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REFINING THE DESIGN AND ANALYSIS OF THE IRIS PRESSURIZER

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ABSTRACT

The pressurized light water cooled, medium (1000 MWt) power plant IRIS (International Reactor Innovative and Secure) has been under development for four years by an international consortium of over 20 organizations from ten countries. The plant conceptual design was completed in 2001 and the preliminary design is nearing completion. The pre-application licensing process with NRC started in October, 2002 and IRIS is one of the designs considered by US utilities as part of the ESP (Early Site Permit) process.

IRIS is a pressurized water reactor that utilizes an integral reactor coolant system layout. Its containment is only a fraction of the size of corresponding loop reactors, resulting in a significant reduction in the overall size of the reactor plant. The IRIS reactor vessel houses not only the nuclear fuel and control rods, but also all the major reactor coolant system components including pumps, steam generators, and pressurizer. The pressurizer is located in the upper head, above the internal control rod mechanisms and, in the current design has an overall volume of about 80 m^3 (~2800 ft^3). The current configuration is very convenient since it minimizes the dimensions of the vessel, operates with both of the closure flanges at a uniform temperature, and maximizes the overall pressurizer volume, while providing adequate space for placements of the reactor coolant pumps and internal CRDMs. The pressurizer design and its main features are discussed in this paper.

Since the early design stages, when the option for a steam pressurizer without active spray was made, there has been an increasing number of performance requirements set for the pressurizer. Examples of these are the elimination of power operated relief valves and the constraint to reduce the number of events that could cause the opening of the pressurizer safety valves. Several internal design documents have been prepared to properly define the functional requirements as well as the means to assure compliance with them. As a result, more detailed and sophisticated models have to be developed to cope with this new level of refined analysis. This paper summarizes the most relevant functional requirements and their means of implementation, describes some features of the models used for pressurizer analysis, and presents and comments on some of the results obtained so far.

1 KEY PRESSURIZER DESIGN GUIDELINES

New reactor concepts like IRIS [1, 2] try to address ambitious goals of safety, reliability, economics and waste reduction in a synergistic approach. In the case of IRIS, the key concepts are aimed at using design options that are somewhat more holistic than those of conventional reactors. This means that design options conceived to address primarily one of the goal areas have also to be a useful lever to enhance performance in some other areas.

One of the cornerstones of the IRIS concept, the "safety by design" approach [1], takes full advantage of the integral reactor configuration of IRIS to substantially reduce the number of physically possible accidents, lower the probability of the remaining ones and decrease their consequences. This approach is a kind of a proactive layer that has been added to the defense-in depth design philosophy. "Safety by design" is also a powerful lever for reliability (and availability) because it promotes the elimination of many initiating events as well as provides more means to deal with the remaining ones, thus reducing their probability of degradation. As one can see, operational performance and economic goals are also enhanced by this design approach.

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As it has been mentioned in previous articles [1-3], a distinguished characteristic of IRIS is its capability of operating with long cycles, a powerful lever to plant availability and economics. To take full advantage of this characteristic a very high reliability of primary system components and a reduced frequency of out-of-service inspection/maintenance has to be achieved to make possible the "Extended Maintenance Cycle" target by IRIS [4]. This has led to an approach that one might call "design for maintainability", that means a threefold approach encompassing the use of reliable advanced diagnostics and prognostic, provisions for in service inspection of key components and easiness of maintenance. Although more specifically focused on the achievement of a high plant availability and economic goals, such as a 48 month uninterrupted operational cycle, this approach also contributes to the assurance of highly reliable systems with positive effects on the credibility of the IRIS PRA.

These carefully conceived and discussed interrelations of IRIS design principles are then reflected on the operational principles and equipment functional requirements. For example, for the IRIS pressurizer, two key design requirements are influenced by the overall plant objective of increased reliability.

The first is the definition of the IRIS Power Operation Program. For IRIS the range from 20% to 100% is named Normal Power Operation - PO, meaning that the plant can be normally feeding the grid at any level in this range, while the range from 0% to 20% is just for Power Ascension Operation (or startup, SU). Three different plant operation strategies were studied for each range and they are symbolically referred as: POi and SUj (with i, j = 1,3), respectively for the PO and SU ranges. A detailed discussion of these different programs goes beyond the scope of this paper, but the final selection was for a PO1-SU3 control strategy, based on the desire to follow a policy of minimum detour from conventional control scheme, and thus take advantage of the extensive experience in the design and operation of other PWRs.

The second key requirement is related to a desire to minimize the operation of the charging pumps of the chemical and volume control system. IRIS design requirement was that the charging pumps should only be operated to compensate for leakage from the reactor coolant system on a daily basis, but should not be required for any level control function during normal operational transients. This means that there will not be any manipulation to control pressurizer level, which is equivalent to saying that a constant primary coolant mass program has been adopted, corresponding to a "natural" pressurizer level program that is only function of the reactor coolant system $T_{avg.}$

Abiding by these restrictions, the solution PO1-SU3 causes a modest pressurizer level variation in the 20% to 100% power range and, like all others POi-SU3, it presents a very adequate level variation from 0% to 100%.

These two examples are simply provided to demonstrate how the design of the operational programs for the IRIS pressurizer is heavily influenced by the overall objective of maximize the plant reliability, both by minimizing component operations and by relying on current technology and expertise wherever feasible and convenient.

2 PRESSURIZER ROLE

The pressurizer is a critical component for PWRs, since it absolves two fundamental functions: it provides the means for monitoring and controlling the reactor coolant system pressure and thus maintain a sufficient degree of subcooling in the core to prevent fuel damage, and it also provides the means of monitoring and controlling the reactor coolant system inventory and thus preventing the potential for a dangerous reduction in the liquid level in the system.

As part of the design of the IRIS pressurizer, a set of functional requirements that this component and its ancillary systems must be capable of performing was identified. These functional requirements were then analyzed in terms of critical design features that need to be optimized to guarantee that all of the functional requirements are satisfied. These critical design features (or main design parameters) can be summarized as follows:

- Full Power Steam Volume. It has to provide an inherent mitigation of any pressurization transient, minimizing the actuation of the safety valves (none for operational transients) and also minimizing the actuation of other protective measures (e.g. reactor trip) during de-pressurization transients.

- Full Power Water Volume. It has to improve the response to cool down events (for example a loss of a feed water heater or an increase in steam flow) and maintain the pressurizer water level within its measured span without the need for adding (charging) water to the primary system. In addition, there should be enough margin to enable reasonably elastic water level setpoints, in such way that, on the long run, actuation of the charging (and letdown) system are minimized.

- Level Program. A non manipulated level program consistent with a constant primary coolant mass program shall be possible for the operational strategy that was decided, PO1-SU3, as discussed above.

- PI Controlled Heater Power. There should be a bank of heaters govern by an proportional-integral controller and this PI bank shall be designed so that its power is at least double the maximum heat losses from the pressurizer at hot zero power conditions. It is believed that the design should maximize the power for the PI bank, since this is a very desirable feature for this type of pressurizer. There is also a requirement on the total heating power (PI + backups) related to the desired plant pressurization rate during plant heat up procedures (i.e. total time between refueling conditions to hot zero power lower than 36 hours).

- Backup Heaters Power. There should be two banks and each one should be capable alone of compensating for the maximum heat losses (with some margin) from the pressurizer, a condition that happens at hot zero power conditions.

- Safety Valves, Quantity and Dimensions. They have to provide steam relief capacity required to maintain the reactor coolant system within appropriate pressure limits during design basis events and also some beyond design basis events. The optimal combination of the number of valves and a staggered scheme for valve opening setpoints should be developed. In the case of IRIS, given the mild evolution of design basis events, the sizing of the pressurizer safety valves is based on ATWS (Anticipated Transient Without Scram) considerations.

- Surge Holes. The total flow area of the surge holes shall be sufficiently large to minimize the pressure difference between pressurizer and reactor coolant system during all anticipated transients, and to assure that the inverted top-hat structure separating the reactor coolant system volume from the pressurizer volume is not overstressed even in the occurrence of beyond design basis events such as an ATWS.

- Pressurizer Water Chemistry Control. A means to assure an adequate mixing of the pressurizer and RCS water must be provided.

- Pump Suction Venting. Following refueling and after the pressure vessel head is connected to the vessel body, a mean must be provided to eliminate any gas (air or nitrogen) that might be trapped in the pump suction volume.

A detailed discussion of how these key design parameters have been addressed is beyond the purpose of this paper and is also limited by considerations of proprietary material. Some of the most relevant considerations are discussed in the following sections.

3 DESIGN EVOLUTION

3.1 Early Design

A conventional steam pressurizer was from the very beginning selected for IRIS, although some variants have been studied in parallel. Three different alternative concepts were explored: The use of self pressurization for the integral IRIS reactor is inherently excluded due to its power level and NPSH (net positive suction head) requirements of the spool pumps. A hot pressurizer, with nitrogen partial pressure for over-pressure, results in too high a nitrogen content in the cooling water which adversely impacts the plant LOCA mitigation performance. A cold gas pressurizer (with nitrogen providing all the pressure) requires a complex layout and was never used in integral reactors. The most interesting of these alternatives, the hot gas pressurizer where pressure can be controlled by controlling the inventory of nitrogen in the system, has still been discarded due to the lack of any advantage from a performance point of view when compared with a steam pressurizer, and due to the increased costs, both in development and implementation, that this solution would require.

From the early IRIS design, designers have observed [5] that the IRIS integral configuration was allowing a significant increase (compared to loop PWRs) in the ratio of pressurizer volume (Vp) to reactor power (Po) This ratio is in IRIS more than three times greater than in the AP600 reactor (77m^3/1000MW for IRIS versus 45.3m^3/1940MW for AP600), which is actually the advanced plant design with the most favorable ratio among loop PWRs. As it shown in figure 1, IRIS pressurizer is located in the upper head, above the internal control rod mechanisms. This layout is considered optimal for the IRIS design, since it does not dictate the dimensions of the vessel, operates with both of the closure flanges at a uniform temperature, and maximizes the overall pressurizer volume; while providing adequate space for placements of the reactor coolant pumps and internal CRDMs

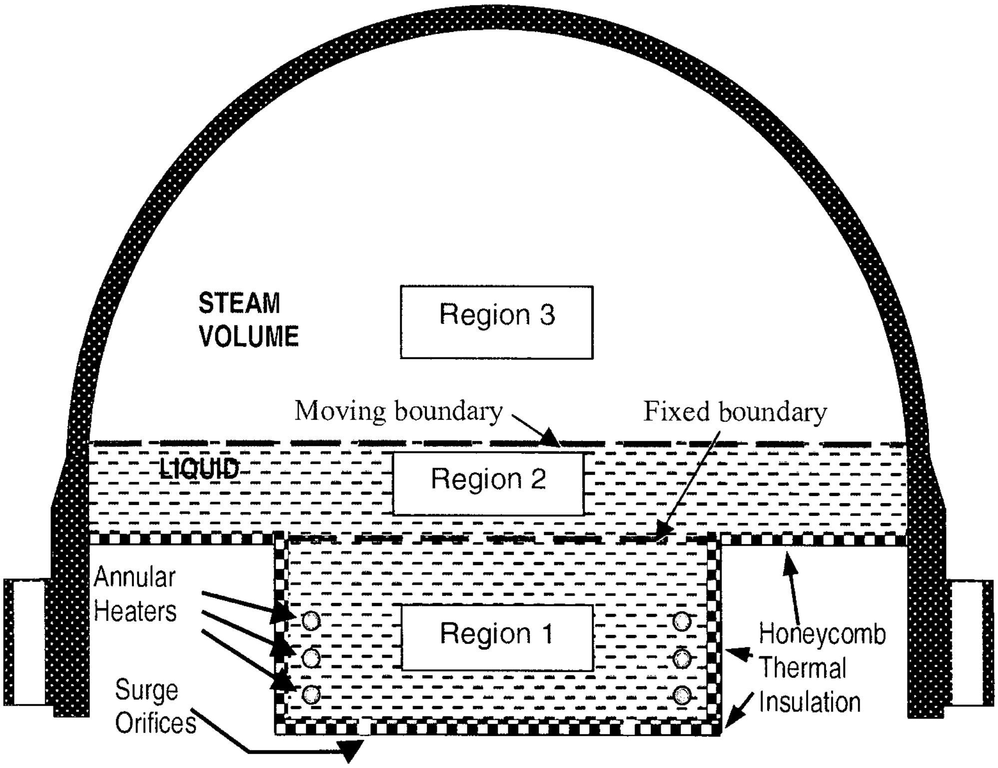

Figure 1 – Basic Pressurizer Layout for IRIS

The ratio between steam volume and reactor power, is the best indicator of the pressurizer inherent capacity to attenuate pressure variations. If, on one hand, the integral configuration makes possible a very favorable volume to power ratio, on the other hand, it makes very difficult to implement a conventional spray system. Therefore the IRIS pressurizer design goal was defined since the early design phase to take advantage of the increased volume to power ratio that inherently mitigates pressurization transients, to support the elimination of the need of a spray system. This is consistent with the overall IRIS philosophy to rely on inherent design features to eliminate the need for additional systems. It must be noted that a normally isolated auxiliary spray line and internally mounted spray nozzle will be provided. This auxiliary spray, that will have no function during power operation, shall be used during plant shutdown to collapse the steam bubble to fully depressurize the reactor vessel prior to head removal for refueling/maintenance operations.

During the first phases of design, when dimensions were still very preliminary and the design envelop transients and conditions to assess the pressurizer behavior were not completely identified, some conservative calculations were made just to appraise if the proposed solution had the potential to provide enough margin to endure possible changes in its functional requirements as the overall reactor design evolves.

A simple pressurizer adiabatic model was used to check maximum pressure in the case of loss of feedwater and also a non detailed RELAP simulation was run for the same event. Both results were very satisfactory for the objective of the assessment, and confirmed the potential of the selected configuration thus allowing the initiation of more detailed design studies.

3.2 Parametric Design Studies

As more information was available on the systems design and some control parameters estimates were needed, another self standing model for the pressurizer was developed. This model included a simple simulation of the primary system sufficient to allow an acceptable estimation of the surge flow and temperature during various operational maneuvers. A saturation line model of the pressurizer was used and the full dynamics of heaters, heat losses and controls for the heaters and pressurizer level were included.

The model was implemented through 11 MS Excel Worksheets linked via some Visual Basic Macros [5]. It became an effective tool capable of allowing a quick review of the data of IRIS pressurizer and automating several simulations of its behavior under different configurations of reactor coolant temperature / power programs, control characteristics, pressurizer level programs and CVCS charging capacity.

Several parametric studies could be performed using this simple tool. Also some characteristics of this pressurizer have been unveiled by these studies, for example, due to the absence of spray, the amount of thermal losses has a considerable influence on the time for the pressure decrease to its setpoint after a pressurization transient. Many other factors that could affect performance such as the use of "constant coolant mass level program" versus a "CVCS manipulated constant level program" were studied. Several values for the total heating power, as well as different partitions between the PI and backup heaters were tested. The results of these scoping studies were provided to Westinghouse and discussions between Westinghouse and CNEN of these results heavily influenced the final pressurizer design requirements.

Just to illustrate a pressure transient curve generated with this model for a ramp turbine generator load decrease from 100% to 80% at 5%/minute is shown in Figure 2. The total heater power was 1600kW with 1000kW in the PI bank and 300kW in each of two back up banks. As expected, the set points of backup heaters were not reached and proportional and integral gains were respectively $K_p = 200$ W.MPa^{-1} and $K_i = 1.6667$ W.MPa^{-1}. This simulation assumed that convection breakers were being used to insulate the pressurizer bottom, so the thermal losses were very small, 60.689 kW in steady state. This was one of the many cases that were simulated to study the pressure and level responses of two different level programs: a constant level program and non manipulated level program consistent with a constant primary coolant mass program. For the case at hand - constant level program – there was some control action causing a small compensating flow to and from the CVCS. This action, although not envisioned to cope with transients, has helped attenuating the pressure variation to a certain extent. In the first phase of the transient, load control (through feedwater control) was the main driver to the transient and reactor power control was trying to follow it. The small mismatch between those two has caused a surge flow into the pressurizer, which was only reverted at about 255 seconds. PI controller has turned off the electricall power to the heaters from 7 to about 450 seconds, causing the pressure to starting recover a few seconds later. The small gain of the integral part as compared to the proportional one, plus the help of the CVCS letdown/charging flow to control the level explain why no overshoot is observed on the pressure behavior.

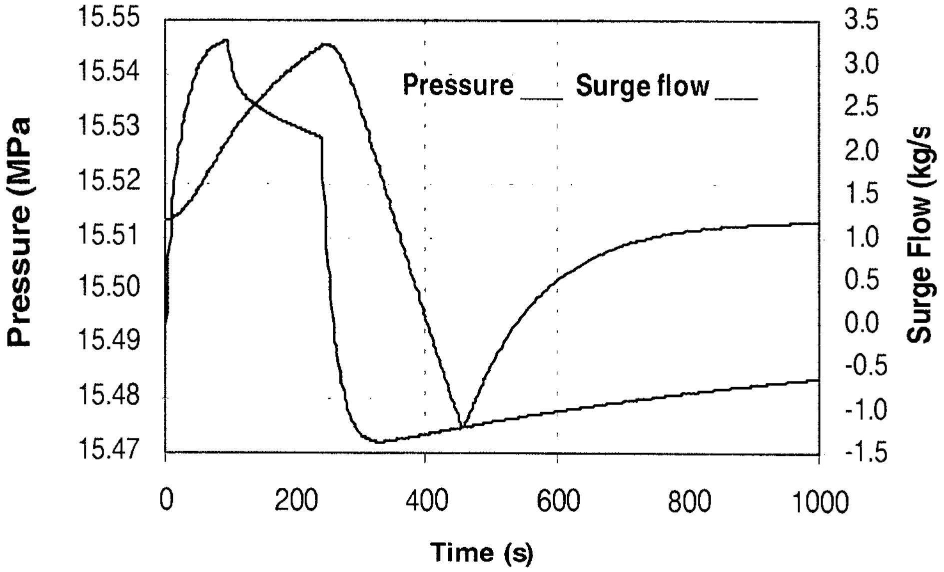

Figure 2 – Pressure Behavior in Power Ramp Maneuver (100% to 80% @ 5%/min.)

3.3 Current Design Status and Activities

For the present phase of design many decisions have been made and most of the key parameters have been frozen. One does not expect changes that can affect the dimensions of the pressurizer, but still design has to advance keeping some room to make choices and to endure requirement changes. To this aim, a number of main design parameters and their respective acceptance criteria have been established. The optimal pressurizer design will emerge as the combination of these design parameters that satisfies all of the identified acceptance criteria, and provides the best overall performance. The path forward can be summarized as follows:

- Insurge or outsurge flow and temperature time histories, for the different limiting transients will be determined with detailed RELAP simulations. Those will be used to feed separate pressurizer models to confirm the adequacy of the current preliminary sizing and the effectiveness of subsystem configurations under consideration. The results of these analyses coupled with engineering judgment of the design team will result in a judicious assessment of the optimal selection of the design parameters.
- A preliminary pressurizer design shall be completed reflecting the above mentioned selection.
- A complete set of detailed analyses of the limiting transients shall be performed. The results will be used to further optimize the preliminary design and provide a final design of the pressurizer. Detailed design drawings will be completed, and some additional design parameters that were not optimized as part of the "main design parameters" will be defined.

4 MODELS AND ANALYSIS OF THE IRIS PRESSURIZER

Figure 2 depicts the basic tasks of the final phase of the preliminary design. In parallel tracks, a database containing the design envelop of surge flow and temperature time histories is being generated and another data base of experimental data available in the open literature (or proprietary of members of the IRIS consortium) is being assembled. This will be used to check the prediction accuracy of both the new self standing model - a computer code written just to simulate IRIS pressurizer and of a separate detailed RELAP model just for the pressurizer, that uses time dependent control volumes and junctions to input boundary conditions obtained from the full plant model.

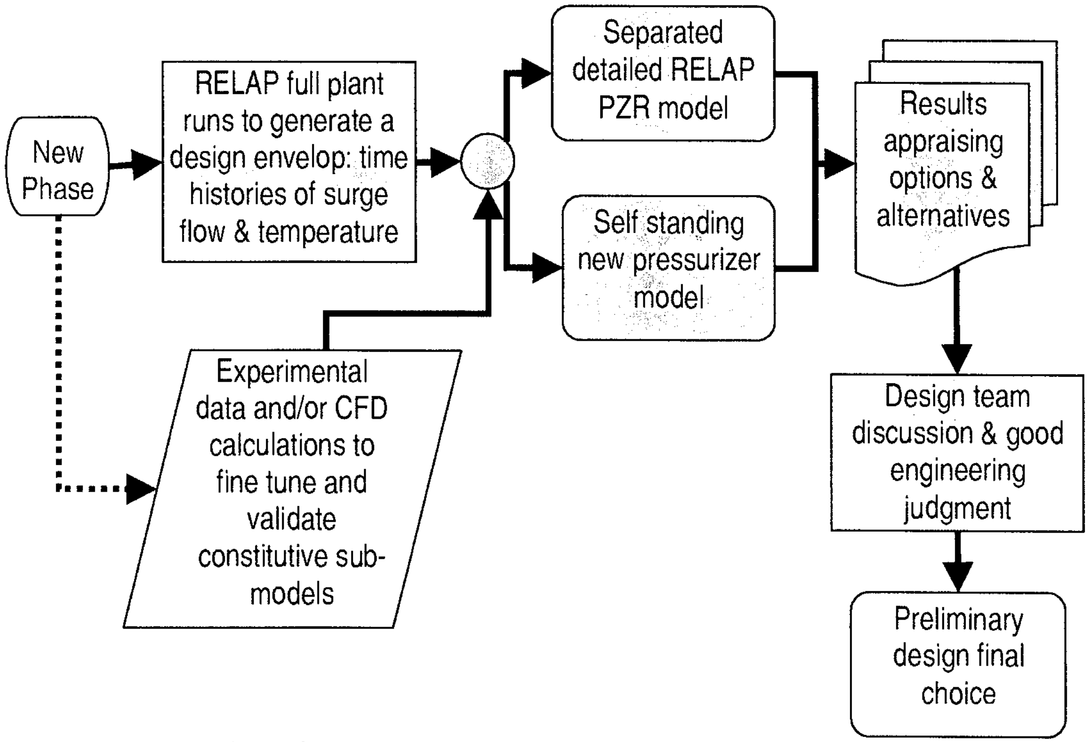

Figure 3 – Outline of the remaining tasks to complete the IRIS preliminary pressurizer design

CFD calculations will be used to provide the tuning of sub-models that are used by the self standing model, such as boiling and bubble distribution profile around the heaters, convective circulation insulation efficiency, mixing phenomena, and others.

The rest of this paper will be dedicated to briefly describe the above mentioned model and also to show some results obtained in the beginning of this new design phase.

4.1 Modeling Assumptions

The pressurizer model developed for the detailed design studies implements a nonlinear, non-equilibrium three region model, which incorporated most of the distinguishing features of the models being described in the literature [6 to 9]. The basic characteristics are as follows:

- The bottom region is a fixed control volume and the other two regions are separated by a movable boundary, as indicated in figure 1.
- Thermodynamic non equilibrium conditions are considered among the regions.
- All the relevant thermodynamic and transport processes are taken into account.
- Both wet and collapsed water levels are modeled. By wet level it is meant the boundary between regions 2 and 3 and, a value slightly different from the collapsed level because the model assumes voids in regions 1 and 2 as well as moisture in region 3.
- Control devices are simulated, including control signals, logic and actuators.

The basic unknowns are the region volumes V_i, the volume averaged enthalpies h_i and the pressure p. The mass continuity equations govern the behavior of the region volumes, the energy equations that of the region enthalpies and the closure equation, derived from the fact that the total pressurizer volume is fixed, govern the pressure behavior.

The closure equation and the fact that first region has a fixed volume allow for reducing the number of nonlinear coupled differential equations from 7 to 5 and this system, shown below, is solved simultaneously. Functions describing water-steam properties were based on the IAPWS Industrial Formulation 1997.

Functions calculating derivative of these properties were implemented constrained to be very precise and not to introduce errors that could compromise the formulation.

It is not the purpose of this article to discuss the model and the solution procedure, but for the sake of completeness the resulting equation set and the notation used is presented below:

$$- \frac{V_2}{v_2^2} G_2 \frac{dp}{dt} + \frac{1}{v_2} \frac{dV_2}{dt} - \frac{V_2}{v_2^2} F_2 \frac{dh_2}{dt} - \mathrm{O}_2 = 0;$$

$$- \frac{V'-V_2}{v_3^2} G_3 \frac{dp}{dt} - \frac{1}{v_3} \frac{dV_2}{dt} - \frac{V'-V_2}{v_3^2} F_3 \frac{dh_3}{dt} - \mathrm{O}_3 = 0;$$

$$- v_1 \frac{dp}{dt} + \frac{dh_1}{dt} + \frac{v_1}{V_1} O_1 h_1 - \frac{v_1}{V_1} (Q_{1in} + R_1) = 0 ;$$

$$- v_2 \frac{dp}{dt} + \frac{dh_2}{dt} + \frac{v_2}{V_2} O_2 h_2 - \frac{v_2}{V_2} (Q_{2in} + R_2) = 0 ;$$

$$- v_3 \frac{dp}{dt} + \frac{dh_3}{dt} + \frac{v_3}{V'-V^2} O_3 h_3 - \frac{v_3}{V'-V_2} (Q_{3in} + R_3) = 0 ;$$

Where:

$$O_1 = w_{su} - w_{rb1} - w_{12} ;$$
$$O_2 = w_{12} + w_{rb1} + w_{cs} + w_{cb} - w_{rb2} + w_{it} ;$$
$$O_3 = w_{sp} + w_{rb2} - w_{cs} - w_{cb} - w_{sa} - w_{it} ;$$
$$Q_{1.in} = q_{aq} - q_{1w} ;$$
$$R_1 = w_{su} h_{su} - w_{12} h_{12} - w_{rb1} h_g ;$$
$$Q_{2.in} = q_{it} - q_{2w} ;$$
$$R_2 = w_{12} h_{12} + w_{rb1} h_g + w_{cb} h_f + w_{cs} h_{cs} + w_{it} h_{it} - w_{rb2} hg ;$$
$$h_{su} = h_r \ (riser\ enthalpy)\ if\ w_{su} > 0\ and\ h_{su} = h_1\ otherwise ;$$
$$h_{12} = h_1\ if\ w_{12} > 0\ and\ h_{12} = h_2\ ortherwise ;$$
$$Q_{3.in} = -q_{3w} ;$$
$$R_3 = w_{rb2} h_g + w_{sp} h_{sp} - w_{it} h_{it} - w_{cb} h_f - w_{cs} h_f - w_{sa} h_3 .$$

Where the basic notation for the variables is:

V – volume; v – specific volume (V/M); w – mass flow; h – enthalpy; p – pressure;
T – temperature; t – time; Q – heat inputted to control volume; q – heat exchanged at an interface; x – title or quality;

and the subscripts should read as:

sp – spray; sa – safety valves; cw – condensation on the wall; cs – condensation via spray;
w – wall; su – surge; cb – bulk condensation (raining); rb – rising bubbles from boiling;
it – steam-liquid net interface exchange (positive if condensation); g – saturated (dry) steam;
f – saturated liquid; i = 1, 2, 3 are the running indexes for regions.

4.2 Some Results

Next a simulation of a loss of normal feedwater, considering the availability of control systems, is shown. Both startup feedwater and steam dump systems were assumed to work properly and the plant was brought to hot zero power conditions. This transient is important: (a) to confirm the ability of the pressurizer to endure a large and fast insurge flow, at the beginning, with just a small pressure increase; and (b) to show that the level is still kept comfortably above the turnoff setpoint of the heaters, during the subsequent extensive outsurge. The time histories of surge flow and temperatures were generated by the RELAP full plant model and feed to the pressurizer model, where different configurations for heaters, control parameters and insulations can be tested more easily.

At the beginning, the reactor is initialized at 100% power, steady state conditions, thermal losses are calculated as about 233 kW and an equal amount of power is supplied by the PI bank. Transient starts 15 (fifteen) seconds later. The two cases represent different choices of backup banks configuration, as shown below.

Pressure Setpoints		Value (Mpa)
Normal pressure		15.50
BU bank #1	Set on	15.35
	Set off	15.50
BU bank #2	Set on	15.25
	Set off	15.50
	Power Partition	
	Case A	Case B
PI bank	1000 kW	500 kW
BU bank #1	300 kW	600 kW
BU bank #2	300 kW	500 kW

Table 1 – Loss of Normal Feedwater Transient: Conditions Used for Case A and Case B

General Comments

As the behavior in both cases were very similar, it is better to comment the transient as a whole and then concentrate on the differences.

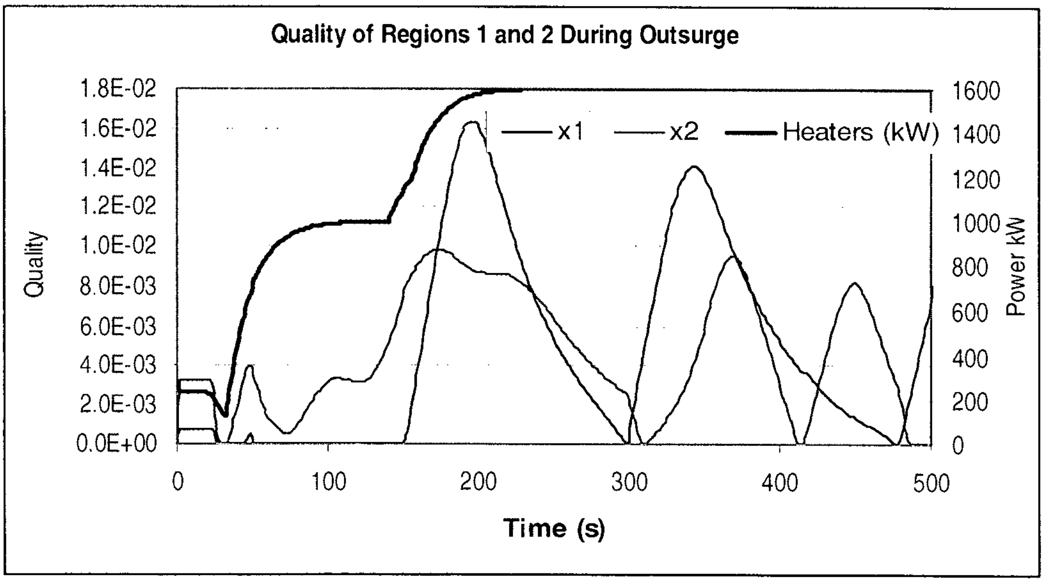

Figure 4 – Quality of the Liquid Regions during the First Phase of the Transient

The surge flow history, generated by a RELAP full plant simulation, presents some oscillations between positive and negative values during the fist 70 seconds, but with a dominance of positive (insurge) flows. However, this pressurizer is more sensitive to outsurges and, although the pressure has gone up in the very beginning, at about 33 seconds it has already dropped below its normal setpoint (15.5 MPa). Due to heaters thermal inertia when the power being delivered to water is starting to decrease (from 22 to 35 seconds) pressure is already decreasing and the PI controllers react delivering power to the heaters. During this short period a combination of heating power smaller than the thermal losses (whose majority is from region 1 to the reactor riser) and negative surge flows (from 29 to 45 seconds) has caused: (a) the pressure to drop, (b) some flashing to occur and (c) the liquid in regions to become subcooled. As the pressure continued to drop, the setpoints of backup heaters are reached (respectively at 140 and 157 seconds) and more heat is imparted to the water, then region 1 has started to show some quality at about 150 seconds.

From this point on, thermal losses became unimportant and the dynamics of the conditions in region 1 and become to show an dumped oscillatory behavior due multiple causes and some of them are commented in the sequence . On the boundary of region 2 and 3 there is some flashing and bubbles crossing to region 3, causing a cooling effect on region 2. Outsurge causes a net flow from region 2 to region 1, which combined with the bubble flow on the reverse direction promotes an homogenization between the properties of the two regions. Considering that the before mentioned phenomena have different time constants, this can explain the calculated oscillatory behavior displayed in figure 4.

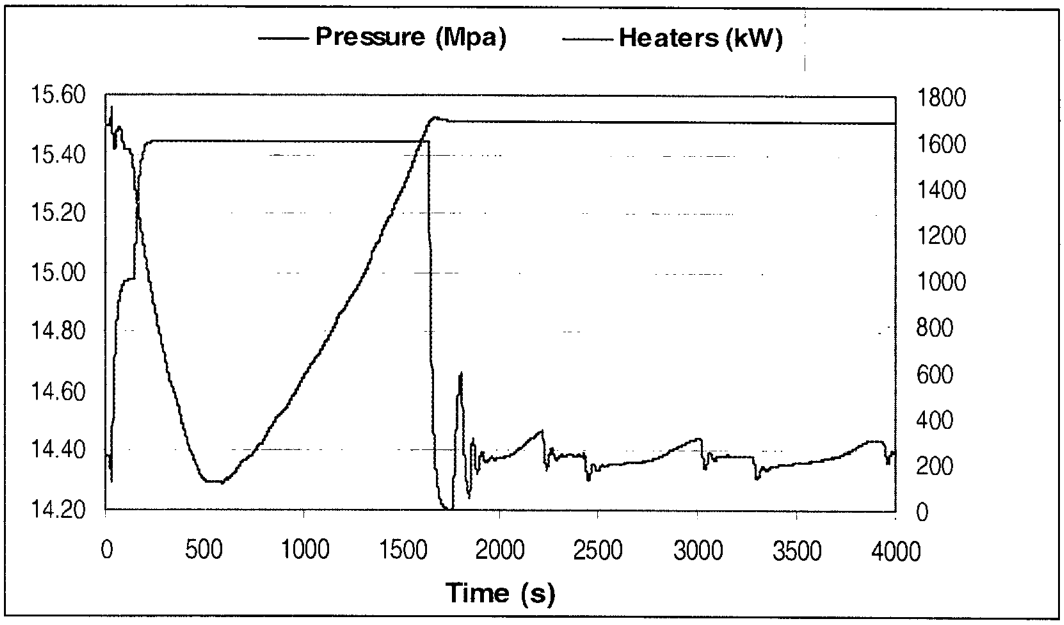

Figure 5 – Pressure and Heaters Power Variation for Case A

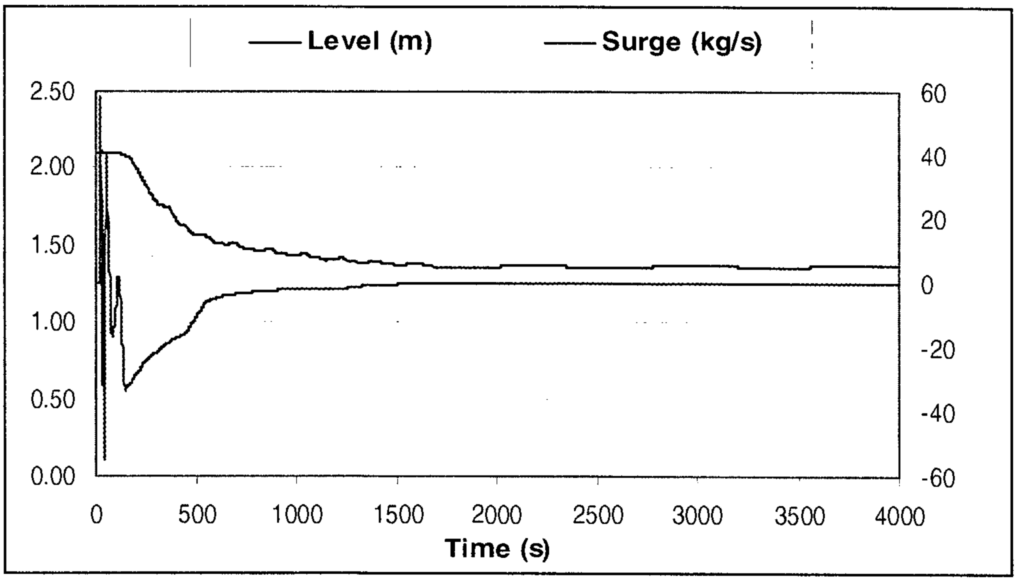

Figure 6 – Pressurizer (Wet) Level and Surge Flow Variation for a Case A.

As it can be seen in figures 5 and 6, after 500 seconds the outsurge flow has become smoother and also has decreased in magnitude to a point that its effect are controllable by the heaters power. As a consequence, pressure has started to recover and at about 1600 seconds it has come back to normal range, with a small but long lasting overshoot.

As one can see, even in such a severe transient, although the level has decreased some 35% as expected, the maximum pressure decrease was only about 7.8%, staying well above the reactor low pressure trip signal. Also the initial pressure increase was less than 0.5%. It must also be noted that the minimum value calculated for level (1.355 m) is comfortably greater than the heaters turn off set point of about 1.1 m.

It should be pointed out that this new pressurizer simulation tool is still undergoing a validation test program and for this reason, until its validation is concluded, these analyses will be employed primarily to provide additional directions to the designers.

Case Differences

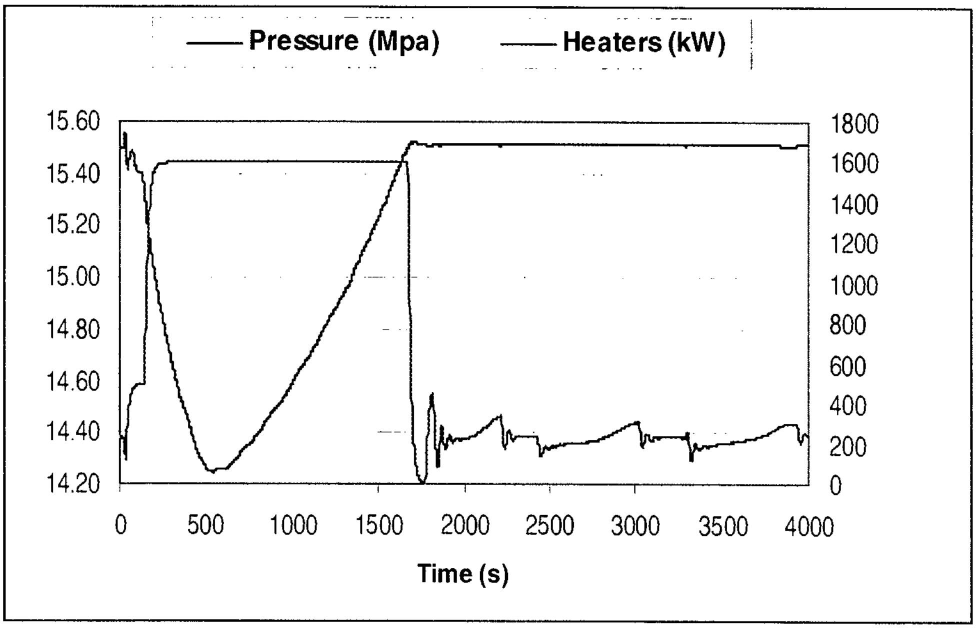

Figure 7 – Pressure and Heaters Power Variation for Case bB

Looking to the Figures 5 to 7 there are no apparent differences between the cases and in fact they are very minor. For case B both the minimum pressure and level were slightly smaller, i. e., 14.291 MPa / 1.3552 m for case A and 14.245 MPa / 1.3483 m for case B. It is fair to assume that for this kind of transient it is not relevant how the total heater power is divided between PI and backup banks.

5 CONCLUSIONS

The IRIS pressurizer design is rapidly proceeding to a final design configuration. Detailed analyses are being used to optimize some critical design areas and are confirming that all the functional requirements set for the IRIS pressurizer will be met, with margin available to accommodate design changes and optimizations.

The design approach that is followed, presents sufficient diversity of means to analyze and validate the design to give good assurance that the optimal design performance will be achieved.

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