AGEING MANAGEMENT OF AG3NET NEUTRON BEAM TUBES IN ORPHEE RESEARCH REACTOR

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ABSTRACT

As technical support of the French Nuclear Safety Authority (ASN), the "Institut de Radioprotection et de Sûreté Nucléaire" (IRSN) has assessed, in the framework of the second periodic safety review of ORPHEE research reactor, the risks associated to the loss of reactor's reactivity control. In this context, IRSN was interested in the prevention of AG3NET neutron beam tube breakage. Indeed, these equipments are exposed to irradiation and become fragile. Their complete failure causes a sudden reactivity insertion. Thus, IRSN assessment focused on the ageing management of these tubes. This led the operator to revise the replacement schedule of the tubes and the associated criteria, as regard to safety issues related to the breakage of one or several neutron beam tubes.

1. Introduction

As technical support of the French Nuclear Safety Authority (ASN), the "Institut de Radioprotection et de Sûreté Nucléaire" (IRSN), analyzes periodic safety reviews performed by operators of nuclear facilities. In the frame of the assessment of the second periodic safety review of the French research reactor ORPHEE, operated by the Atomic Energy and Alternative Energies Commission (CEA), IRSN examined the risks of loss of reactor's reactivity control, in particular the scenarios of sudden reactivity insertion. In this respect, the risks associated with the breakage of neutron beam tubes have been evaluated.

The AG3NET involved in ORPHEE's neutron beam tubes, and more generally aluminum alloys, are used in many French research reactors such as Jules Horowitz reactor (JHR) and OSIRIS reactor, also operated by the CEA, and the High Flux Reactor operated by the Laue-Langevin Institut (ILL). Indeed, these alloys are interesting for reactors which produce neutron flux or perform samples irradiation in the core, since they are quite "neutron-transparent". Nevertheless, their mechanical properties evolve with irradiation and they become fragile. Therefore, operators have to pay attention to the ageing management of these materials when they are subjected to neutrons flux.

This paper presents the analysis performed by the IRSN, in the frame of ORPHEE's safety review, concerning the prevention of neutron beam tubes's breakage, considering the evolution of AG3NET mechanical properties with irradiation.

2. Safety issues related to the breakage of ORPHEE's neutron beam tubes

In ORPHEE reactor, nine neutron beam tubes guide the neutron flux from the core towards experimental stations located outside the reactor. For that purpose, the noses of each tube, filled with helium gas, are located near the maximum flux plane, in the heavy water tank surrounding the core (Fig 1).

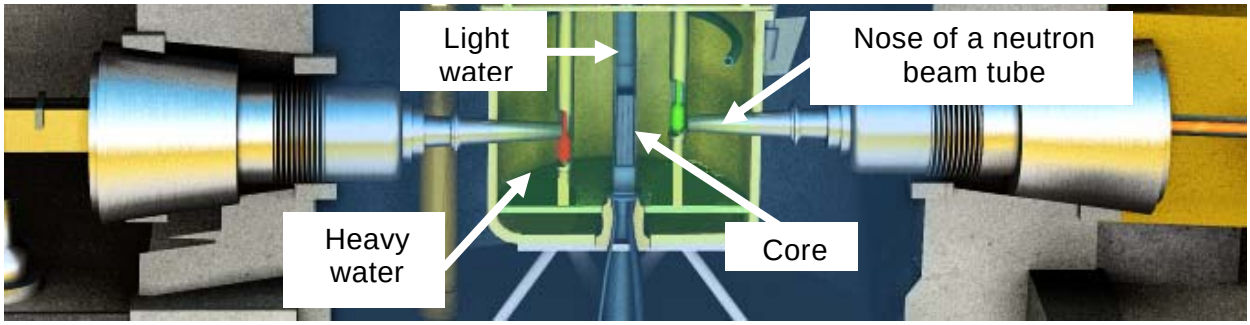

Fig 1. View of the core of ORPHEE reactor

In case of a total breakage of the nose of a neutron beam tube, the flooding of the nose by heavy water (void effect, Fig 2 and 3) or the replacement of the structure of the nose by heavy water (structure effect, Fig 2 and 4) will increase the amount of reflector and moderator nearby the core and then will cause a sudden reactivity insertion.

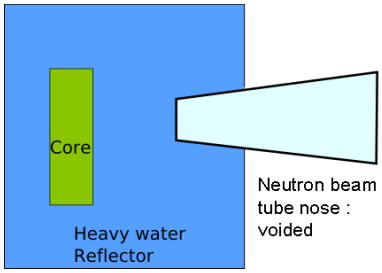

Fig 2. Initial situation

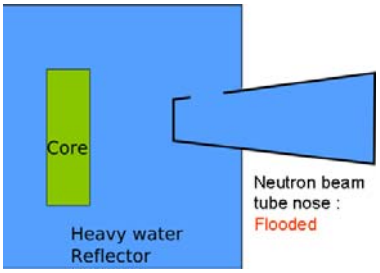

Fig 3. Flooding of the nose

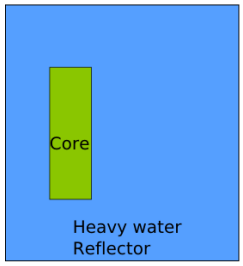

Fig 4. Destruction of the nose

In order to estimate safety issues associated with the breakage of one or several neutron beam tube noses, IRSN has performed, in the frame of the assessment of the periodic safety review, neutronic calculations with the French Monte Carlo code MORET 5 [1].
The study, aiming at evaluating the reactivity worth of each neutron beam tube, showed that the void effect has been underestimated at the design stage. Nevertheless, for most of the tubes, the effect of a nose breakage can be managed by the control rod system and safety issues are linked to the breakage of several beam tube noses with a risk of partial core meltdown, what remains consistent with the safety analysis of the operator. But for one specific neutron beam tube, the study pointed out that its reactivity worth is particularly high and the consequences of its breakage, which are not known yet, have to be evaluated.
Considering safety issues associated with the breakage of one or several neutron beam tube noses, the IRSN then focused on the prevention of these breakages.

3. Neutron beam tubes ageing management

The prevention of the breakage of neutron beam tubes noses mainly relies on the robustness of their design and on the ageing management of these equipments.

Temperature and pressure in ORPHEE's heavy water tank are not very high (maximum 60°C and 3 bars). Therefore stresses on neutron beam tubes noses are not high. Moreover,

neutron beam tubes show very large margins with regard to stress limits defined in construction codes for usual loadings and accidental loadings such as seism (more than 50%).

However, AG3NET's properties evolve with irradiation. Indeed, aluminium disintegrates into silicon, according to the reaction $^{27}Al + ^{1}_{0}n \rightarrow ^{28}Al \xrightarrow{\beta} ^{28}Si$. The silicon formed precipitates with the magnesium of the alloy. This effect is intensified with increasing neutron flux and thermal neutron flux/fast neutron flux ratio. This results in a hardening of the material. Indeed, the yield stress and the ultimate stress increase when irradiation increases but the elongation to failure decreases. This last effect induces a brittle behaviour of the material (Fig 5). Moreover risks of corrosion appear at a high level of irradiation.

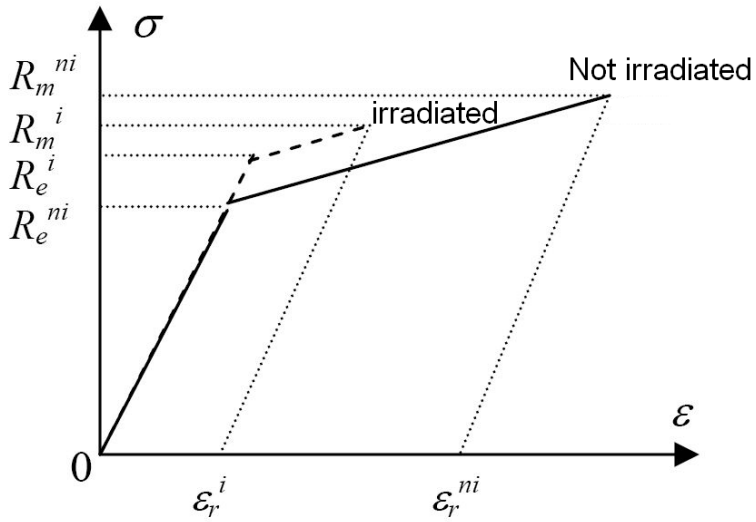

Fig 5. Schematic representation of the evolution of AG3NET mechanical properties (stress σ versus strain ε) with irradiation (R_e : yield stress; R_m : ultimate stress ; ε_r : elongation to failure)

Considering these phenomena, measures, such as replacement of the equipments, have to be taken before the performances of the components are deteriorated to the point that safety requirements could no longer be met.

In the frame of the second periodic safety review, the ORPHEE's operator took into account these irradiation effects since he had established a replacement schedule of the neutron beam tubes depending on a criterion corresponding to an irradiation level of the material. This criterion can also be expressed as a rate of formed silicon, considering the reaction of formation of silicon.

IRSN first assessed this replacement schedule, considering the criterion defined by the operator. As design and construction codes, such as the French RCC-MX (Rules for Design and Construction of the Mechanical Materials of Nuclear Installations), define mechanical stress limits taking into account the evolution of the mechanical properties with irradiation only for a range of irradiation weaker than that of ORPHEE's tube noses, the acceptable limit of irradiation of the noses has been evaluated on the basis of experimental data on the AG3NET from other French research reactors (see RR1 to RR3 on Fig. 6), for the range of irradiation of ORPHEE's tube noses (Fig 6).

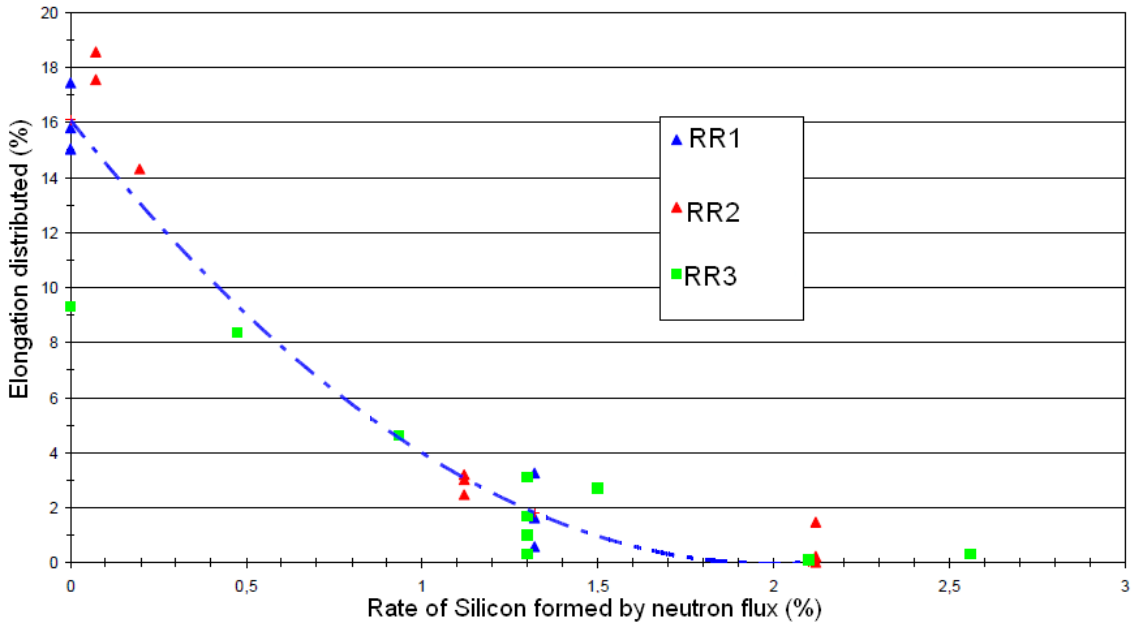

Fig 6. Experimental correlation of the elongation with the rate of silicon formed in the AG3NET with neutron flux

IRSN considered the replacement criterion defined by the operator acceptable to avoid corrosion of the material but not sufficient to avoid a brittle behavior of the material. Moreover, even if the material present large margins as regard to the mechanical limits recommended by construction codes for a lower irradiation, these limits are always determined considering a residual amount of ductility of the material. Therefore, IRSN concluded that the replacement criterion of the operator is unacceptable, despite the weak stresses undergone by the equipment during its life, because it does not guarantee a sufficient residual ductility.

However, as previously seen, safety issues are rather associated with multiple breakages of tube's noses. Therefore IRSN considered that the replacement schedule should be adjusted to avoid the concomitant breakage of several tube's noses since this situation, depending on the tubes involved, can lead to a core meltdown. Finally, IRSN recommended that the operator elaborates a new replacement schedule for tube's noses so that the concomitant rupture of all the brittle tubes's noses does not lead to unacceptable consequences for the core.

4. Conclusion

In view of the assessment performed on the ORPHEE reactor, IRSN considers that the ageing management of the AG3NET tubes must take into account safety issues related to the breakage of these equipments. Moreover, even if design and construction codes take into account irradiation to define acceptable stresses, these codes do no necessarily cover the specific range of irradiation concerned by the equipment.

The analysis process implemented for ORPHEE's neutron beam tubes in the frame of the second period review of the reactor can also be applied to others research reactors such as RHF reactor.

5. References

[1] Y. Chegrani, F. Gupta, S. Pignet, V. Tiberi, L. Heulers, “Safety approach of BORAX type accidents in French research reactors”, Proceedings of the International Conference on Research Reactors : safe management and effective utilization, Rabat, Morocco, 14-18 November 2011, IAEA-CN-188