DE MATIAS*
*2) Antonio ACHA*
*3) José PUGA*
*4) José F. SERRANO*
*5) Félix CALVO*
*6) Luis REBOLLO*
*7) Rafael CARO*
*8) Ricardo SALVE*
*9) Eduardo R. MAYQUEZ*

After a host of tests in all the industrialized countries along many years, and for a variety of reasons aside from the scientific-technical ones, it was finally concluded that light water moderated and coole systems with slightly enriched uranium oxide as the fuel were the best for this first phase of intensive exploitation of nuclear fission power. The nuclear industry expanded rapidly in the decade of the '60's, and at least in Europe light water systems were increasingly used at the cost of national prototype models.

Since the first criticality of the CP-1, special attention had been paid to nuclear safety, establishing the principle of Defense in Depth with the implementation of successive barriers to prevent an uncontrolled radioactive leak outside the containment building in the improbable event of a severe accident. The Design Base Accidents, which were ideal situations conceived as the most severe that could possibly occur in the nuclear plant, provided the initial and boundary conditions for the defense and safeguard system that had to be provided in the plant for its Defense in Depth. All this required a tremendous research and development effort. From the beginning, two possible kinds of possible accidents were identified: those associated with rapid energy releases caused by an unsuitable reactivity value, and thermohydraulic accidents associated with deterioration and the more or less partial fusion of the fuel due to a lack of cooling. In both cases, core deterioration occurs, in the former due to mechanical reasons and in the latter to thermal reasons. In the history of nuclear safety as a discipline, two accidents are cited as archetypal examples: Chernobyl in the Soviet Union, and TMI-2 in the United States. In the early years of nuclear technology, the most novel accident was undoubtedly the reactivity accident, as it could cause a release of energy through a process that is qualitatively analogous to a nuclear explosion. The experiments performed in the BORAX and SPERT installations in the United States and CABRI in France

served to analyze in detail the phenomenology associated with this latter type of process, confirm existing theoretical models, and validate the calculational codes developed for them. The Chernobyl accident, which fell within this category, did not prove to be different from what was learned with those experiments, nor did it bring anything new to light.
However, although in the decade of the 70's knowledge of the phenomenology of thermohydraulic type accidents was considered to be sufficient, there was a gradual realization that the Design Base Accident as a unique safety philosophy should not be the only and undeniable reference point. The Reactor Safety Study (WASH-100) published by Rasmussen in the United States, and the Risikostudie by Birkhoffer in Germany, clearly demonstrated this fact. Finally, as definitive, undesirable evidence of this thesis, the Harrisburg accident on March 28, 1979, inequivocally proved the necessity of including "beyond design base" accidents as reference, i.e. those that had always been classified as class 9.
When core damage is caused by an imbalance between the energy generated and the energy released, regardless of whether the reactor is operating or not, the rise in temperature that takes place can theoretically cause the following series of events:

1. Oxidation of fuel rod cladding and of other steel core elements, with the resulting generation of hydrogen.
2. Chemical and physicochemical interactions between core materials and liquefaction of part of them.
3. Relocation of the liquefied materials at the bottom of the core or at the bottom of the vessel, possibly causing the latter to fail in parallel.
4. Enegy transfer towards the primary system (in a PWR).

Obviously, it is fundamental to have a detailed knowledge of this phenomenology, in the first place to manage the pertinent mitigation procedures during the accident, and also because these

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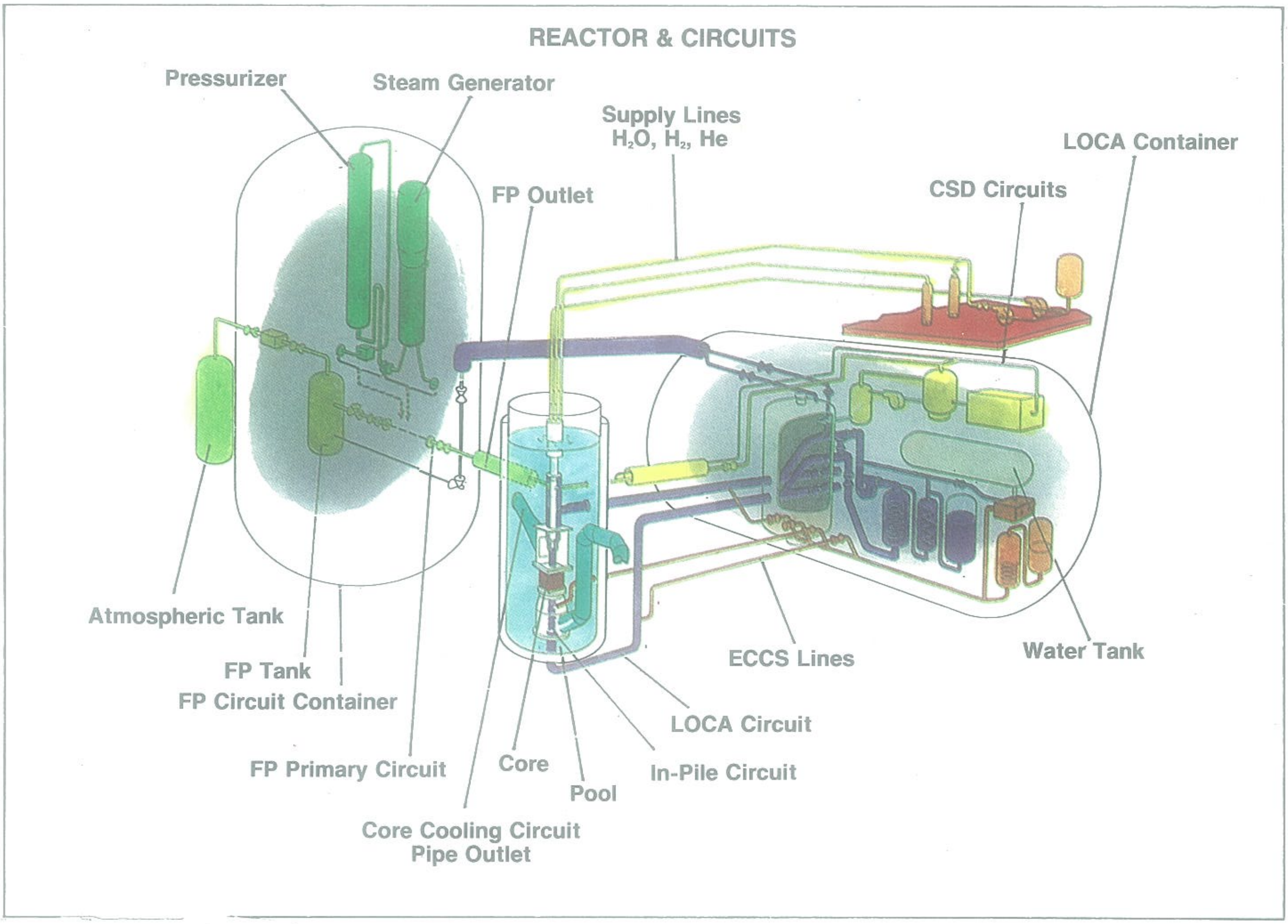
**NATIONAL CONSORTIA FOR PARTICIPATION IN INTERNATIONAL PROJECTS (*)**

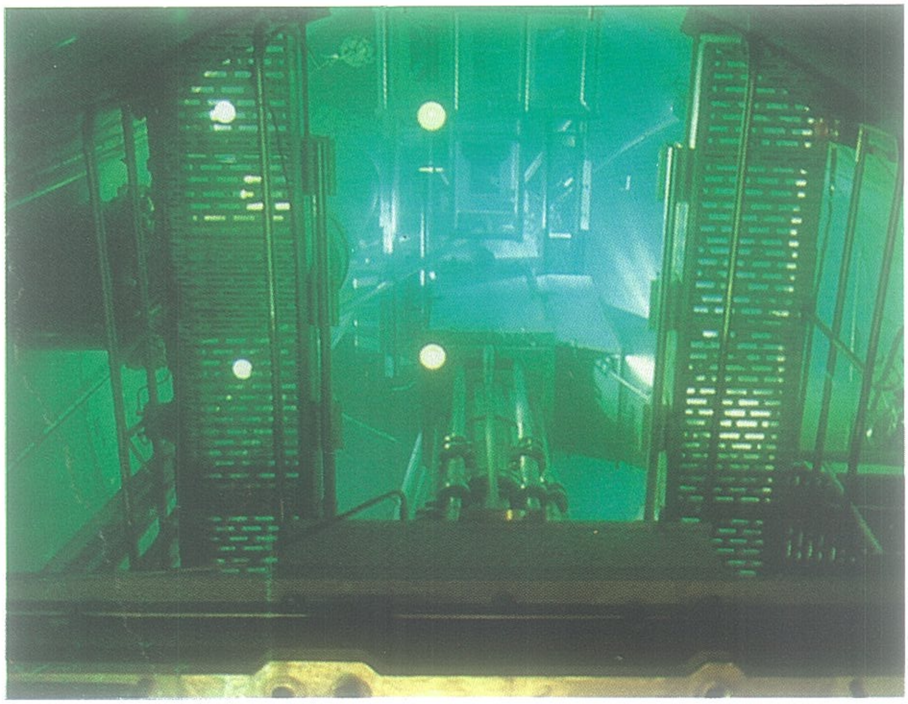
| Project | Participants |
|---|---|
| OECD/LOFT | CIEMAT, CSN, ENRESA, ENUSA, UPM. |
| PHEBUS CSD | CIEMAT, CSN, ENRESA, ENUSA, UNESA. |
| EPRI/LACE | CIEMAT, CSN, ENUSA, TECNATOM, UNESA, UPM. |
| EXP. ESPAÑOL | CIEMAT, CSN, ENUSA, TECNATOM, UNESA, UPM. |
| OECD/TMI-2 GA | CSN, UNESA, UPM. |
| OECD/TMI-2 VEP | CSN, CIAT, ENSA, TECNATOM, UNESA. |

(*) The institutions are listed in alphabetical order (Taken from Ref. 1).

F I *Phebus Installation.*

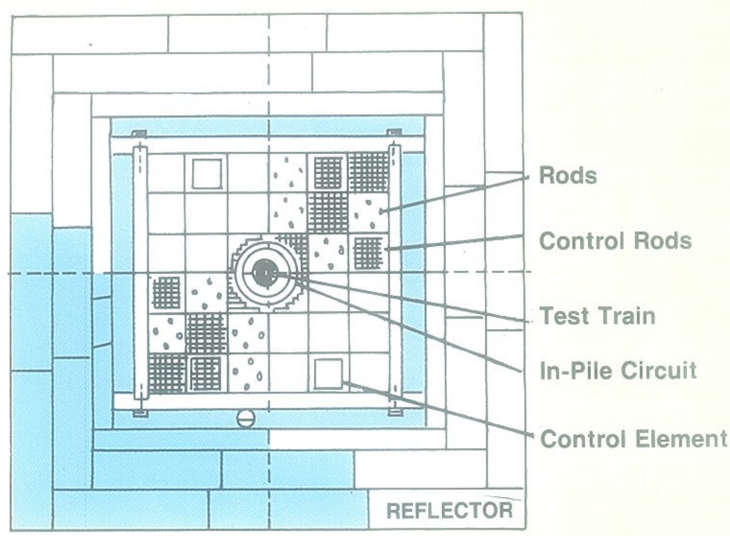


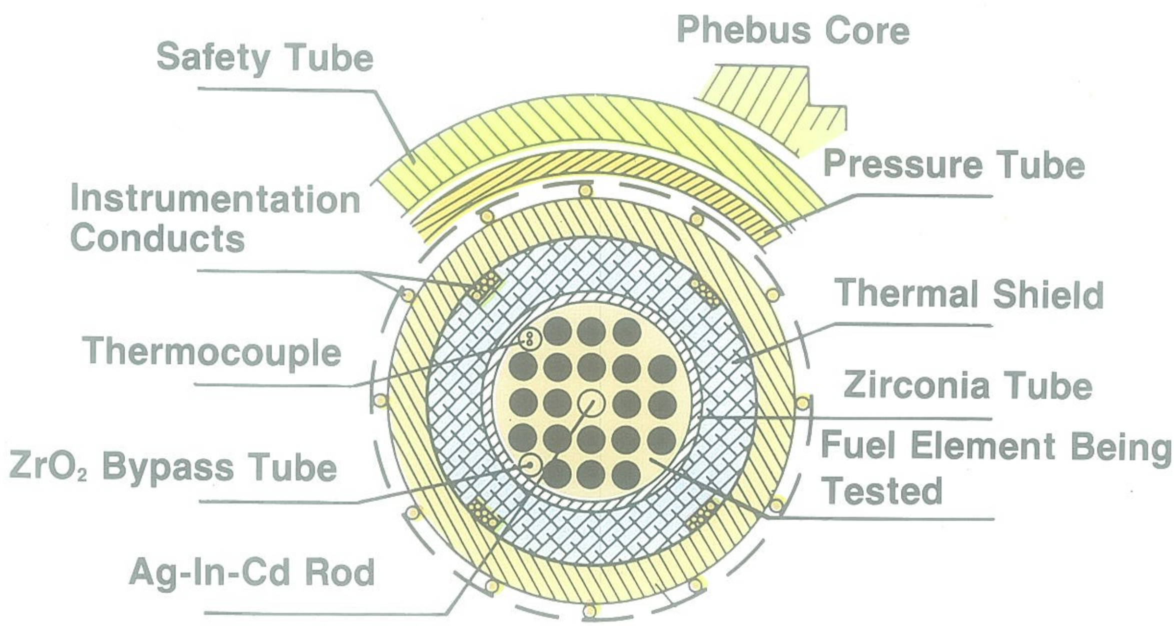
phenomena provide the data required for designing the containment and source term and analyzing consequences.
Properly detailed research of all these processes requires very specialized personnel, in addition to large sums of money; on the other hand, the problem concerns the entire international community. The conclusion is obvious: we must resort to international collaborations such as Euratom, NEA (OECD), etc., or else through bilateral or multilateral relations. The procedure will always be the same: more or less partially simulate a severe accident, and then interpret it by incorporating knowledge acquired from a calculation code, thus achieving experimental validation. It should be emphasized that having these codes is almost equivalent to having the experimental installation, and certainly more convenient.
In Spain, this philosophy has been clearly understood, and this country has participated in international projects by forming national consortia. Table I shows several examples in this category, some of which have been successfully concluded, as is the noteworthy case of LOFT/OECD.
In the specific case of the Phebus-CSD (Core Severely Damaged) Project, to which the Spanish Nuclear Society has devoted this monographic issue, the purpose of the installation and experiments performed therein, which will be described in detail in the following articles, is to acquire a thorough knowledge of the degradation mechanisms of a poorly cooled pressurized water reactor core under different operating conditions.
The installation was erected in 1977 in Cadarache (France) (fig. I) and basically consists of a pool type reactor (fig. II) with a vertically penetrating circuit that can house the fuel element to be experimented on (figs. III and IV), a containment tank for LOCA type experiments and another tank for fission product (FP) transport experiments. The first experimental program performed in this installation, which was completed in 1984, was an assembly related to the LOCA type accident.
The experimental program covered by this monographic issue, the Phebus-CSD, included six extensive experiments for the detailed study of the above mentioned phenomenology: B9, in December 1986, for thermal calibration of the experimental device; C3, in October 1987, for analysis of the cladding-pellet interaction; B9R, in April 1988, for studying the effect of rapid cooling throughout the pellet; C3+, in November 1988, for investigating the dissolution of $UO_2$ in Zr; B9+, in January 1989, regarding overall degradation of the fuel rod; and AIC, in June 1989, regarding the influence of control rod materials on the above phenomena. It is noteworthy that the next to last experiment, B9+, was chosen to be included in the NEA (OECD) as "International Standard Problem no. 28".
Spain's interest in participating in these activities dates back to 1986, when the first contacts between the "Consejo de Seguridad Nuclear", interested in principle on the subject of severe accidents, and the French IPSN ("Institut de Protection et Sûreté Nucléaire") were established. Both parties considered that this project could form the basis of the first specific agreement between the two organizations. The CSN thought then that Spain could participate through a consortium that would be called Phebus-España, in which the CSN, UNESA, ENUSA and JEN would take part. One year later, ENRESA joined this group. On November 25, 1987, the CSN-IPSN General Collaboration Agreement was signed, along with Specific Agreement no. 1, regarding the Phebus-CSD Project, which also included



**F II** *Phebus Reactor Pool.*

**F III** *Core Cross Section at Medium Height.*






**F IV** *Test Element.*

the possibility of using the Cathare code and of collaborating with CEA/IPSN on the radiological risk associated with PWR accidents. On December 1 of that same year, the CSN-CIEMAT-UNESA-ENUSA-ENRESA Agreement was signed to institutionalize the Phebus-España Consortium. In this agreement, the "Consejo de Seguridad Nuclear" was the leading entity.

Appendix 1 to Specific Agreement no. 1 specifies that the shared experiments will be B9, C3, C3+ and B9+, Appendix 2 deal with administrative matters, and Appendix 3 includes experiment AIC with those mentioned above. The experiments and their interpretation are the responsibility of a group of personnel that basically consists of the following four subgroups: data compilation and instrumentation, management and performance of the experiment proper, interpretation of results including "protest" analyses, and code development. Spanish participation has been notable in all these groups, but particularly in the latter two, both in Cadarache and in the laboratories of the Phebus-España Consortium's member firms.

As a courtesy, we should mention some of our French colleagues, whose hospitality and collaboration facilitated development of this joint program: M. Hache, overall coordinator; M. Tattegrain, in experimental management; M. Adroguer, in matters of interpretation, and M. Porrachia in software. Obviously, we have not listed all the names, which is inevitable under these circumstances, and for which we apologize in advance.

It should be mentioned that we are in the preliminary phase of a new series of experiments, sponsored by the European Community and generically named Phebus PF, which are intended to research the behavior and transport of fission products produced in a severe accident. This series of experiments closes the logical accident sequence. The first was the Phebus-LOCA to investigate the thermohydraulic sequences that lead to loss of core cooling; next was the Phebus-CSD, which is now being completed and that investigated core deterioration as a result of loss of cooling; and now research will focus on transport and in general the behavior of fission products that are released due to loss of core integrity. This will be the Phebus-PF phase, and as indicated above, it is the logical and inevitable next step in the overall severe accident research process.

Finally, it is only fair to mention the Spanish participation, which in any case is self-explanatory from the authors of the articles in this monograhic issue. In collaboration with our French colleagues, they have done a magnificent job that will undoubtedly contribute to improve nuclear power plant safety worldwide.

## REFERENCES


1. Thomson and Berkely Editors. The MIT Press, 1964. *"The Technology of Nuclear Reactor Safety".*
2. ALOMSO, A. Rev. Soc. Nuclear Española, October 1989. *"La investigación sobre accidentes severos".*
3. RASMUSSEN, N. E., et al.: *"Reactor Safety Study WASH-1400".* US Nuclear Regulatory Commission, 1975.
4. BIRKHOFER, A., et al.: *"German Risk-study, Nuclear Power Plants, Phases Aad Bo".* (GRS) mbH.
5. GONNIER, C.; FABRIGA, S.; SCOTT DE MARTINVILLE, E., and GEOFFREY, R.: *"In-Pile Investigations at the Phebus Facility on the Behaviour of PWR-Type Fuel".* Intern. Conference on Thermal Reactor Safety (NUCSAFE'88) ANS/ENS, october 1988, Avignon (France).
6. MARKOVINA, A.; FASOLI STELLA, P., and MAILLIAT, A.: *"Analytical Assessment of the Capability of a Scaled-Down In-Pile Test Facility to Simulate PWR Phenomena under Severe Accident Conditions".* AAAR'89, 8th Annual Meeting, October 1989, Reno, NV (USA).
7. BUSSAC, J.: *"The Need for Further Nuclear Safety Research. A Present French View".* Nucl. Eng. and Design, Vol. 108, 1988, 1-5.
8. U.S. Nuclear Regulatory Commission Nureg-1150 Severe Accident Risks, 1988.
9. HAGEN, S.; SEPOLD, L.; HOFMANN, P., and SHANZ, G.: *"Out-of Pile Experiments on the Meltdown Behaviour of LWR Fuel Elements: Influence of (Ag, In, Cd) Absorber Material".* Inter. Conference on Thermal Reactor Safety (NUCSAFE'88), ANS/ENS, October 1988, Avignon (France).