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Letter to the Editor

Design Robustness and Safety Adequacy of India's Fast Breeder Reactor

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The article of Ashwin Kumar and M.V. Ramana published July 21, 2009 related to safety of the Indian 500 MWe Prototype Fast Breeder Reactor (PFBR) focuses particularly on the positive coolant void coefficient, core disruptive accident and containment. This article highlights the robust design and safety features that have been incorporated in PFBR.

Sodium coolant used to remove the heat from the core in a sodium-cooled fast reactor can boil once its temperature exceeds about 900°C and produces voids. In a fast spectrum reactor, once these voids are formed at the center, they introduce positive reactivity. The fact is that such a positive void coefficient by itself is not a concern, in view of the feedback coefficients like fuel Doppler effect (higher neutron absorption cross-section at higher fuel temperature) and fuel expansion coefficient, which are much stronger and act well ahead of the occurrence of significant sodium boiling, thereby keeping the power coefficient of reactivity negative at all operating and accident conditions. However, adopting the defense in-depth philosophy, neither bulk coolant boiling nor burnout at local hotspots is allowed during any design basis events postulated in the event analysis. Any possibility of blockage of sodium flow to fuel subassembly or global flow reduction is prevented by several core design features, such as multiple radial entry holes for the coolant in the grid plate sleeve and subassembly foot, adapters to provide an alternate passage for the coolant in the event of blockage at the top and sufficiently high flywheel inertia to ensure very slow flow reduction under the loss of power supply to the primary sodium pumps. Moreover, multiple fault detections by measuring the sodium

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temperature rise at the subassembly outlet by thermocouples and detecting the anomalous reactivity by reactivity meter in the case of sodium boiling or gas passing through the core, can minimize the risk of accident. Analysis indicates that the whole core sodium void coefficient in PFBR is two times the delayed neutron fraction (a nuclear fission releases on an average 2 to 3 neutrons). Most of the neutrons are released in a very short time of 10^{-12} seconds. However, a small, but very influential fraction of neutrons called delay neutrons are produced from fission fragments' radioactive decay in a time span of a few seconds. In fact, super prompt critical excursion experiments conducted with much higher sodium void coefficient on a test facility in the United States, Southwest Experimental Fast Oxide Reactor (SEFOR), have clearly established that such excursions are very well arrested by Doppler reactivity feedback. Hence, it is understandable that there was no safety incentive to reduce the sodium void coefficient further for PFBR.

As regards to the core disruptive accident, in early years—as early as 1956—this accident was defined with high levels of conservativeness based on which the mechanical energy release had been estimated to give an order of magnitude of high energy release. This has been quoted by the authors. Subsequently, a vast spectrum of data accumulated over the years through realistic numerical and experimental simulations of severe accident scenarios with refined neutron cross section data have helped to understand the mitigating effects of delayed neutrons, Doppler feedback and fuel movement within the cladding. In view of the above, much reduced energy release will happen. The trend of considering lower energy release, or even core disruptive accident not to be considered in the design, can be seen internationally.

Comprehensive safety analysis carried out for PFBR, involving the possible initiating events, indicates that the mechanical energy release is insignificant (<1 megajoule), caused by loss of flow accident in conjunction with the complete failure of two shutdown systems. It is worth mentioning that the complete failure of both shutdown systems is a very low probability event ($<10^{-6}$ / y). However, in view of the fact that the PFBR is the first power generating reactor being constructed in the country, it has been decided to consider a moderate energy release of 100 mega joules for which the reactor containment building has been designed. This has been approved by the safety committee after in-depth deliberations. Compared to the mechanical energy values expressed in terms of fraction of thermal power (0.03, 0.024, 0.031 and 0.04), considered in the recently designed international reactors, viz. SPX2 (Improved design of SPX1 in France), BN800 (Russian reactor under construction), DFBR (demonstration reactor designed in Japan) and EFR (European Fast Reactor), the value considered for PFBR (0.08) is high.

With reference to the containment issue, the design basis pressure for the containment building of a sodium-cooled fast reactor is derived from the temperature and pressure rise resulting from a sodium fire, consequent to the sodium expulsion from the top shield during a core disruptive accident. It is worth mentioning here that the thermal reactor containment is designed for pressure resulting from a loss of coolant accident caused by the rupture of primary heat transport water piping as well as a steam line break. Containment design against an airplane crash is an independent issue. It is pertinent to note that the containment function for PFBR is needed only in the case of a core disruptive accident. In summary, there is no one-to-one relationship between the containment pressure of sodium-cooled reactors and pressurized heavy water reactors. In fact, the Department of Atomic Energy (DAE) has a sound knowledge of design and construction of containment for heavy water cooled and sodium-cooled reactors.

Apart from the above mentioned arguments, the best design and safety practices, and the lessons learned from about 400 reactor years of fast reactors operating experience, have been incorporated for PFBR. Unlike the fast reactors of the past era, PFBR has been designed with two independent fast acting shut down systems, dedicated decay heat removal system and provision of in-service inspection of the main vessel. Further, a qualified in-vessel core debris collection system, called “core catcher” has been incorporated as a defense-in-depth. Considerable efforts have gone into ensuring the safety of the PFBR through extensive analytical and numerical analyses as well as experimental investigations simulating the actual environments, including sodium and temperatures, which were executed through in-house expertise/facilities and extensive collaborations. Apart from this, the post accident heat removal capability of the four decay heat removal heat exchangers has been ensured by elaborate testing and evaluation by application of twice the design basis mechanical energy release.

More political rather than scientific reasons are behind the adverse posturing of a few countries against fast reactors or for that matter nuclear power itself. Even those countries appear to be slowly and surely walking away from their rigid stand. The comparative assessment of various reactor systems for the future carried out by GEN-IV indicates that the sodium-cooled fast reactor is considered as the earliest realizable advanced nuclear energy system, by 2020.