DEVELOPMENT OF AN EMERGENCY CORE COOLING SYSTEM FOR THE CONVERTED IEA-R1m RESEARCH REACTOR

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ABSTRACT

This present work describes the development program carried out in the design and construction of the Emergency Core Cooling System (ECCS) for the IEA-R1m Research Reactor, including the system design, the experiments performed to validate the design, manufacturing, installation and commissioning. The experiments were performed in two phases. In the first phase, the spray flow rate and distribution were measured, using a full scale mock-up of the entire core, to establish the spray header geometry and specifications. In the second phase, a test section was fitted with electrically heated plates to simulate the fuel plates. Temperature measurements were carried out to demonstrate the effectiveness of the system to keep the temperatures below the limiting value. The experimental results were shown to the licensing authorities during the certification process. The main difficulties during the system assembly are also described.

INTRODUCTION

The research reactors designed and constructed in the 50's and 60's have undergone a series of upgrading in order to improve their experimental capabilities and safety, as well as to extend their operational life. The main changes are the fuel enrichment reduction from HEU to LEU and core power increase, requiring backfitting of existing systems and/or addition of new systems. Pool type research reactors with MTR type fuels operating up to 3 MW does not need ECCS to mitigate the consequences of LOCA (Loss Of Coolant Accident) with core uncovering, according to studies by Webster [1], which were based on experimental data. However, for higher power levels, additional systems and modifications in existing systems are needed to assure core integrity during a LOCA event. The most usual systems and modifications adopted were: ECCS with spray header (Omega West Reactor [2], Rossendorf Research Reactors [3], RAS Research Reactor [4], and RP10 Research Reactor [5]), siphon breakers [2], double walled piping (FRG-1 Research Reactor [6]) and replacement of the primary pipes by more robust pipes.

In the IEA-R1m Research Reactor, the following systems were added to the original project: an ECCS, two motorized isolation valves installed at inlet and outlet of the primary piping near the pool and an isolation system for the Beam Hole ports. This work describes the design, experimental validation, construction and commissioning of the ECCS.

ECCS - SYSTEM DESIGN

The system parameters needed for the design of the ECCS are: system flow rate, system flow rate distribution over the core and the system capacity, i.e., the time interval with maintained flow rate. Calculations performed by Maprelian [7] shown that in occurrence of a full scale LOCA, the core begins to uncover after 300s. Maprelian calculation also shows that after operating at 5 MW during infinite time, the core needs emergency water cooling during a minimum period of 13.5 hours. Preliminary calculations indicated that a flow rate of 3.5 m^3/h would be sufficient to cool the core. The confirmation that this value would be adequate was done through experiment to determine the spray flow rate distribution over the core and by experiment with heated plates cooling. For a flow rate of 3.5 m^3/h and a minimum operating time of 13.5 hours, the minimum water volume capacity required was calculated to be around 50 m^3.

An ECCS must have redundancy in its water supply and the feeding should be preferably driven by passive means, e.g., by gravity. This leads to the requirement of having two independent feedwater reservoir with a total capacity of 100 m^3. Fortunately, near the reactor building, two reservoirs with 75 m^3 capacity each, constructed for other purposes were not being used, being available for the ECCS. The reservoirs pressure head is enough to provide the necessary drive. Every reservoir when full and without make-up has the capability to supply the system at nominal flow rate for more than 20 hours. The use of these reservoirs reduced significantly the cost and time for ECCS implementation, being only necessary to perform some minor repairs.

The ECCS [8] is equipped with two independent branches and physically separated to avoid that a common event could damage both of them simultaneously. These branches are conducted above the ground up, to facilitate inspection and maintenance, to the reactor building. The branch A enters directly into the reactor hall while the branch B pass through the Emergency Room before entering the reactor hall. Inside the reactor hall both branches merge together into one feedwater line to feed both the spray header over the core and the periodical testing spray header. Each branch is equipped with two solenoid valves in parallel which are actuated automatically by signals coming from three level switches located in the pool. These valves can also be actuated manually from a control panel in the Emergency Room.

The manual procedure is also used for the routine inspections and periodical testing. The electrical supply for these valves actuators come from a no-break system. Downstream each solenoid valve, a flow switch indicates at the control panel the open/close condition of these valves. The branch B has, in addition, parallel to the solenoid valves, a fast acting manual ball valve. The opening of one of the five valves is sufficient to feed the spray header with the design flow rate. This flow rate is monitored by an electromagnetic flowmeter with indication in the Emergency Room control panel. The testing spray header set up was constructed to weekly routine testing before each reactor start-up, checking the system operational conditions and to perform the reservoirs water renewal. Any abnormal deviation detected from the expected operational condition during these testing must be investigated and corrected to operate at 5 MW.

The ECCS instrumentation is composed by a flowmeter, level switches and flow switches. The flowmeter is electromagnetic and its transducer in the Emergency Room control panel indicates both instantaneous flow rate as well as integrated water volume. After every solenoid valve is installed a flow switch to indicate the open/close conditions. Two level switches were installed in each water reservoir to indicate low and low-low level and they deny reactor operation at 5 MW. Three redundant level switches in the pool are adjusted to open automatically the solenoid valves when the pool water level falls below 4500 mm from the normal operating level. All these instrumentation are electrically supplied by three no-break modules. The Figure 1 shows the ECCS flow diagram of the IEA-R1m Research Reactor.

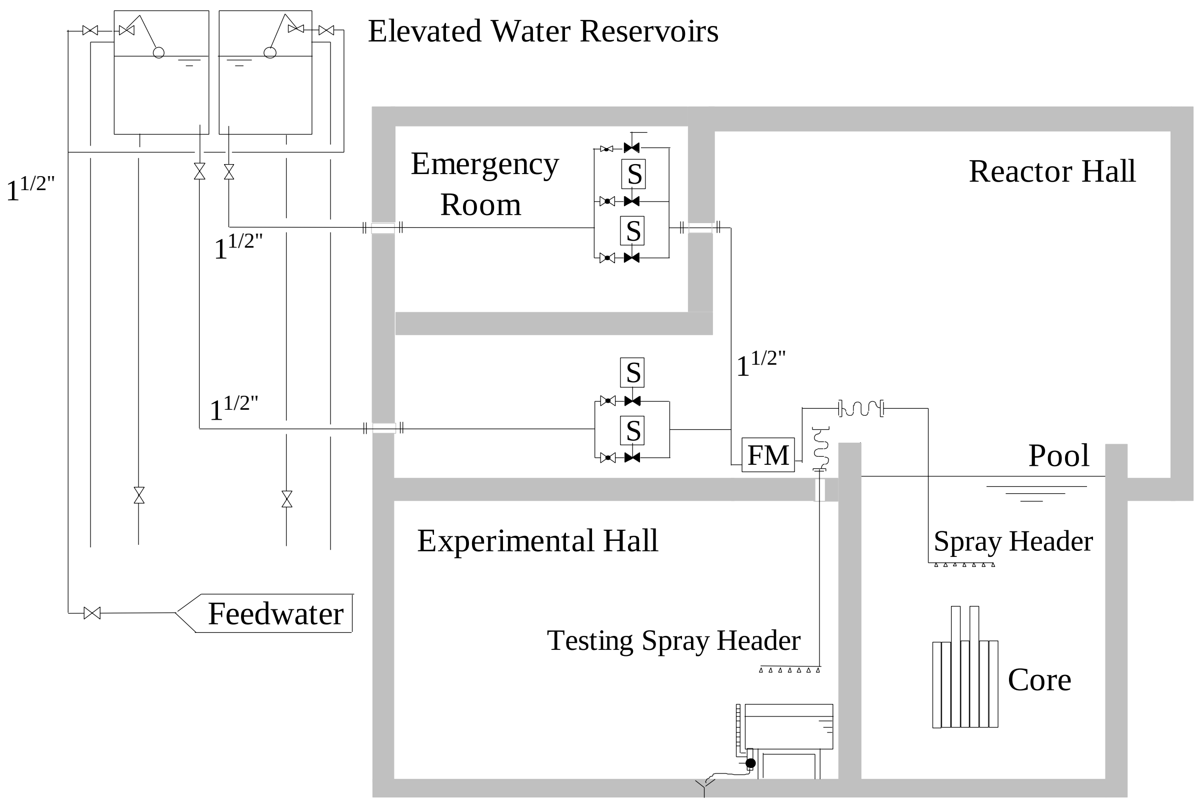

Figure 1 - Schematic Diagram of IEA-R1m Emergency Core Cooling System

The development of the ECCS was divided into the following subsequent phases:

a. Spray Header Flow Rate Distribution Experiment
b. Heated Plates Cooling Experiment
c. ECCS - Manufacturing, Construction and Installation
d. ECCS - Commissioning

SPRAY HEADER FLOW RATE DISTRIBUTION EXPERIMENT

The spray header flow rate distribution experiment main objective is to define the characteristics necessary to provide an adequate flow distribution over the core, assuring that every core fuel element receives the needed amount of water. A full mock-up in natural scale of the core and the U shaped spray header was constructed for this purpose. Among other studies, this mock-up allowed the study of the shadowing effects caused by the control elements and neutron detectors housing over the other fuel elements .The experimental data and results were used to define the spray header and its spray nozzles specifications. Figure 2 shows the test section and experimental circuit, and Figure 3 shows the normalized flow rate distribution results for the chosen header configuration actually used for the ECCS.

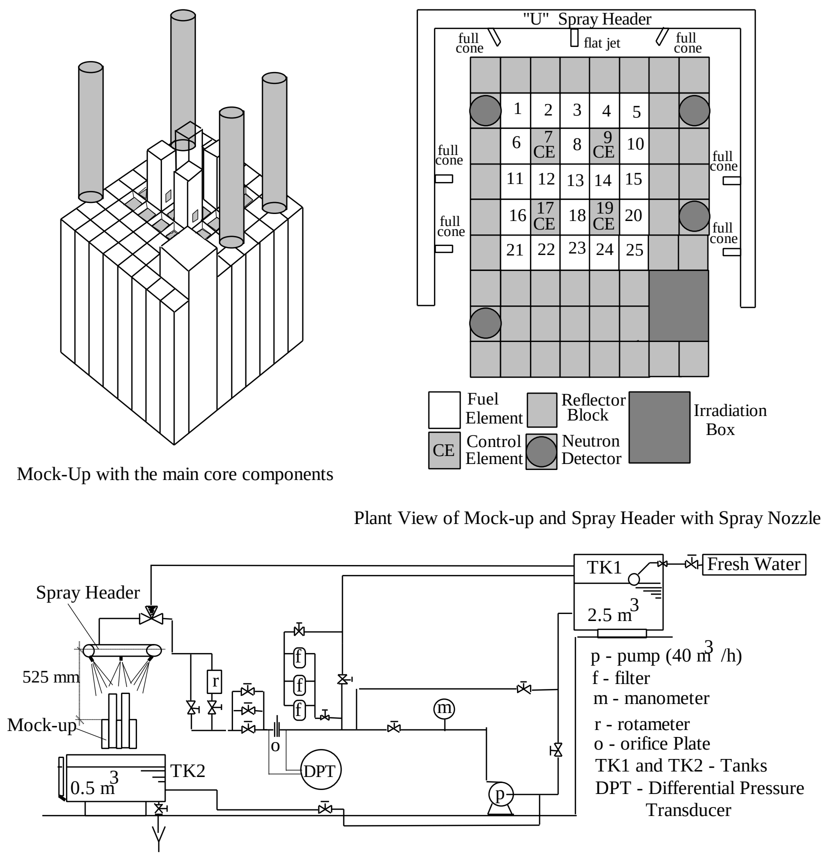

Figure 2 - Schematic Diagram of Experimental Test Circuit and Mock-up.

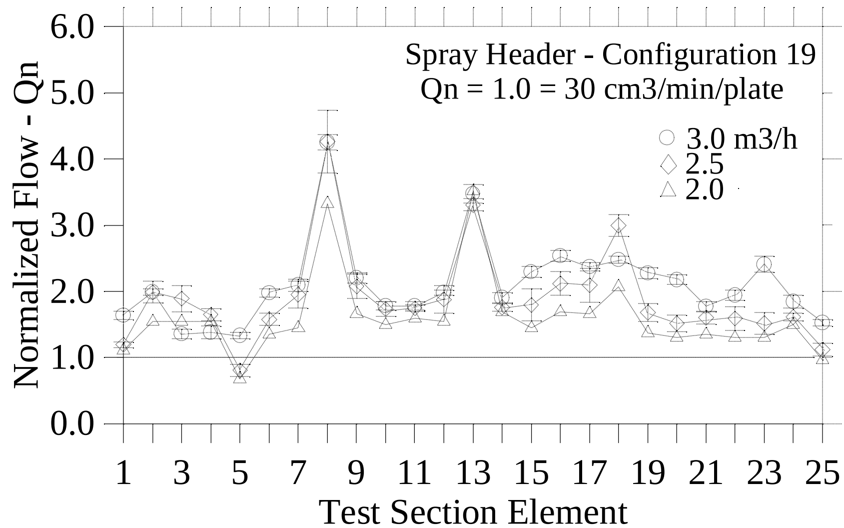

Figure 3 - Normalized Spray Flow Distribution

HEATED PLATES COOLING EXPERIMENT

The heated plates experiment main objective is to demonstrate the effectiveness of the ECCS spray system to cool the core and to keep the temperatures below the limiting value. For this experiment, the same mock-up of the spray header flow rate distribution was used with a test section (STAR) formed by four electrically heated plates made of Ni-Cr alloy and generating a heat flux equivalent to the residual heat in the core after shutdown. The four plates connected in series and electrically fed by a current rectifier were placed at position of the fuel no. 12, as defined in the Figure 2.

Figure 5 shows the values of the uniform heat flux induced in the heated plates during one of the tests (STAR53). Such condition simulates the fuel channel in the core with the largest energy integral. In Figure 6 one can see the recorded temperatures in the plates 2 and 3 for a flow rate of 3.5 m^3/h, demonstrating that all values were below the limiting value of 500°C. These tests were accompanied by inspectors from the Comissão Nacional de Energia Nuclear (CNEN - Brasil), which is the Brazilian licensing authority, and the results were the base for the ECCS certification.

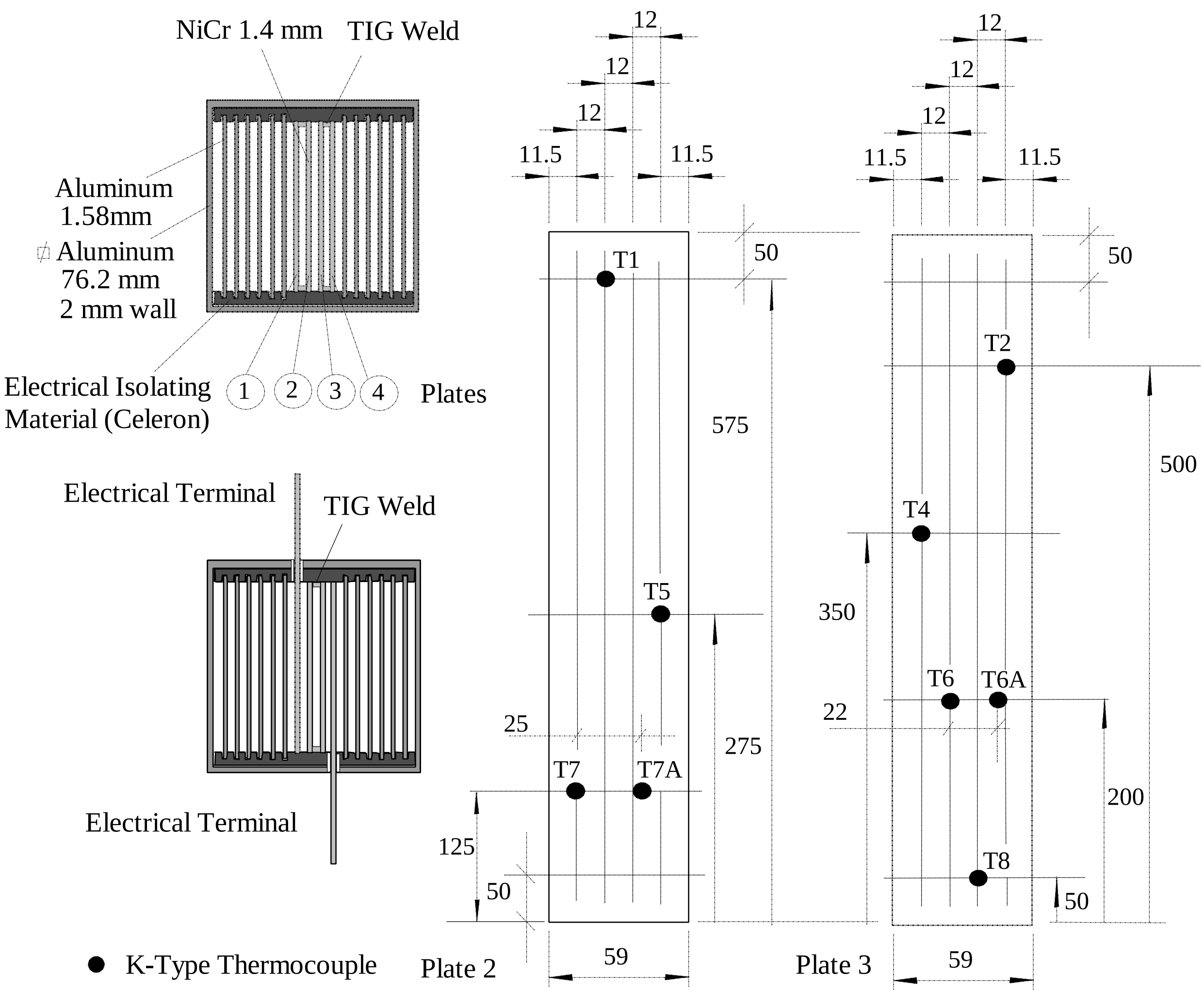

Figure 4 - Heated Plates Test Section - STAR

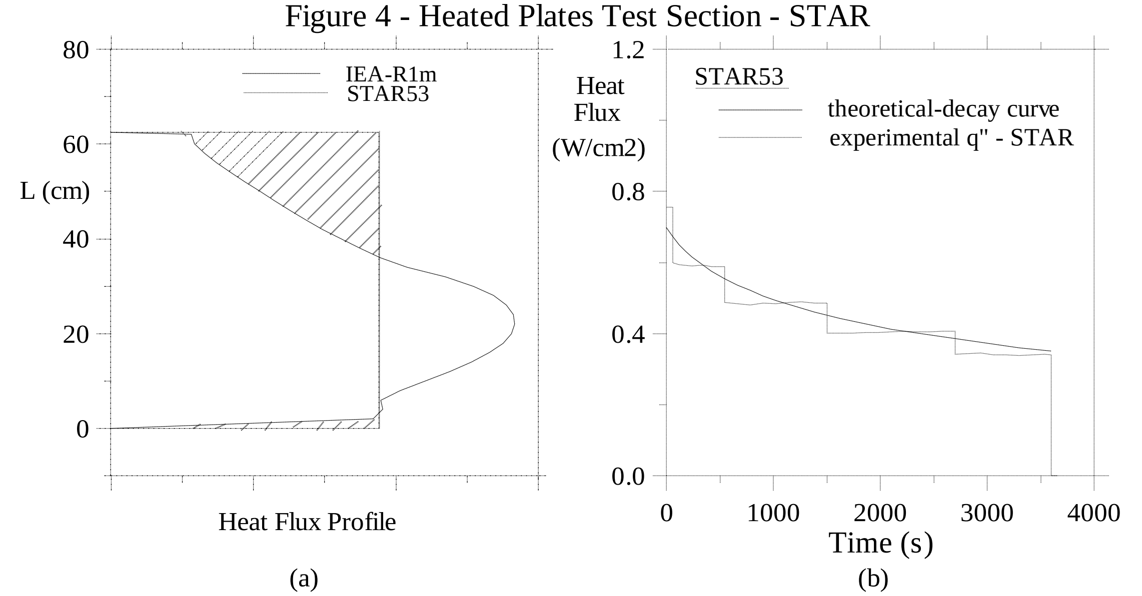

Figure 5 - Theoretical and Experimental Heat Flux Profile (a); Heat Flux time history (b)

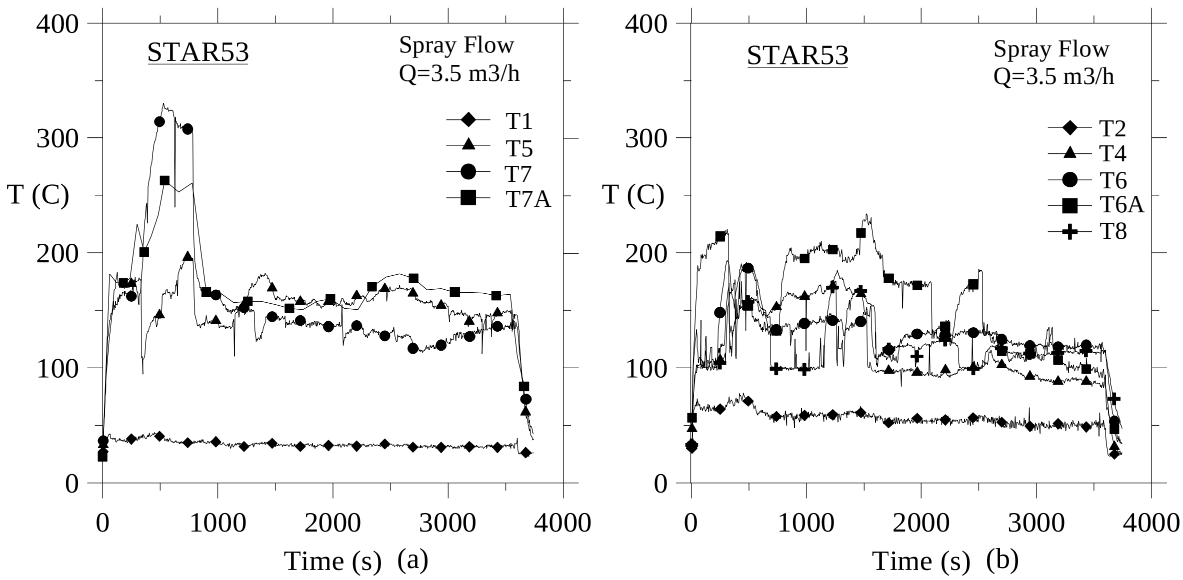

Figure 5 - Temperatures in Plates 2 (a) and 3 (b)

ECCS - MANUFACTURING,CONSTRUCTION AND INSTALLATION

The IPEN engineers developed the system design and specifications up to a point where a bidding was carried out to contract the detailed design, construction and installation of the system. Two contracts were signed to perform these tasks: a) Reservoirs and Piping and b) Spray Header and Support Structures.

a) Reservoirs and Piping. This contract conducted the installation of the two main system branches A and B, the feedwater line to periodic testing header, the reservoir feedwater line, other lines of reservoirs and maintenance of the reservoirs.

In the system branches A and B lines, from the reservoirs up to the pool borders, two materials were employed. From the reservoirs up to the reactor building 1 ½ in. galvanized carbon steel pipe and threaded connections were used. These pipes were green painted with red stripes to provide clear identification. The rest of the line, up to pool border, was manufactured with stainless steel pipes and threaded connections. Flanges were used in the transition between the two materials. The connection between the feedwater line and spray headers is made up with flexible tube and fast action connections.

The feedwater line to the testing spray header spray, from the pool border up to the Experimental Room, was assembled using 1 ½ in. PVC pipes and connections. The testing spray header is constructed in 2 in. PVC with the same geometry as the operating header. The spray nozzles in the testing spray header are geometrically identical to the spray nozzles used in the pool spray header.

The two elevated water reservoirs were fed by normal city water service through 2 in. PVC pipes. Alternatively, their make-up can also be done by another main reservoir inside the Institute. Level switches are installed in these reservoirs and they are displayed in the Control and Emergency Rooms. The other lines of reservoirs was assembled using 1 ½ in. galvanized carbon steel pipe and threaded connections. The two ECCS reservoirs were constructed in early 70's , so it was necessary the execution of maintenance work.

All the ECCS piping work did not present any difficulty except at the reactor building wall, where 40 cm length and 3 in. diameter holes had to be opened using special drilling devices resistant to the high strength concrete used in the construction.

b) Spray Header and Structures. This contract conducted the manufacturing design and installation of the spray header and its support structure in the pool. Many difficulties were found. The first difficulty was to find a company to perform the installation, since the service should be done without emptying the reactor pool. Another difficulty arose in the design phase of the spray header and support structure, where the geometrical information were incomplete and available only in old drawings from the reactor manufacturer. The position and type of support for the spray header required many lay-out studies until the definition of to supporting the header in a separated structure, laid at the bottom of the pool and fixed at its borders. This type of supporting was chosen since it allows free movement of the core support structure without difficulties. To work with the completely filled pool excluded the possibility of as-built measurement of important dimensions of the core and pool components (e.g. depths) necessary to the precise dimensioning and construction of the spray header and support structure. This caused impacts during installation, when several mechanical adjustments had to be made until final assembling after serious delays in the time schedule. The overall size and weight also complicated the installation due to the limited space for maneuvering caused by the presence of the beam hole tubes.

Another difficulty was related with the spray header and its support material specification. In order to avoid increase in radiation dose caused by structural material activation and galvanic corrosion problems, Aluminum was specified as the material for every part of the spray header and their support structure. In general, Aluminum made components are not readily available in the market and almost all items had to be custom manufactured. Spray nozzles presented special difficulty in manufacturing.

ECCS - COMMISSIONING

In the ECCS commissioning the nominal flow rate in the two branches were verified. For this, the header test section was employed and the solenoid valves were actuated manually in the Emergency Room control panel. During the first commissioning tests, residual material used in the reservoirs impermeabilization were found in the main system lines which eventually caused partial obstruction of the spray nozzles of the header test section and also obstructed the solenoid valves seating. The spray nozzles and valves were opened and cleaned and pipe lines were flushed. The level switches in the reservoirs were also checked during the filling-up and the pool level switches were also checked. All indications in the panels located in the Control Room and Emergency Room were also verified.

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