Safety characteristics of an accelerator driven reactor

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Abstract

The MYRRHA reactor that is being designed at SCK•CEN can operate in both critical and in subcritical mode. This paper present the major differences in the safety behavior of both operational modes.

In a fast reactor designed to effectively transmute very high concentrations of minor actinides into less radiotoxic isotopes, the amount of delayed neutrons is so small that reactivity insertion events can no longer be safely controlled by absorbing rods. In a subcritical mode, reactors with a low fraction of delayed neutrons can still be safely operated. For such reactors an external neutron source is necessary to sustain a steady state power operation. The reactivity response dynamics of such a system is very different from a critical reactor. In principle, the safety case for a subcritical reactor with no delayed neutrons can be successful, if the subcritical level of the system is larger than the amplitude of each fast reactivity injection mechanisms. Since the reactivity injection mechanisms for a subcritical system do not substantially differ from a critical system, a small subcritical level (of 500 pcm for instance) is enough to compensate for the absence of delayed neutrons and to successfully make a safety case. With such a low subcritical level, it would still be necessary to foresee a safety related reactor scram system to compensate for slow and long term reactivity feedbacks, such as power feedbacks and cooldown feedbacks. For MYRRHA the choice was made to operate at a subcritical level that does not need an additional reactivity control to assure safety on the long term. With such choice, reactivity control becomes an inherent property of the design and inherent safety is always the preferred option for safety. For MYRRHA the subcritical level that compensates for all reactivity injection mechanisms and feedbacks is determined to be around 4000 pcm. This is a very conservative value that compensates for all uncertainties and that supposes a very unlikely long term safe state in which the reactor is brought to room temperature.

The response of a strongly subcritical core driven by a neutron source, to an increase of its reactivity that is small compared to the subcritical level, is easy to approximate: at constant beam current the relative increase of power corresponds to the relative decrease of the subcritical level. For MYRRHA, with a subcritical level of about 4000 pcm, a 5% power increase at constant beam current would require a reactivity injection of 200 pcm. A power increase by 5% can be sustained almost indefinitely without safety implications. When MYRRHA is operating in critical mode, the same reactivity injection of 200 pcm requires a reactor shutdown in about 3 seconds, to prevent cladding failure.

The operation in subcritical mode however has a less desirable influence on some unprotected transients. Unprotected transient are postulated in safety analysis to examine the physical behavior and inherent safety of a reactor design. For critical reactors intrinsic negative reactivity feedback are often optimized to increase the survival time for unprotected transients. In case of an unprotected

reactivity injection (UTOP) the Doppler effect and fuel column expansion give a very desirable negative reactivity feedback that importantly increases the survival time for a UTOP. In case of an unprotected loss of flow (ULOF), the reactivity feedback due to temperature increase of the coolant and structures are optimized to improve the survival time for that transient. In a subcritical core these inherent reactivity feedback have a much smaller and in most cases negligible impact on the power of the core. For the reactivity induced UTOP this is irrelevant because the inherent power response of the subcritical system to reactivity increase is benign. For the ULOF however the strong reduction of the impact of the negative reactivity feedback on the power, importantly decreases the unprotected survival time for that transient.

The subcritical operation introduces a completely new mechanism for overpower: the unintentional increase of beam intensity. Neglecting the reactivity feedbacks, a good approximation for a strongly subcritical system, the power is proportional to the source intensity. For the MYRRHA core, we have calculated that an increase of the beam power by 100% requires the shutdown of the accelerator within about 2 seconds to prevent damage to the fuel cladding. Even for lower beam intensity increase the fuel cladding will not survive for long if the transient is not protected. The mechanisms for unintentional increase of beam intensity are complicated and the envelope case will depend on the accelerator design and operation. For the MYRRHA accelerator a maximum allowed beam intensity increase of 80% is specified in the design basis.

The protection of overpower or overtemperature transients in subcritical mode relies on shutting down the accelerator beam. This action is much easier and more reliable to accomplish than the protection of a critical core by insertion of neutron absorbing rods. Therefor the practical elimination of unprotected transients is much more reliable and robust for a subcritical reactor compared to a critical reactor. The postulate of unprotected transients therefor makes much less sense for subcritical reactors. Not only from the point of view of the deterministic safety demonstration but also from the point of studying the physics this postulate makes less sense because the response is simple and there are no design changes possible to improve the physical response.

Subcritical operation introduces one more new risk. The beam line constitutes a bypass of two important confinement barriers: the primary system and the containment. The window that separates in normal operation the accelerator from the is a highly stressed component and therefor the failure of this component is considered to be very likely. The analysis of the phenomena Involved in the unprotected response to a window failure indicate that the integrity of the fuel clad is not compromised and that the activity released from the coolant is limited and will rather contaminate the accelerator than escape to the environment. Beam window failures will therfore not evolve into severe accidents. However, protection is being developed to prevent the contamination of the accelerator during this likely event. This approach will cover the safety demonstration for the public risk.