The Integrated Approach to the Accident Evaluation for Advanced LWRs

Francesco Oriolo, Sandro Paci

Dipartimento di Costruzioni Meccaniche e Nucleari, via Diotisalvi, 2 56126 - Pisa (Italy)

Abstract

The present paper discusses some relevant phenomena occurring in advanced LWRs during postulated accident scenarios. In particular, the operation of ESF is the starting point for analysis of those phenomena that cause the mutual influence between PS and containment in these plants. As a consequence, it is highlighted as accident analyses which treat PS and containment phenomena completely separated may be not adequate when applied to innovative reactors. Exemplified thermal-hydraulic analyses are presented for AP600 and SBWR, using the FUMO integrated model, for highlight accident evolution taking into account these interactions. The architecture of this integrated code is presented highlighting the importance of an integrated approach to the safety analysis in innovative reactors.

Introduction

All innovative reactors have challenged code developers with special characteristics of systems to be analysed, in particular concerning the thermal-hydraulic simulation [1]. As is clear from the working principles of their ESFs, based on passive systems, the stronger coupling that exists in these reactors between PS and containment phenomena during accident conditions with respect to the present NPP generation, requires an integrated simulation of both systems in order to get a reliable information. This is essentially because, in advanced LWRs, almost all accident sequences are changed in low-pressure scenarios by PS depressurization procedures. The ESFs operation, performing some basic safety functions, was taken as a basis for classifying phenomena or aspects that cause the mutual influence between PS and containment in a previous paper [2]. For instance, in SBWR, the timing of operation of GDCS strongly depends on the differential pressure between PS and containment; therefore an accurate evaluation of pressure in both systems is required [3], together with an accurate PCCS characterisation.

Accident analyses which treat PS and containment phenomena as completely separated are not adequate when applied to advanced reactors [4]. In fact, with the sequential calculation approach, which uses PS calculation results to define mass and energy releases to be used in containment calculations, approximate boundary conditions are applied to reactor coolant loop and inaccurate sources are obtained for containment pressurisation especially when, after depressurization, sub-critical flow conditions are possible. Only a continuous interaction between PS and containment models can lead to the evaluation of the tight coupling existing between the two systems. The FUMO integrated code [5], presented in the following of the paper, is an example of this integrated approach, supplying to a well assessed containment code the lacking information on boundary conditions.

Safety Characteristics of Innovative Reactors

Innovative reactors represent an evolution of proven reactors in which the aspects related to passive and inherently safe characteristics of the plant are strongly enhanced. Moreover, thanks to the simplifications introduced in the plants and to the adoption of protection systems based on readily understandable principles, innovative reactors may promote a greater public acceptance of nuclear power. In addition to the power reduction, the adoption of simplified systems accomplishing the basic safety functions (i.e., control of coolant inventory, control of reactivity, decay heat removal and fission product retention), making use of natural forces only, helps to increase the “walk-away time”, that is the period during which no external actions are needed to maintain the plant safety. These passive safety features should not have the characteristics of “first of a kind” systems but should be chosen among proven devices of well known behaviour. Nevertheless, as they are intended to withstand a wide range of accident conditions, they must be thoroughly analysed both experimentally and theoretically to assess their characteristics. In particular, as the driving forces available to perform their function are generally weaker than in corresponding active safety systems, studies must be carried out to make sure that they are enough strong to cope with postulated accidents.

A consequence of the introduction of passive devices to inject coolant is the decrease of the pressure value of that must be reached to obtain the long term cooling of the plant. While in proven reactors a depressurization down to about 2. MPa was enough to start the RPV flooding by the active low pressure injection systems, in innovative reactors the pressure equalisation between PS and containment is needed to start the water injection from the large capacities included inside the containment. Therefore, ADS must be introduced to change every high pressure sequence in a low pressure one, in the aim to let a quicker gravity driven coolant injection.

In both AP600 and SBWR reactors, after a postulated LOCA, the core decay heat is rejected from the containment to the environment by passive mechanisms, including natural circulation and vapour condensation. In particular, in AP600, vapour condensation occurs on the internal surface of the steel containment liner and is routed toward the reactor cavity. External spray systems enhance the heat transfer from the outer liner surface in the medium term, while air natural circulation provides a sufficiently effective heat removal mechanism in the long term. The lower containment compartments are designed to collect water from the PS and from the storage tanks in order to maintain a minimum water level above the main cooling lines. This creates natural circulation flow paths involving both PS and containment which accomplish long term core cooling and decay heat removal. In SBWR, vapour from the DW is condensed in HXs having drain lines connected with the GDCS pool, while venting lines discharge noncondensable gases in the WW. From the GDCS pool, water is continuously fed to the RPV where it is vaporised and again discharged to the containment through break and valves. The above points out that the PS behaviour in innovative reactors is strictly linked to thermal-hydraulic phenomena occurring within the containment. In fact, the way the mentioned natural circulation flow paths take place depends on the containment geometry and cooling efficiency and on the location of valves and breaks through which different flow patterns may occur.

Modelling Requirements

The serial approach adopted for current generation NPPs, in which the results obtained in the analysis of PS are used to evaluate containment behaviour, is no more suitable for innovative reactors [6]. In fact, by a serial approach neither the right boundary conditions are made available to study PS behaviour nor the correct STs are obtained to analyse containment pressurisation and long term cooling. As a consequence only integrated PS-containment analyses are capable to give a consistent picture of accident scenarios. Present PS computer codes are not qualified to cope with containment phenomena and difficulties were found even in their use for the simulation of innovative reactor PS scenarios [1], especially when low pressures and noncondensable gases are involved. On the other hand, containment analysis tools have generally no capability to adequately represent PS. The optimum solution [4] in this respect could be the development of a new code, or the qualification of an existing one, in order to get a tool capable to treat simultaneously PS and containment with a reasonable computational efficiency.

In the case in which only PS or only containment phenomena are mainly addressed, approximate representations of the containment behaviour, in the former case, or of the reactor response, in the latter, may be considered acceptable. So, existing qualified codes for PS or containment analyses may be coupled with simplified modules supplying the lacking information on boundary conditions. Such an approach, which is more attractive if fast-running code performances are needed, has been adopted at DCMN, where a simplified PS module [5] was set up, to be coupled with the FUMO containment code.

The Integrated FUMO Code

DCMN started the integrated thermal-hydraulic analysis approach by upgrading the FUMO containment code [7], developed to analyse transients in LWR containments, with the introduction of a PS module called SIMSIP. In this integrated tool for advanced NPPs [5], containment models are the same as in FUMO stand alone. Various models can be used to define thermodynamic conditions: the common choice is to consider a two-region model, consisting of a homogeneous air-water mixture and a liquid pool with allowance for presence of 6 non-condensable gases chosen among most significant ones in SAs. The effect of hydrogen production by corium-water interaction and combustion are also taken into account. PS is simulated by a simplified module (SIMSIP); homogeneous equilibrium balance equations consider the contributions of both the junctions which connect volumes and of those used to simulate the operation of various injection devices (e.g., ESFs, level control systems, etc.) and the connections with the containment. Passive injection devices involving water storage tanks are simulated by a quasi-steady model which takes into account water discharge from a tank with a pressure behaviour calculated by the containment module.

Validation of tools for so long lasting transients is a difficult task due to the lack of applicable down-scaled data, especially for combined behaviour of PS and containment. As a consequence, no direct validation of an integrated code can be presently performed. The alternative is to separately validate PS and containment modules, thus obtaining a qualitative idea of the accuracy in the prediction of known phenomena. In this respect, the containment module has been thoroughly validated, also for advanced NPPs [8]. Concerning PS module, the usual assessment procedure, based on analysis of separate effect and integral tests is not applicable. This is due to the model simplicity and considering also the module purpose, being to supply containment with realistic boundary conditions in long term analysis. A model shakedown was carried out by comparing its results with those obtained by other PS codes for some relevant transients and a limited assessment based on the analysis of PS simulators has been also performed for both SBWR and AP600 [6].

Relevant SBWR Phenomena

The containment model adopted for SBWR has 13 control nodes (Fig. 1). DW is split into three main volumes: cavity, lower DW and upper DW. Also the RPV head zone belongs to the DW, together the GDCS pool and PCCS. Vents were not treated as independent but were collapsed in the upper DW. Only one volume was employed for the WW. The external building is split into five volumes: one (not represented in Fig. 1) where all the small cubicles around the reactor cavity and the WW were collapsed; another for the refuelling zone (not in Fig. 1), and the others for the IC and PCCS pool zones. For junctions, the three vents are particularly relevant, together with the VB between DW and WW, and the junctions linking the PCCS to the DW, to the WW and to the GDCS. A particular modelling was used for the structure that represents tubes of PCCS HXs. In fact, the outer pool level can significantly

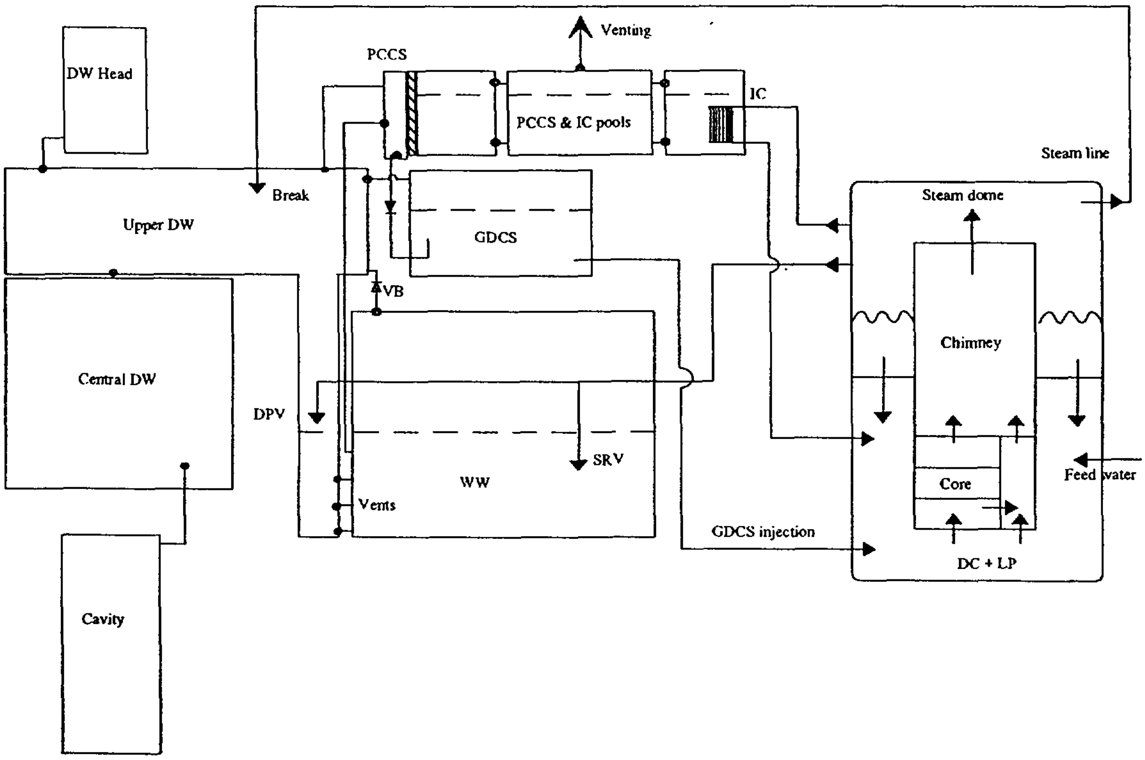


Fig. 1: Nodalization of SBWR plant for the integrated FUMO code

decrease during a sequence, resulting in degraded heat transfer capabilities. HX surface is therefore split into two regions, the first submerged in the pool, the second uncovered. Their area is varied during the calculation according to the pool level. The RPV loop is modelled by seven volumes, still obtaining a reasonable representation of reactor phenomena. Lumped parameter models simulate the FW line, the steam lines and the various ESFs. Significant phenomena to be evaluated in this context are:

- degree of thermal stratification achieved in the pools, which affects both the capability to store the energy coming from steam condensation and the vapour partial pressure above the free surfaces;
- efficiency of PCCS and IC in removing the decay heat, considering the effects of noncondensable gases and the gravity heads in the lines which connect the HXs with the DW and the WW.

Different assumptions concerning this phenomena may result in strongly different predictions of the pressure trend. In particular, since the level of containment pressurisation is determined by the vapour and noncondensable partial pressures in the WW, assuming a higher PSP surface temperature leads to predict a higher overall pressure. On the other hand, if a similar assumption is made for the water contained in the vent pipes, a lower rate of condensation of DW vapour onto the liquid is obtained because of the increased surface temperature. This turns out to decrease the predicted containment pressure, owing to the reduced energy transfer from DW to PSP. In fact, in this case most of decay power is routed to the PCCS.

Sensitivity studies were performed with the integrated FUMO to understand the relevance of the mentioned phenomena in the long term after a MSLB [9]; firstly, a dynamic phase is experienced in which vent pipe clearing occurs and the steam is condensed in the PSP; at the same time, the great part of noncondensable gases is transferred from the DW to the WW. Later on, the above mentioned heat transfer mechanisms come into play, determining the containment pressure trend. As far as vapour condensation onto pool surfaces is concerned, it was necessary to three different sensitivity calculations:

1. condensation on vent pipe water evaluated assuming the superficial pool temperature equal to the average liquid temperature (maximum credible condensation rate) (label "max cond");
2. condensation on vent pipe water neglected ("no cond");
3. condensation evaluated by a realistic model taking into account pool side thermal resistance on the basis of a free convection model ("realistic").

In Fig. 2 the calculated long term pressure trends in the DW are shown. It can be seen that in the cases without condensation and with realistic modelling of pool resistance, DW pressure show a very limited increase with respect to the third case. It must be emphasised that FUMO predicts, in some phases of the transient, an almost complete clearing of non-condensable gases from the DW, to which the vent pipes belong. This condition could be not appropriate to represent the air zone of the vents, where an high condensation rate on the pool surface would lead to a high local gas concentration, greatly inhibiting continued condensation. This local effect cannot be simulated adequately by a lumped parameter code as FUMO, leading to the prediction of a very high condensation rate. Nevertheless, it can be noted that the containment design pressure (483. kPa) is well above the maximum pressure

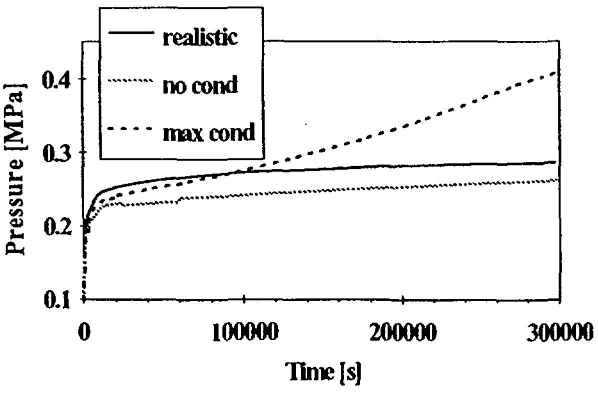


Fig. 2: SBWR - DW pressure with different assumptions about condensation.

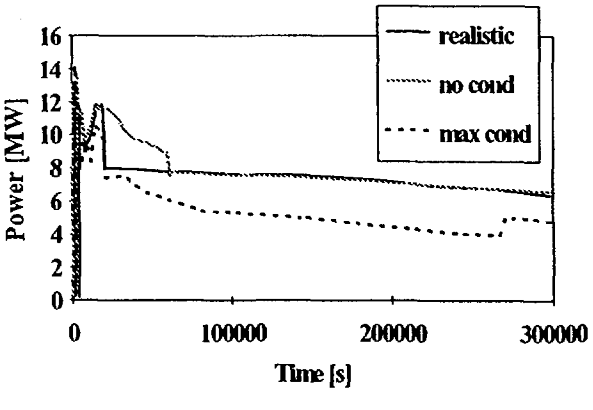


Fig. 3: SBWR - PCCS power with different assumptions about condensation.

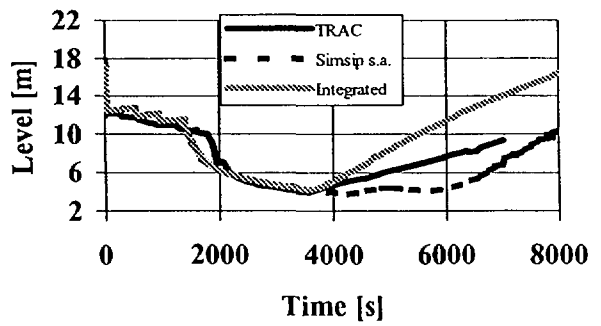


Fig. 4: SBWR LOFW - DC level.

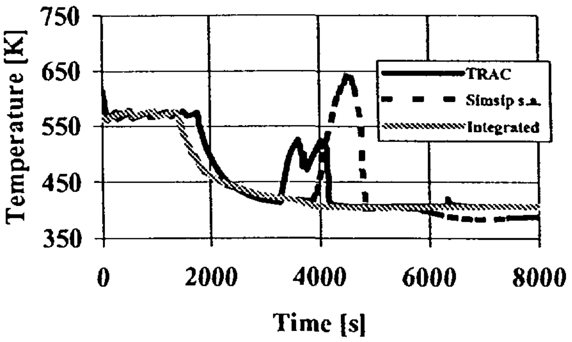


Fig. 4: SBWR LOFW - Core rod temperature.

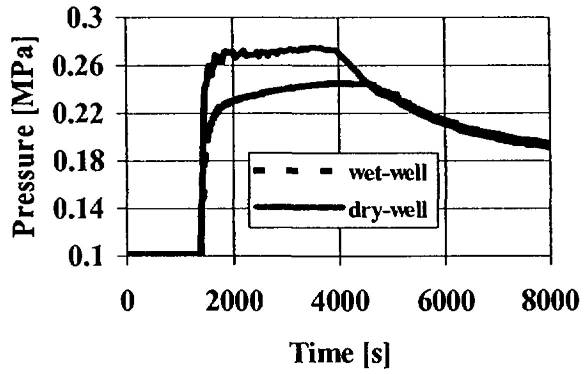


Fig. 6: SBWR LOFW - DW and WW pressures (integrated).

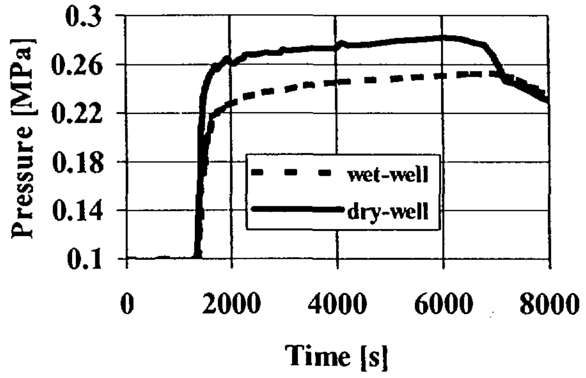


Fig. 7: SBWR LOFW- DW and WW pressures (stand alone).

reached at the end of the three days period, even with very conservative assumptions about condensation. This demonstrate the strong safety margins considered in the SBWR design.

Figure 3, reporting the power extracted by the PCCS for the three cases provides the reason for the differences in the containment pressure trends. In fact, as previously noted, a greater vapour condensation on water in the vent pipes decreases the amount of vapour available for condensation in the PCCS and is responsible for storing decay energy in the PSP. This, in turn, determines the long term increase of containment pressure.

The relevance of an integrated approach on SBWR analysis is highlight in a sensitivity LOFW sequence with conditions of degraded ESF performance [9]. Figures 4 and 5 compare results obtained by integrated FUMO and by SIMSIP stand-alone, with a TRAC run. DC levels and core rod temperatures show the effect of the different assumptions adopted for containment pressure on GDCS intervention timing and then on the core cooling conditions. In stand-alone module, the containment pressure was set to a constant value drawn from previous separate calculations; on the other hand, in both integrated runs, the actual containment pressurisation was simulated, leading to a higher dry-out. Finally, Figs. 6 and 7 show the differences between integrated and stand-alone calculations on the side of containment phenomena. The feedback of containment pressurisation on DPVs flow rate results in different DW and WW pressure histories. In particular, equalisation of the pressure in the two compartments is predicted earlier in the integrated code than in the separate calculations.

Relevant AP600 Phenomena

Figure 8 shows the complete AP600 nodalization for FUMO integrated (LOFW sequence). For the internal containment a 11 control nodes have been employed, while four nodes have been developed for the external space between the steel containment shroud and the concrete shield. To better simulate the spray effects, the temperature of the gas mixture in the node 13 (ascending gap) is not a lumped value but the vertical temperature profile of the air and of the water film along the height of the steel containment vessel is evaluated, hence an equivalent heat transfer coefficient is derived. For simulating the heat capacity of the solid structures, 94 heat slabs and 2 cylindrical sinks are used. The steel containment liner was split in two structures in order to allow the simulation of a partial wetting of its

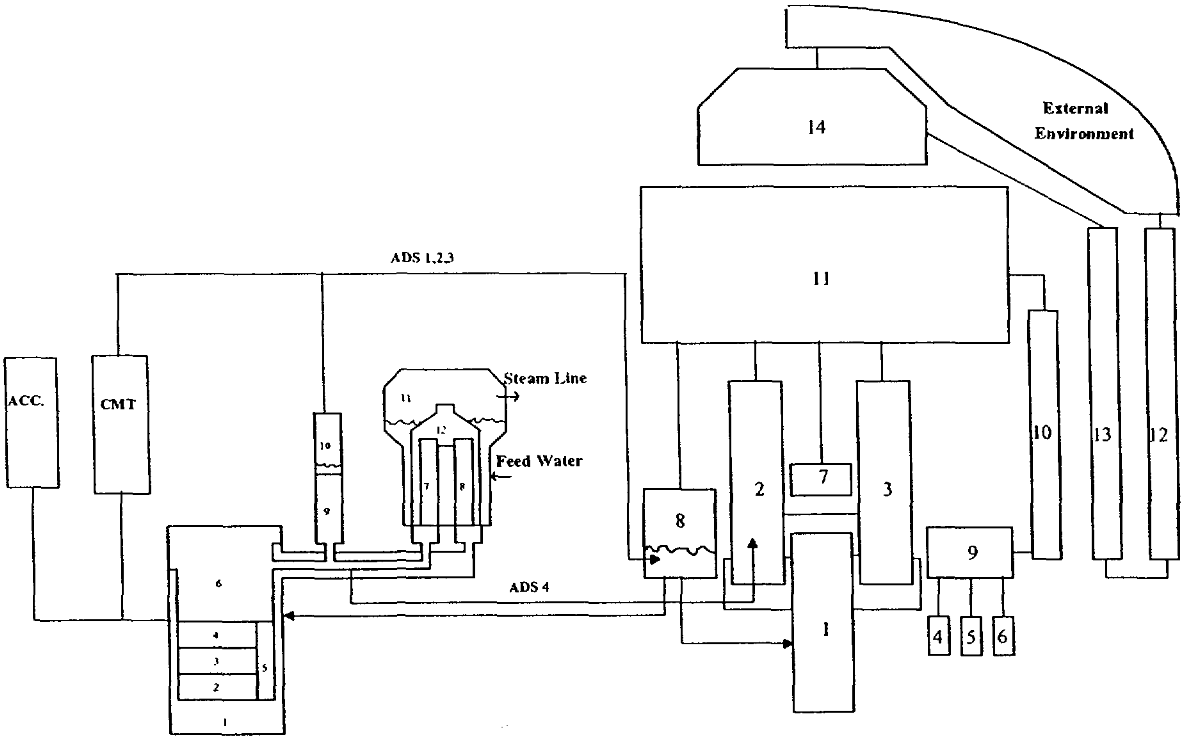


Fig. 8: Nodalization of AP600 plant for the integrated FUMO code.

surface. There is an intrinsic limitation in this hypothesis, representative of a situation where the bad water distribution occurs at large scale, and not at small scale, as expected. If a frequent alternation of wet and dry zones is present, the thermal conductivity of the metal liner is probably able to make the liner temperature uniform and enhance the heat transfer. The employed approximation should therefore provide conservative results.

The PS nodalization has been set-up to obtain a reliable model essentially oriented to provide the mass and energy exchange terms to the containment module. It can be noted that the two cooling loops of the AP600 plant have been collapsed in a single equivalent loop. Clearly such an approximation does not allow to appreciate asymmetrical behaviour of the cooling loops in some accident scenarios. However it is considered suitable to provide reasonable blow-down terms to the containment even in such conditions. The PS model consists of 12 control volumes, 17 implicit junctions connecting the control nodes among themselves, 18 heat structures and 16 (Large LOCA sequence) or 20 (LOFW sequence) explicit junctions inter-linking the control nodes of the PS with the containment nodes.

The spectrum of the studied sequences is restricted (only two scenarios have been considered), and it is therefore not straightforward to draw conclusions about the AP600 containment system. There are however some typical characteristics of this plant that have been pointed out: the pressure level achieved in the long term is a direct function of the equivalent external heat transfer coefficient and the pressure peaks inside the containment are rapidly reduced by the PCCS. Even in the worse case from the point of view of the pressure load on the containment, i. e. the Large LOCA sequence, the pressure is kept well below the required limits. There is of course an intrinsic limit in the pressure reduction, linked to the absence of active systems. High temperature, and in consequence high pressure, is the only driving forces for carrying outside the decay heat, so in the long term, the pressure trend is almost flat, and, unless some active system is activated, can only decrease following the decay heat generation.

Analysis of a Large LOCA Sequence

The purpose of these analyses is to assess the long term behaviour of the system in order to check if the PCCS concept, together with the heat sinks, is able to guarantee the desired safety margins. This sequence was calculated until 250,000. s. Following the break opening and the subsequent reactor scram, the RPV rapidly depressurizes from the nominal pressure of about 15. MPa to about 0.25 MPa (Fig. 9) and in a very short time attains the containment pressure that is meanwhile increasing due to the

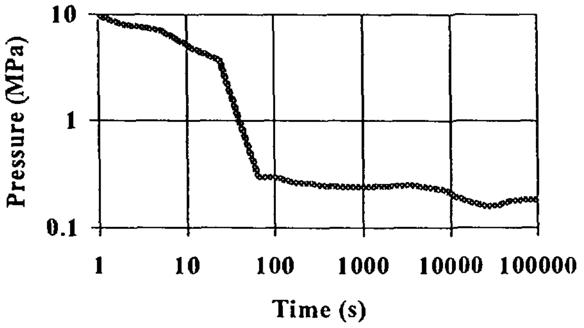


Fig. 9: AP600 LOCA - RPV Pressure.

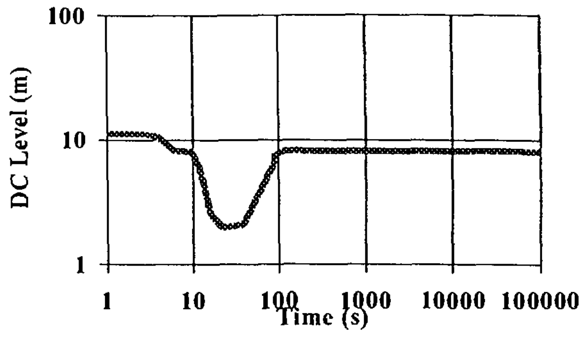
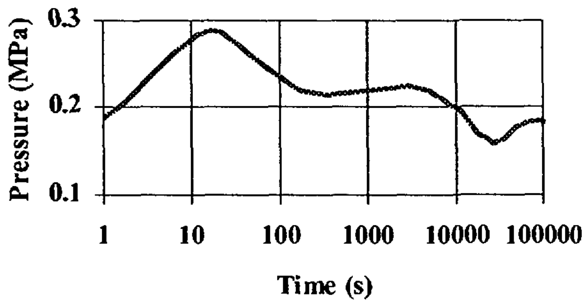


Fig. 10: AP600 LOCA - DC Level.



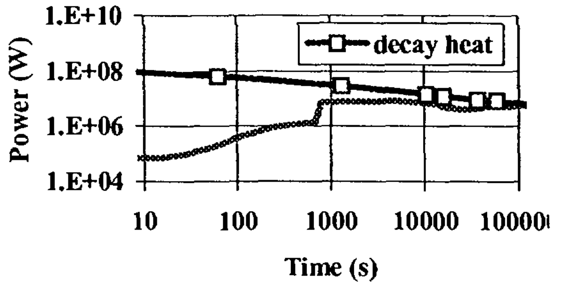


Fig. 11: AP600 LOCA - Containment Pressure.

Fig. 12: AP600 LOCA - Power removed.

blow-down from the break. The water collapsed level in the DC (Fig. 10) sharply decreases during the first phase of the transient and it is restored by the accumulator, CMT and IRWST injections.

Concerning the mass and energy exchange between the PS and the containment system, a phenomenon deeply influencing the containment pressure stands out from the calculation. The flow-rate from the break show a temporal window between about 6,000. and 40,000. s where the flow is constituted by a steam/liquid water mixture. This window is linked to the period of high injection rate from the IRWST and leads to a depressurization of the containment system due to the reduction of the steam production. After this period the IRWST injection rate is considerably reduced by the equilibrium that is reached among the injection tank level and the levels present inside the RPV and the sump of the SG room where the break is located.

In Fig. 11 the pressure trend in the containment internal volumes is shown. It is characterised by two initial peaks, the first one linked to the main coolant release, the second one to the release of the latent heat contained in the SGs and also linked to the effect of the thin metallic structures. The pressure is rapidly dropped by the operation of the PCCS system. In the phase between 10,000. and 40,000. s its value becomes very small, due to the lack of a significant steam source, as previously discussed. In the long term (100,000. s) an almost stationary pressure level is reached; ~~this~~ pressure level is not strongly dependent on the accident history but it mainly derives from the evaluation of the global heat transfer resistance given by all the mechanisms which play a role in carrying the decay heat outside the containment, in particular on the external side. In the long term phase of the sequence, the decay power is in equilibrium with the exchanged power (Fig. 12). On the contrary, in the previous phase the decay energy is also transferred to the containment structures and to the IRWST water. So, the thermal-hydraulic conditions that are reached are strongly dependent on the PCCS operation.

Analysis of Long Term Core Cooling Recirculation

After the complete loss of the normal FW, a reactor trip, caused by the FW/steam flow mismatch signal, occurs at the time of about 4. s. The SG isolation, with the MSIV closure, follows at time of about 20. s. With SG isolated, the decay power transferred from the primary to the secondary side of SGs, causes an increase of the steam pressure until the set-point of SG SRV 1 is reached. The steam discharge through SRVs causes a SG secondary side mass decrease. The decay heat is removed by the SG SRV operation and the PS (Fig. 13) undergoes to a slow depressurization. Due to the continuous decrease of

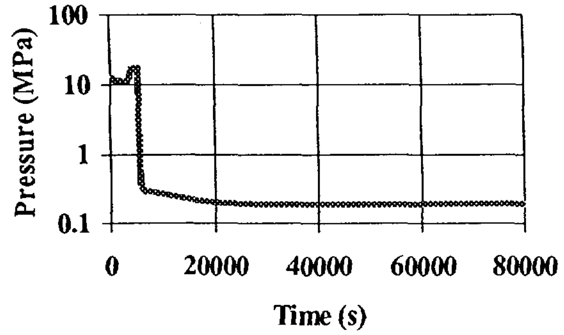


Fig. 13: AP600 LOFW - RPV pressure.

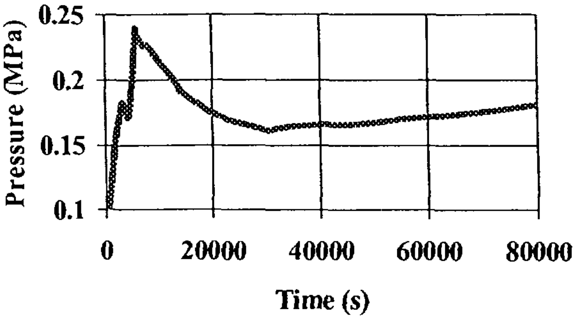


Fig. 14: AP600 LOFW - Containment pressure.

the level in the SG secondary side, the heat transfer from the PS to the SG is progressively reduced, so the PS pressure increases and the pressurizer SRV set-point is reached. Coolant is lost through the pressurizer SRV and the PS mass inventory decreases. Meanwhile the fluid temperature rises, the CMT actuation signal is reached. After about 5,000. s from the beginning of the transient, the 1st stage of ADS opens followed by ADS 4th stage and a drastic reduction of PS pressure and water inventory is observed. An increase in the water inventory follows the accumulator intervention. After the further PS depressurization, due to the ADS, the IRWST injection finally occurs. During this sequence the source of the containment pressurisation is the steam released from the SG secondary side and overall from the ADS 4th stage. The total pressure trend inside the containment is given in Fig. 14. The peak which occurs at about 5,000. s is rapidly dropped by the cooling action of the heat structures and by the PCCS. The containment repressurization, at about 30,000. s, is due to the decreasing of the IRWST water level below the ADS1 injection elevation, leading to a steam release directly in the atmosphere of the containment.

Conclusions

In the previous sections some aspects involving an effect of the containment phenomena on PS accident evolution have been discussed for AP600 and SBWR. General design features were briefly outlined with reference to the passive safety features introduced to cope with postulated accidents. The strong coupling existing between the two systems has been the main outcome of the discussion.

The need for integrated calculation tools capable to analyse the whole plant is the obvious conclusion on the side of accident analysis. In fact, with the conventional serial approach making use of codes for separate analyses of PS and containment, it is very difficult to obtain reliable information on boundary conditions to be applied in the study of the two systems. Various choices in the development of such integrated tools are possible, including qualification of existing PS codes for containment analyses and coupling of PS and containment qualified codes. The particular choice adopted at DCMN, i.e. the development of a simplified PS module to be introduced inside the FUMO containment code, has been highlighted. The code has been obtained by coupling a well assessed containment code with a PS module developed on the basis of engineering approximations. The tool is mainly intended for the prediction of containment phenomena; the objective for introducing the PS module in FUMO was to partly eliminate the uncertainties about releases of mass and energy from the PS which arise in separate calculations. Nevertheless, the results obtained in SBWR and AP600 applications show that indications on the overall reactor behaviour can also be obtained. This information could be used as a basis for further and more sophisticated PS analyses, aimed at investigating more subtle local details.

Some characteristics of the long term behaviour of the two plants have been highlighted. In particular, the performed sensitivity analyses demonstrated the need for the development of models providing BE description of phenomena as pool stratification and surface condensation and for condensation in PCCS and IC conditions. In fact, the competition between the various heat transfer mechanisms in the containment determines the long term pressure trend. But, in the two plants, there is an intrinsic limit in the pressure reduction, linked to the absence of active systems. High temperature, and in consequence high pressure, is the only driving forces for carrying outside the decay heat, so in the long term, the pressure trend is almost flat, and, unless some active system is activated, can only decrease following the decay heat generation.

Abbreviations

ADS	Automatic Depressurization System
ASME	American Society of Mechanical Engineering
BE	Best Estimate
CMT	Core Makeup Tank
CSNI	Committee on Safety of Nuclear Installations
DC	Down-comer
DCMN	Dipartimento di Costruzioni Meccaniche e Nucleari
DPV	Depressurization Valves
DW	Dry Well
ESF	Engineering Safety Features
FW	Feed Water
GDCS	Gravity Driven Cooling System
GE	General Electric
HX	Heat Exchanger
IAEA	International Atomic Energy Agency
IC	Isolation Condenser
IRWST	In Containment Refuelling Water Storage Tank
JSME	Japanese Society of Mech. Engineering
LOCA	Loss Of Coolant Accident
LOFW	Loss Of Feed Water
LP	Lower Plenum
LWR	Light Water Reactor
MSLB	Main Steam Line Break
MSIV	Main Steam line Isolation Valve
NPP	Nuclear Power Plant
PCCS	Passive Containment Cooling System
PRHR	Passive Residual Heat Removal
PS	Primary System
PSP	Pressure Suppression Pool
RHR	Residual Heat Removal
RPV	Reactor Pressure Vessel
SA	Severe Accident
SBWR	Simplified Boiling Water Reactor
SG	Steam Generator
SRV	Safety Relief Valve
TCM	Technical Committee Meeting
VB	Vacuum Breaker
WW	Wet Well

References

[1] F. D'Auria, M. Modro, F. Oriolo, K. Tasaka *"Relevant thermal-hydraulic aspects of new generation LWRs"*, CSNI Specialist Meeting on Transient Two-Phase Flow, System Thermal-hydraulics, Aix-en-Provence (F), 1992.

[2] W. Ambrosini, A. Manfredini, F. Oriolo, S. Paci, *"The influence of containment response on PS accident evolution in innovative LWRs"*, IAEA TCM on "Advanced Containment Technologies", Aix-en-Provence (F), 1992.

[3] B.S. Shiralkar, R.E. Gamble, G. Yadigaroglu, *"PCCS Performance in SBWR"*, International Meeting on Advanced Reactor Safety ARS'97, Orlando (USA), 1997.

[4] F. Oriolo, S. Paci, F. Parozzi, *"An integrated approach between PS and containment to evaluate Source Term in advanced LWRs"*, International Meeting on Advanced Reactor Safety ARS'97, Orlando (USA), 1997.

[5] W. Ambrosini, P. Barbucci, G. Fruttuoso, A. Manfredini, G. Mariotti, F. Oriolo, *"An integrated model for evaluating the thermal-hydraulic behaviour of PS and containment in innovative LWRs"*, International Conference on "Design and Safety of Advanced NPPs", Tokyo (J), 1992.

[6] W. Ambrosini, G. Fruttuoso, A. Manfredini, F. Oriolo, S. Paci, *"The Coupled Phenomenolgy of Accident Evolution for Containment and Primary System in Innovative LWRs"*, Post-SMiRT 14 Seminar "Passive Safety Features in Nuclear Istallations", Pisa (I), 25-27 August 1997.

[7] A. Manfredini, M. Mazzini, F. Oriolo, S. Paci, *"The FUMO code manual"*, DCMN University of Pisa, RL 533 (92), 1992.

[8] F. Oriolo, S. Paci, *"Validation of the FUMO code for analysis of gas distribution phenomena in a LWR containment system"*, 22nd Spanish Nuclear Society Meeting, Santander (E), 1996.

[9] W. Ambrosini, P. Barbucci, V. Cavicchia, G. Fruttuoso, A. Manfredini, G. Mariotti, F. Oriolo, S. Paci, *"PS and containment phenomena during SBWR accident sequences"*, ASME/JSME 1995 Conference "Validation of System Transients Analysis Codes", Hilton Head South Carolina, 1995.