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Review of the Safety Issue on Automatic Emergency Shutdowns by Negative Reactivity (A.U.R.N.) in Phénix

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1. Introduction

In the end of 1989, the first prototype SFR in the world named Phénix encountered an earlier unexperienced phenomenon that lead to an automatic emergency shutdown by negative reactivity (A.U.R.N. in French) while operating at full power [1, 2]. The signal of the neutron chambers registered very rapid oscillations with high amplitudes. Between 1989 and 1990, four A.U.R.N. occurred at the reactor. These events never occurred from 1973 to 1989, and occurred no longer after 1990.

After the fourth A.U.R.N., the operation of Phénix was stopped and an extensive investigation program was conducted to explain the cause of A.U.R.N.. Although an expert committee including CEA, IRSN, the French Advisory Committee for nuclear reactors etc. studied all possible scenarios, the committee has not find the causes of the event. The committee concluded that assumptions involving outward movements of the core are most convincing.

In this paper, A.U.R.N. as one of important safety issues for SFR is reviewed and the instrumentations and insights for prevention of A.U.R.N. is identified.

2. Negative Reactivity Trips (A.U.R.N.)

2.1 Operation Phases of Phénix

During 35 years from 1973 to 2009, the operations of the Phénix power plant represent 4 phases in Table I [1]. As shown in Table I, it is noted that A.U.R.N. is one of important operation issues in Phénix.

Table I. Operation phases of Phénix

Phases	
1974~1990	Operation and demonstration for this type of reactor
1990~1993	**Investigation subsequent to negative reactivity trips (A.U.R.N.)**
1994~2003	Renovation
2003~2009	Final operation at 2/3 power

2.2 Overview of A.U.R.N.

During the time period between 1989 and 1990, Phénix suffered from A.U.R.N. four times. The events occurred while operating at or close to full power; the first three at 580 MWth and the last one at 500 MWth. A.U.R.N. were all detected by the neutron chambers, which are located beneath the reactor vessel and measure the neutron flux. During all events, the registered signal of the neutron chamber had the following behavior as shown in Fig 1.

1. An almost linear reactivity drop with high amplitude.
2. A symmetrical increase to a maximum below the initial value
3. A second short decrease, though with lower amplitude then the initial reactivity drop
4. A secondary peak, which slightly exceeds the initial power of the reactor
5. A decrease due to the insertion of the control rods into the core (t≈250ms)

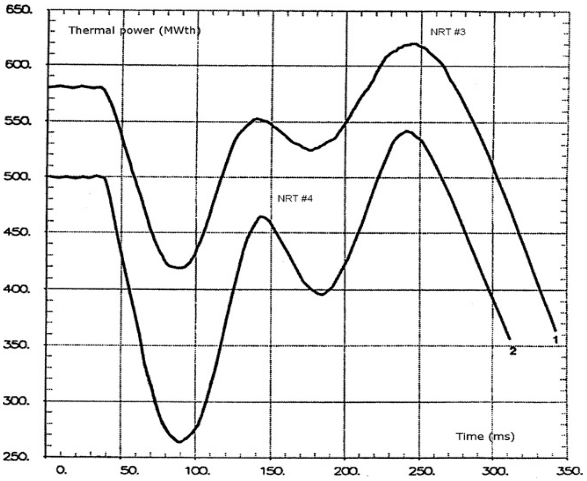

Fig 1. Power signal recorded during A.U.R.N.

2.3 Cause Investigations of A.U.R.N.

After the fourth A.U.R.N., the operations of Phénix were stopped and an extensive investigation program was conducted. An expert committee was appointed (1) to examine every possible cause of the reactor anomalies and (2) to make proposals for preventive measures. After almost two years of investigation, the committee had not found a complete explanation of the phenomenon, though the most probable cause was radial movement of the sub-assemblies.

The latest scenario based on neutronic and thermal−hydraulic interaction between a moderated experimental carrier (DAC sub-assembly) located in the peripheral zone of the core and the surrounding blanket subassemblies lead to a plausible scenario. The conjunction of the increased power in the blankets due to neutron moderation and the low sodium flow in the

DAC can be considered to lead to sodium boiling. The collapse of the sodium vapor bubbles induced core flowering and the corresponding negative reactivity.

2.4 Core Flowering Tests

Core flowering is a type of core movement as shown in Fig 2 and it means that one sub-assembly expands and induces stresses on the surrounding sub-assemblies, causing the core to expand in radial direction:

1. Thermal expansion of the support diagrid or of the wrapper tubes
2. Elastic expansion of wrapper tubes due to internal pressure variations
3. Radial displacement of fuel assemblies

The result from core extension is displacement of the sub-assemblies in the core leading to an increase of the gap between the units. The core extension leads to considerable decrease in the reactivity.

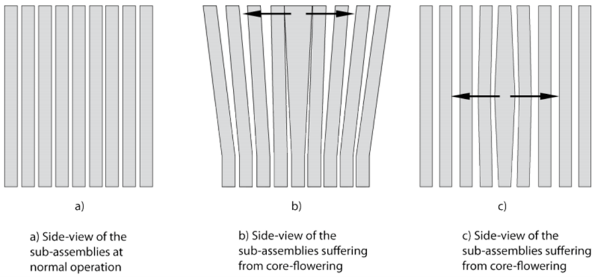

Fig 2. Concepts of Core-Flowering

The reactivity feedback effect induced by core flowering has already been experimentally studied in critical mock-ups such as the ZPPR [4, 5]. In these tests, the bowing and flowering effects were simulated by modifying the fuel and steel compositions or distributions in fixed subassemblies. In EBR-II or FFTF reactors [6, 7], the flowering effect on reactivity was measured and analyzed with irradiated cores by acting on the thermal conditions on wrapper tubes.

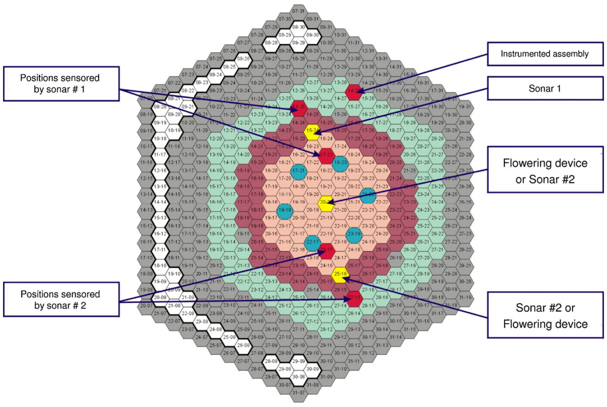

Fig 3. Positions of flowering devices in the Phénix core

In Phénix, the core flowering test was carried out during the last year of Phénix. This was done while the reactor was running at zero power [8]. A mechanical device was inserted into two different positions as shown in Fig 3 such as first at the center of the core and second at a peripheral location of the core.

The mechanical device as shown in Fig 4 put pressure on the surrounding sub-assemblies, causing the gap between all sub-assemblies to increase. The induced stress then resulted in a radial extension of the core and the radius of the core was extended with 3-5 mm. The result was that a small increase of the core radius gives a significant drop in reactivity. In this experiment, the correlation between the negative feedback in k-eff and core extension is about -60 pcm/mm, when the device was placed in the center of the core. The effect was strongly reduced when the mechanical device was placed at the peripheral position.

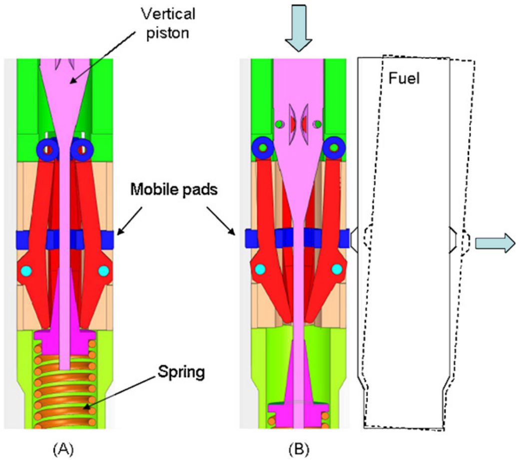

Fig 4. Core-Flowering device: (A)Initial, (B) Flowered

3. Design Considerations for Prevention of A.U.R.N.

Based on the extensive investigation related to A.U.R.N. conducted by the committee, the following instrumentations and insights were identified as the follows [1, 2, 8]:

Instrumentations

1. **Anti-compaction systems**: Phénix used the free standing core restraint concept for keeping the sub-assemblies of the core together, which means that the core support structure is located at the lower part of the sub-assemblies. The concept allows free outward bowing of fuel- and blanket assemblies until the core radius makes contact with the shield assemblies, which are located at the periphery of the core. All the studies have shown that positive reactivity changes were impossible due to anti-compaction systems such as sub-assembly grid straps. These systems are of course to be maintained in future reactors.
2. **Monitoring systems of core movements**: The instrumentation for monitoring of core movements is required to improve a monitoring measure.

Insights

1. Fast reactors are very sensitive to a reactivity change in the event of sub-assembly movement
2. Care is required in setting up irradiation devices in areas where the hydraulic, thermal and neutron fluxes are not well known, not well calculated, monitored.
3. Better understanding is required in the phenomena of gas flow in a reactor and related protection.

The instrumentations and insights as mentioned above are considered to prevent A.U.R.N. for future fast reactors.

4. Conclusions

In this paper, four A.U.R.N. happened in Phénix were reviewed. As the result of the review, the instrumentations and insights for prevention of A.U.R.N. were identified. For future fast reactors, the instrumentations and insight reviewed in this paper are considered in a design stage.

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