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FRESSURE LOADINGS OF SOVIET-DESIGNED VVER REACTOR RELEASE MITIGATION STRUCTURES FROM LARGE-BREAK LOCAs*

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*This work was performed by U.S. DOE Analysis Team.

Pressure loadings of Soviet-designed VVER reactor release mitigation structures from large-break LOCAs*

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INTRODUCTION

Analyses have been carried out of the pressurization of the accident release mitigation structures of Soviet-designed VVER (Water-Cooled, Water-Moderated Energy Reactor) pressurized water reactors following large-break loss-of-coolant accidents. Specific VVER systems for which calculations were performed are the VVER-440 model V230, VVER-440 model V213, and VVER-1000 model V320. Descriptions of the designs of these and other VVER models are contained in the report DOE/NE-0084. The principal objective of the current analyses is to calculate the time dependent pressure loadings inside the accident localization or containment structures immediately following the double-ended guillotine rupture of a primary coolant pipe. In addition, the pressures are compared with the results of calculations of the response of the structures to overpressure. The structural response analyses are presented in a companion paper belonging to the proceedings (Kulak, Fiala, and Sienicki, 1989).

Primary coolant system thermal hydraulic conditions and the fluid conditions at the break location were calculated with the RETRAN-02 Mod2 computer code (Agee, 1984). Pressures and temperatures inside the building accident release mitigation structures were obtained from the PACER (Pressurization Accompanying Coolant Escape from Ruptures) multicompartment containment analysis code developed at Argonne National Laboratory. The analyses were carried out using best estimate models and conditions rather than conservative, bounding-type assumptions. In particular, condensation upon structure and equipment was calculated using correlations based upon analyses of the HDR, Marviken, and Battelle Frankfurt containment loading experiments (Schauer, 1984). The intercompartment flow rates incorporate an effective discharge coefficient and liquid droplet carryover fraction given by expressions of Schwan determined from analyses of the Battelle Frankfurt and Marviken tests (Schwan 1983).

RESULTS

VVER-440 Model V230

The VVER-440 model V230 is a nominally 440 MWe (1375 MWt) PWR that does not incorporate an emergency core cooling system or a full containment. Instead, an emergency makeup capability that can deliver about 100 cubic meters per hour of coolant is provided together with an "accident localization system" assumed to have a total internal volume of 11900 cubic meters. The Soviet design basis accident is the rupture of a 10 centimeter inner diameter pipe with

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unidirectional flow through a 3.2 centimeter diameter flow constrictor. In the event of larger-sized breaks beyond the design basis, the accident localization system is equipped with vent valves that vent excess steam and air from the localization volume directly to the atmosphere outside the reactor building. Figure 1 shows the multicompartment representation of the accident localization system assumed in the analysis. Nine one meter diameter vent valves were assumed to be located in the half of the steam generator compartment in which the break occurs. The reactor pressure vessel upper head is located inside an accident localization compartment assumed to be normally isolated from the other localization compartments by rupture discs installed inside six 20 centimeter diameter interconnecting ducts.

Figure 2 shows the pressure calculated inside the accident localization compartments during the first minute following the double-ended guillotine rupture of a 50 centimeter inner diameter primary coolant outlet pipe. The steam generator compartment pressure rises above a value of 0.18 megapascal absolute (0.08 megapascal overpressure) at which the first vent valve begins to open, at one second after the onset of the break. The pressure is calculated to attain the design value of 0.20 megapascal absolute at which the remaining eight vent valves begin to open, at about two seconds. At this time, the rupture discs installed in the six ducts leading to the upper portion of the reactor shaft containing the reactor vessel upper head are assumed to break. Venting of steam and air through the flow area of the vent valves is effective in preventing the pressures inside the accident localization compartments from exceeding the design pressure. Venting to the atmosphere is calculated to continue for an interval of about fifty seconds. After this time, the steam formation rate near the end of the primary coolant system blowdown is calculated to decrease causing the pressures inside the accident localization system to decrease and the vent valves to close.

Following closure of all the vent valves, operation of water droplet sprays to condense steam and decrease the temperature can reduce the pressure to that exerted by the air remaining inside the accident localization compartments. By this means, the pressure can be subsequently decreased to a minimum subatmospheric value calculated to equal 0.073 megapascal absolute. Over a longer timescale, additional air will leak back into the accident localization volume.

At the design pressure, extensive localized concrete cracking is calculated through the partial thickness of the steel-lined, reinforced concrete walls and floors of the rectilinear accident localization volume (Kulak, Fiala, and Sienicki, 1989). However, gross structural failure is not predicted to occur as the cracks do not extend through the full concrete thickness and neither the steel reinforcement nor the steel liner are calculated to fail.

VVER-440 Model V213

The VVER-440 model V213 incorporates an emergency core cooling system and an accident localization system of about 45000 cubic meters total internal volume that includes a bubbler-condenser tower pressure suppression system. The bubbler-condenser tower houses a number of floors each containing many bubbler condenser trays with subcooled water to condense steam formed during the blowdown following a primary coolant pipe rupture. The tower also houses air trap receiver volumes into which air is expelled through the bubbler-condenser trays and check valves, in order to establish subatmospheric pressures inside the compartments in which the primary system components are located. Unlike the VVER-440 model V230, the VVER-440 model V213 does not incorporate vent valves that discharge to the atmosphere. The Soviet design basis accident is the rupture of a 50 centimeter inner diameter primary coolant pipe.

Figure 3 shows the pressure calculated inside the accident localization volume for the first minute following the rupture of a primary coolant outlet pipe. The pressure inside the steam generator compartment is calculated to attain a peak pressure of 0.20 megapascal absolute, compared with the Soviet design pressure capability of 0.25 megapascal absolute. Similar peak pressures are obtained for the case of an inlet pipe break. The pressure inside the air traps initially lags behind that in the steam generator compartment and the vertical shaft inside the bubbler-condenser tower that convects steam to the various floors of trays. This lag reflects the relatively small flow area through the check valves leading to each air trap. At one minute following break inception, about one-fourth of the steam formed is calculated to have been condensed inside the bubbler-condenser trays. The present calculations do not model the effects of passive sprinkler phenomena accompanying the backward expulsion of water from the bubbler-condenser trays. Additional condensation induced by passive spray effects would result in a more rapid decrease in the pressures inside the accident localization volume than predicted by the calculations.

One minute following break inception, the active sprays are assumed to begin injecting water droplets into the steam generator compartment. Condensation of steam upon the water droplets together with condensation upon structure is calculated to reduce the pressures to subatmospheric values in less than sixteen minutes. Cycling the sprays off and on between pressures of 0.085 megapascal absolute and 0.095 megapascal absolute is calculated to maintain the pressures in this subatmospheric range. Over a longer timescale of tens of hours, air will gradually leak into the accident localization compartments.

At the calculated peak pressure loading, the concrete and steel reinforcement of the rectilinear accident localization volume walls and floors are calculated to respond elastically without undergoing cracking (Kulak, Fiala, and Sienicki, 1989).

VVER-1000 Model V320

The VVER-1000 model V320 is a nominally 1000 MWe (3000 MWt) PWR that incorporates a large, dry-type, full containment having a volume of approximately 65000 cubic meters that completely enclosing the primary coolant system. The Soviet design basis accident is the rupture of an 85 centimeter inner diameter primary coolant pipe.

Following the double-ended guillotine rupture of a primary coolant inlet pipe, a peak pressure of 0.32 megapascal absolute is calculated (Figure 4) relative to the containment design pressure of 0.5 megapascal absolute. A similar maximum pressure is predicted for the break of a primary coolant outlet pipe. Assuming that the containment sprays begin injecting water one minute after the break occurs, steam condensation upon water droplets is calculated to reduce the containment pressure to near atmospheric by less than eighteen minutes following break inception.

CONCLUSIONS

With as-designed functioning of the accident mitigation features, the pressures inside the VVER-440 model V213 accident localization system and VVER-1000 model V320 containment are calculated not to exceed the Soviet design basis values following the rupture of a primary coolant pipe. At the calculated peak pressures, damage to the VVER-440 model V213 accident localization system walls and floors is not predicted. For the earlier VVER-440 model V230, a large break loss-of-coolant accident is calculated to result in pressurization to the design pressure resulting in opening of all of the vent valves and release to the atmosphere of radioactive steam and possibly radionuclides for a period of nearly one minute.

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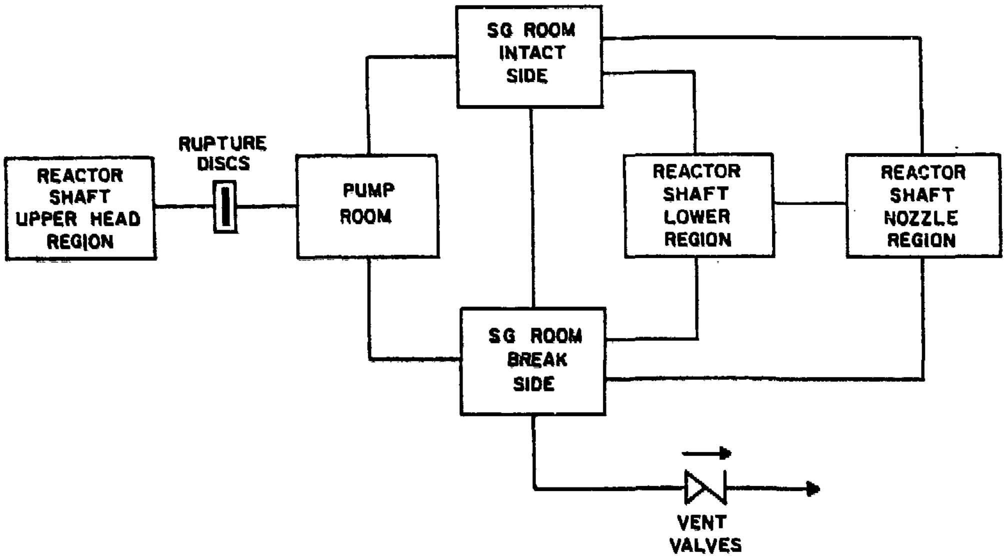

Figure 1. Multicompartment Representation of the VVER-440 Model V230 Accident Localization System.

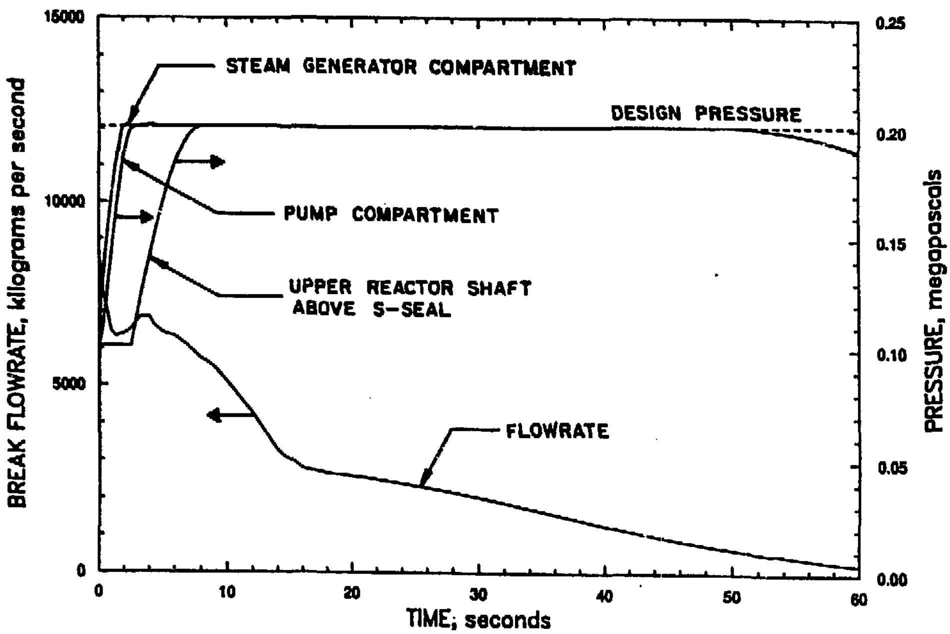

Figure 2. Pressure Loading of VVER-440 Model V230 Accident Localization Volume Following a Primary Coolant Outlet Pipe Break.

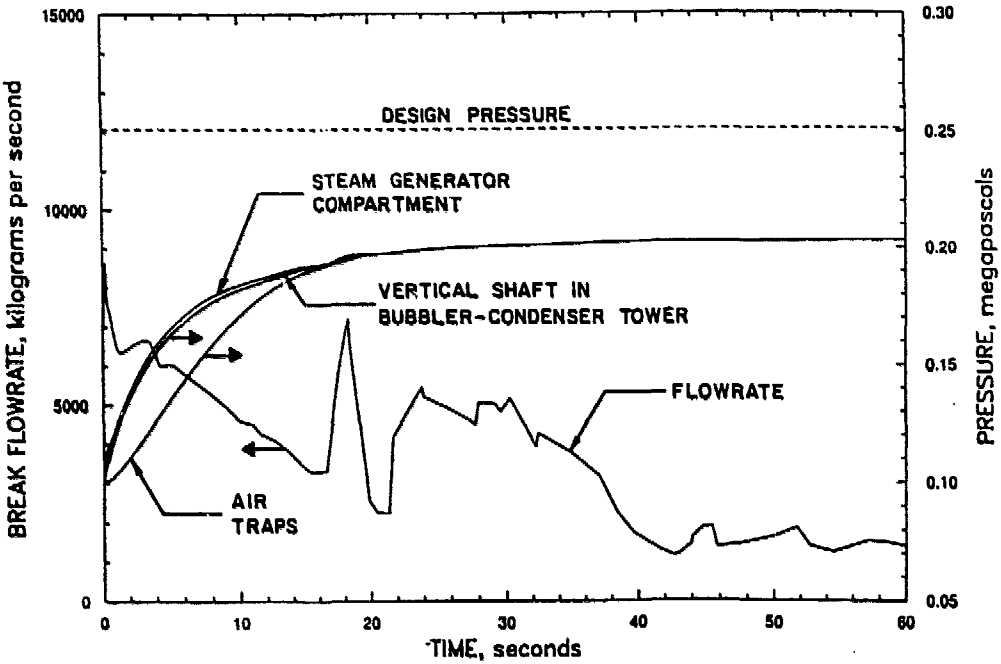

Figure 3. Calculated Pressure Loading of VVER-440 Model V213 Accident Localization Volume Following a Primary Coolant Outlet Pipe Break.

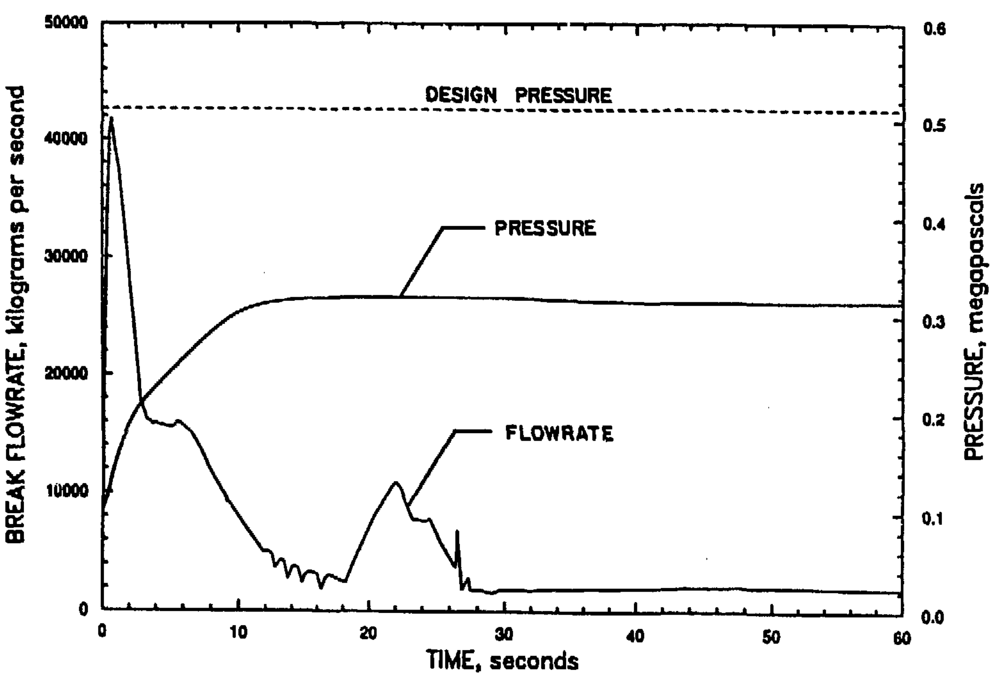

Figure 4. Calculated Pressure Loading of VVER-1000 Model V320 Containment Following a Primary Coolant Inlet Pipe Break.