
Potential Risk of a Criticality Event During Refuelling

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Abstract: Following a core unloading due to an unscheduled shutdown during the cycle of Dampierre unit 4, the plant operator had to operate the refuelling in its previous configuration. During this operation, the fuel assembly concerned by loading step n° 25 was left in the fuel building and the assembly for the following step, n° 26, was placed in the reactor vessel instead of the previous one, causing an irregularity in core pattern only detected at step no. 139. At that point, the refuelling machine operator realized that he was handling an assembly equipped with its rod cluster, whereas according to his handling sheet, the assembly should not be equipped with. Thanks to the favourable conditions (primary system boron concentration = 2345 ppm and cycle burn-up = 2 GWj/tU), the core remained subcritical. However, the incident analysis revealed a potential criticality risk under less favourable circumstances, i.e. refuelling with fresh 1st cycle fuel assemblies and a primary system boron concentration at the lower limit of the range allowed by the Technical Operating Specifications (2000 ppm). Moreover, further studies have shown that the two neutron source range channels (SRC) are able to provide a count rate (reflecting neutron flux) but would not detect a local increase in reactivity under refuelling conditions (normal or defective), unless a reactive pattern was formed in the immediate vicinity of one of the two channels. However, if the criticality is reached, the SRCs are able to diagnose the critical state from the significant power level of 0.1% rated power. The human error that had led to the administrative validation of a fuel handling step that had not been physically carried out highlighted both the fragility of organizational lines of defence and the inadequacy of I&C systems with regard to technical in-depth defence lines. Following these observations, and beyond the preventive measures supposed to limit the occurrence of a divergence during refuelling operations, the IRSN analysis has concluded to the necessity to implement technical devices allowing, as the reactive pattern is in progress during refuelling, a neutron flux measurement connected to the actual reactivity level.

1. EVENT DESCRIPTION

Unit 4 had been reconnected to the grid on December 28, 2000, following Partial Inspection n° 17.

At the time of the incident on April 1, following an unscheduled shutdown that had occurred on February 23, needing to unload the core of campaign n° 18, Dampierre unit 4 was restarting the refuelling.

On April 1, 2001, at about 1.30 a.m., when the refuelling step no. 22 was engaged, the Control Room warned the Refuelling Supervisor (RS) of the need to reset the "high flux on shutdown" alarm threshold on the neutron source range channels (SRC). The RS interrupted the operation to deposit the element n° 22 in position B8, 70 mm from its final position, in accordance with his work sheet, so as not to interfere with the SRC alarm threshold setting operation.

At this point, the assembly of step n° 23 was in the fuel assembly container, in the vertical position, on the reactor building (RB) side, waiting to be picked up by the refuelling machine which was standing by above the reactor vessel.

The RS in the RB did not inform his assistant in the fuel building (FB) of this refuelling interruption, and fuel assembly handling operations continued as normal in the FB.

In the FB, while the fuel container assembly was still on the reactor building side, the Assistant Refuelling Supervisor (ARS), according to the procedure, signed and dated the assembly n° 24 handling sheet and gave it to the Spent Fuel Bridge Operator (SFBO) to allow the assembly to be picked up. The SFBO then signed the step n° 24 handling sheet, noting the time he had picked up the assembly and gave it back to the ARS who then filled in advance the handling sheet, validated and signed the end of step n° 24 in his detailed operation sheet (note: it is normal for this validation to be done by the ARS, but only after the number of the assembly to be transferred to the RB has been identified and has been put down into the fuel container assembly). The element of step n° 24 was still hanging from the spent fuel bridge waiting to be transferred to the RB as soon as the fuel assembly container would become available. At that time, the ARS phoned the RB and was informed that the refuelling operations had been stopped. The FB team then decided to proceed to a shift.

FB shifts are made by a team of 3 people who periodically rotate from one position to another, between two ARS and one SFBO positions. That means the FB is manned simultaneously by one ARS and one SFBO, while the 3rd person takes a break in the changing room.

The person in the ARS position for the step n° 23, after having validated the step n° 24, prepared in advance the handling sheet for step n° 25 (signed in anticipation) and then decided to take a break without waiting for being relieved of his function. While he was having his break, the refuelling operations kept on being interrupted. When coming back, he decided to end the step n° 24 as ARS and not as a SFBO as he should have done. Afterwhile, he took up the position of SFBO and the ARS position was then occupied by the 3rd person who had a break during the previous steps.

On the desk, the new ARS found the handling sheet for step n° 25 prepared in advance by the previous ARS, however with no SFBO's signature and no mention of the time the assembly had been picked up. At that moment, the SFBO was transferring the assembly of step n° 24 to the RB, thus regularizing the validation of step n° 24.

The new ARS, seeing element n° 24 being transferred to the RB and thinking it was element n° 25, entered an approximate time on the handling sheet for step n° 25 (which is in reality the SFBO's function) and filed it without the required SFBO's signature. He then validated the end of step n° 25 by signing the detailed operation sheet without carrying out any checks (control of the assembly number). He started step n° 26 by handing the relevant handling sheet to the SFBO.

The assembly of step n° 25 thus remained in its storage cell in the FB pit.

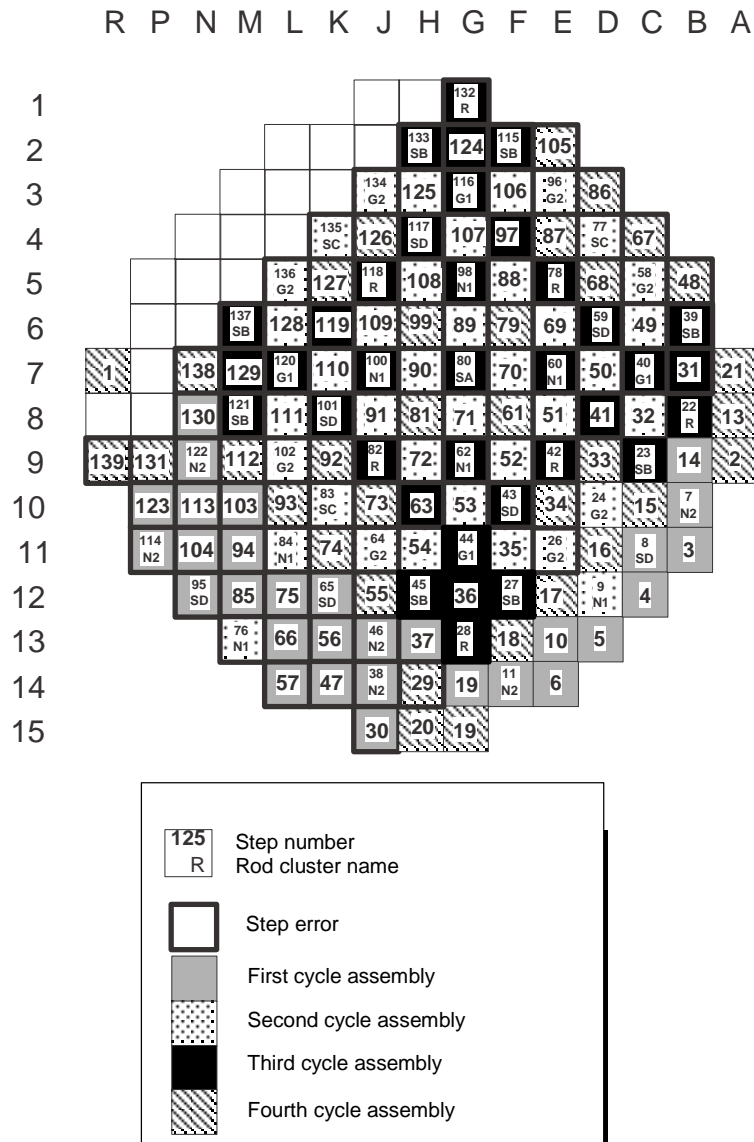
The fuel element of step n° 26 was loaded in the reactor vessel in position E11, that the element of step n° 25 should have occupied. As a result, this step error was passed on throughout the refuelling procedure, until the 138th fuel assembly loading (step n° 139).

At step n° 139, the RB refuelling machine operator noticed that the distribution of rod cluster assemblies in the core under refuelling was not in accordance with the symmetrical pattern expected. At that time, the refuelling operations were stopped.

2. CONSEQUENCES

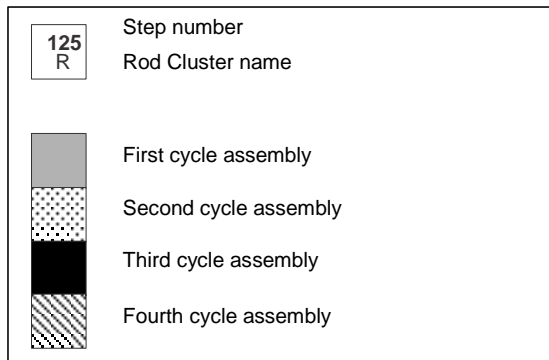
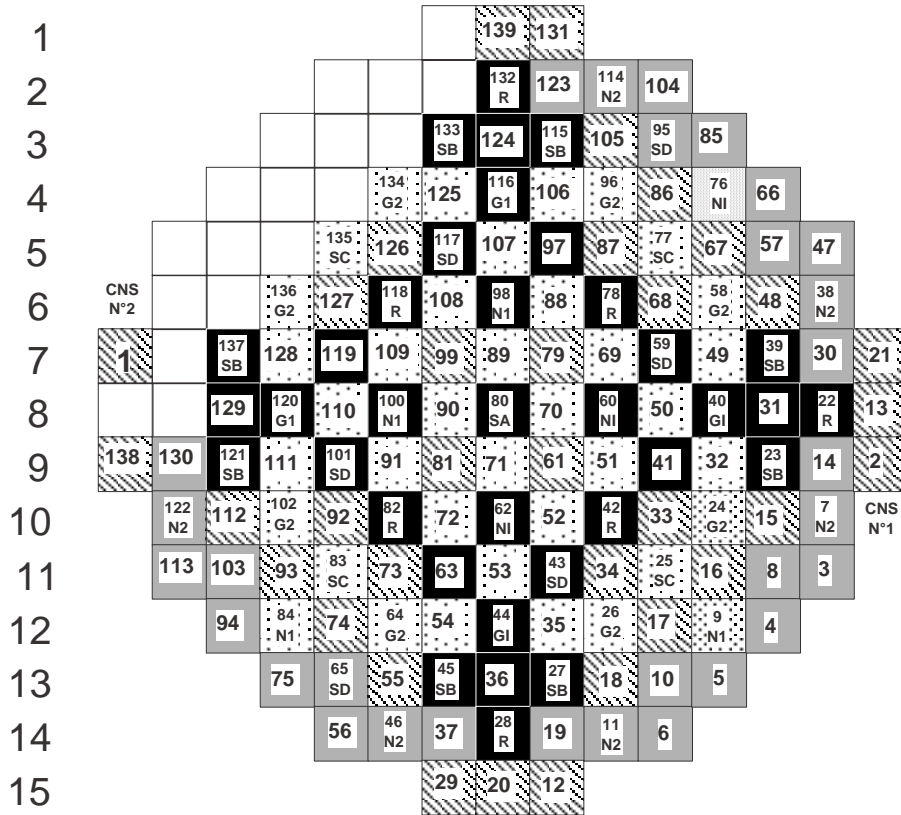
2.1 Actual Consequences

Loading the assembly of step n° 26 in the core in the position of the assembly of step no. 25 led to 113 assemblies being loaded in a wrong position, resulting in an unusual core configuration. A large number of 1st cycle fuel assemblies were loaded in the lower left-hand quadrant as shown below. As a consequence of this core configuration, several 1st cycle assembly patterns (burn-up = 2 GWj/tU) were formed, locally helping to reduce the margin to criticality.



Dampierre Unit 4 Campaign 18 : Core Configuration with handling error

R P N M L K J H G F E D C B A



Dampierre Unit 4 Campaign 18 : Core configuration without handling error

The first two-dimensional calculations of the margin to criticality for the core configuration obtained at the step n° 139 yielded a keff of 0.96. According to the safety analysis report, this value should be less than the reference value of 0.95 (keff = 1 is the value at which criticality is reached). Nevertheless, regarding to criticality aspect due to fuel assemblies mispositioning the value of 0.96 was qualified by EDF as offering some margins with respect to criticality risk, given that the boron concentration in the reactor building cavity remained around 2345 ppm throughout refuelling operations, which is above the 2000 ppm imposed by the Technical Operating Specifications.

The technical operating specifications applied impose a boron concentration of 2425 ppm in the refuelling water storage tank.

2.2 Potential Consequences

Under less favourable conditions (e.g. reactor loaded with fresh 1st cycle fuel assemblies and with a boron concentration of 2000 ppm, the minimum value imposed by the Technical Operating Specifications), a similar error would have caused the reactor to go critical about at the time the 121st assembly was loaded. It has to be said that a study related to Garance fuel management (UO₂, 3,7%), had been carried out in 1991 by the utility to evaluate the criticality risk for different fuel assembly configurations. The refuelling error incident on Dampierre Unit 4 shows several fuel assembly patterns highly similar to the most penalizing cases studied at that time, characterized by a low margin to criticality (150 pcm).

In its initial analysis of this incident, EDF made a pessimistic assessment of the power level liable to be reached by considering the divergence occurring at the time of the loading of the 121st assembly (step n° 122). A penalizing approach consists in considering that the divergence occurs when loading the most reactive fuel assembly close to the 121st fuel assembly, which is the fresh UO₂ assembly loaded at step n° 113 inserting +455 pcm extra reactivity. The formation of this “mini core” made up of a block of highly reactive fuel assemblies would lead to a state of criticality, thereby causing local overheating in the fuel. As the Doppler effect inserts negative reactivity estimated at -111 pcm/% rated power, the increase of power would be stopped when the negative reactivity due to the Doppler effect equals the excess of reactivity brought by the 121st fuel assembly loading. At last, the maximum power level reached would be of $P_{max} = 455/111 = 4.1\%$ rated power. Assuming 20% uncertainty on counter-reaction effects, EDF considered an envelope value of 5.1% rated power to assess personnel exposure risks. This value, as an initial conservative evaluation, has been taken into account until EDF performed finer studies taking into consideration flows in the core during the transient based on a 3D flow modelisation. The conclusions indicated that single-phase conditions should be maintained and that there should have been no departure from nucleate boiling. On the basis of these later conclusions, EDF made a new estimation of the power reached in the event of divergence. The new estimation was less than 1.5% rated power, virtually ruling out the risk of clad failure and the consequent release of fission products.

With regard to radiological consequences in the reactor building, two types of radiation should be considered for personnel protection : neutron radiation and gamma radiation. The main areas exposed to radiation from the core are:

- The 20 m floor, where the dose rate reached would have been negligible because of the 12 m of water above the cavity (providing effective shielding against both types of radiation).
- The primary coolant loops as they are in the direct line of sight of the core. Here, the dose rate would have reached 150 mSv/h (120 for neutron, 30 for gamma radiation), in view of the estimated envelope power level.

In addition to the fact that some teams (working close to the primary coolant loops or the 20 m floor) are equipped with site radiation monitor that would detect and indicate a sudden increase in gamma dose rate, the control room would have triggered the reactor building evacuation warning when the neutron measuring channel thresholds had been reached.

3. SAFETY ISSUES

3.1 Weaknesses in Human Factor and Communication Fields

The refuelling incident results from the combination of several lacks in the organizational procedure. The safety analysis has allowed to highlight the main causes of the refuelling incident, based on human errors, both from organizational aspect and communication. The safety analysis has led to classify the weaknesses identified in two categories of causes designed as “high causality” and “low causality”, according to their contribution to the final outcome.

3.1.1 Lack of communication between the performers located in the FB and in the RB

The operations of the refuelling of the 900 MWe PWR French series are shared by two teams, one geographically separated from the other, located in the fuel building (FB) and in the reactor building (RB) as seen in Appendix 1. As a consequence, the global refuelling process is shifted between the two teams, each acting independently following its own rate. Due to the geographical separation, when one team stops the operations, the other team is liable to go on its own operations. Actually, at the origin of the refuelling incident of Dampierre Unit 4, is the interruption in the RB of the refuelling sequences as required to reset the count rate alarm thresholds on the neutron source range channels (SRC). This interruption was observed in the RB but not in the FB where refuelling operations continued step by step, while the fuel assembly-lifting frame was no more available on this side. Fuel assembly handling steps in the FB, supervised by the ARS were then no more coordinated with those carried out in the RB and supervised by the RS. The analysis highlighted a total lack of communication between the RS and the ARS, during all the fuel assembly handling operations : as a matter of fact, the RS failed to coordinate the refuelling sequence as a whole, from the removal of the assembly from the spent fuel pit (FB) up to its loading into the reactor vessel. Fuel assembly handling operations in the FB and RB were managed in a disjointed manner, with one operating procedure being filled out and validated by the RS in the RB and the other by the ARS in the FB, one independently from the other.

Furthermore, beyond the lack of communication, this incident indicates that no organizational procedure had been set out, firstly to manage any interruption, as the one required by the resetting of the SRC, and secondly to define both the actions to undertake in FB and RB during the shutdown and the conditions to start the operations again.

3.1.2 Fuel assembly identification numbers only performed in FB

The quality assurance for the refuelling is based on the use of detailed operation sheets, one in the FB and one in the RB, identical to each other, corresponding to each step of the refuelling. The checking in the FB of the fuel assembly identification by its own number in accordance with the step operation sheet requirements is the guarantee of an adequate fulfilment of the operations. Fuel assembly identification numbers can be visually checked, in the FB only, by using an underwater camera, and then noted down on the detailed operation sheet. Concerning the RB operations, the refuelling supervisor accepts the assemblies transferred from the FB, following the chronological order of steps listed in his RB operation sheet, without being able to perform any fuel assembly identification numbers. That point reveals a serious lack in the fuel handling process related to refuelling, as no system is available to identify the fuel assembly entering the RB. This aspect has been identified as of major importance in the incident of Dampierre Unit 4 where such a checking would have allowed to prevent from the omission of one step.

3.1.3 Lack of identification of the type of fuel assembly in the RB

The fuel assemblies equipped with rod clusters can be identified :

- Visually in the FB and in the RB
- By manual weighing in the FB
- By an automatic weighing in the RB : the load cell on the refuelling machine automatically distinguishes between assemblies equipped with rod cluster (heavy) from those without rod cluster (light) when it picks them up from the fuel assembly lifting-frame. The difference in weight is about 40 daN.

In fact, according to the local refuelling procedures on Dampierre Unit 4 in use at the time of the incident, the refuelling machine operator in the RB should have checked himself the adequacy of the type of the assembly to be loaded, although an automatic weighing is performed by the refuelling machine.

Furthermore, the analysis has pointed out the fact that all the operators are not capable firstly, to distinguish heavy rod clusters from light rod clusters, and secondly to detect inadequate positions in the rod cluster assembly pattern, thus questioning the adequacy of the skills of the refuelling performers. Actually, considering that the break in the symmetrical pattern expected occurred at step n°29, the refuelling error could have been detected at that time, while the omission has been effectively noticed at step n° 139.

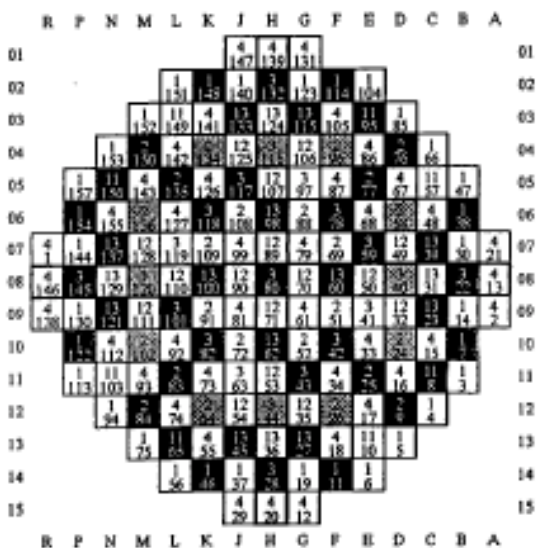
3.1.4 Lack of organizational procedures on the respective roles of the refuelling performers in RB and FB

Finally, the safety analysis highlights that one of the major failures at the origin of this incident is the absence in the organizational procedures of a clear distribution of the functions of the refuelling performers which led to the confusion at the time of job changeovers in the FB with regards to the respective function of each performer and the transmission of the instructions between teams at the relief time.

3.2 Questioning on nuclear safety technical concerns

3.2.1 Introduction

The incident, which occurred on Dampierre Unit 4, is characterised by the fact that 113 fuel assemblies have been misplaced, before the error was detected. Considering this, the consequences of the error in terms of a potential reduction of the margin to criticality during refuelling have been evaluated in order to check if the criticality could have been reached in less favourable conditions (BU = 0 GWj/tU, boron concentration = 2000 ppm) due to the 1st cycle assembly high concentration in the lower left-hand quadrant, and in that case if the detection of its approach would have been efficient.

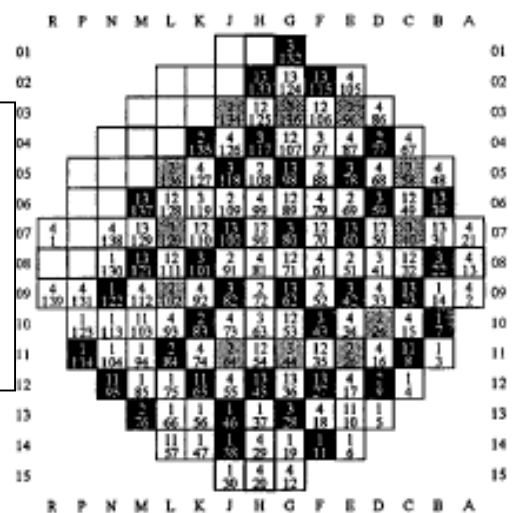


Normal Refuelling

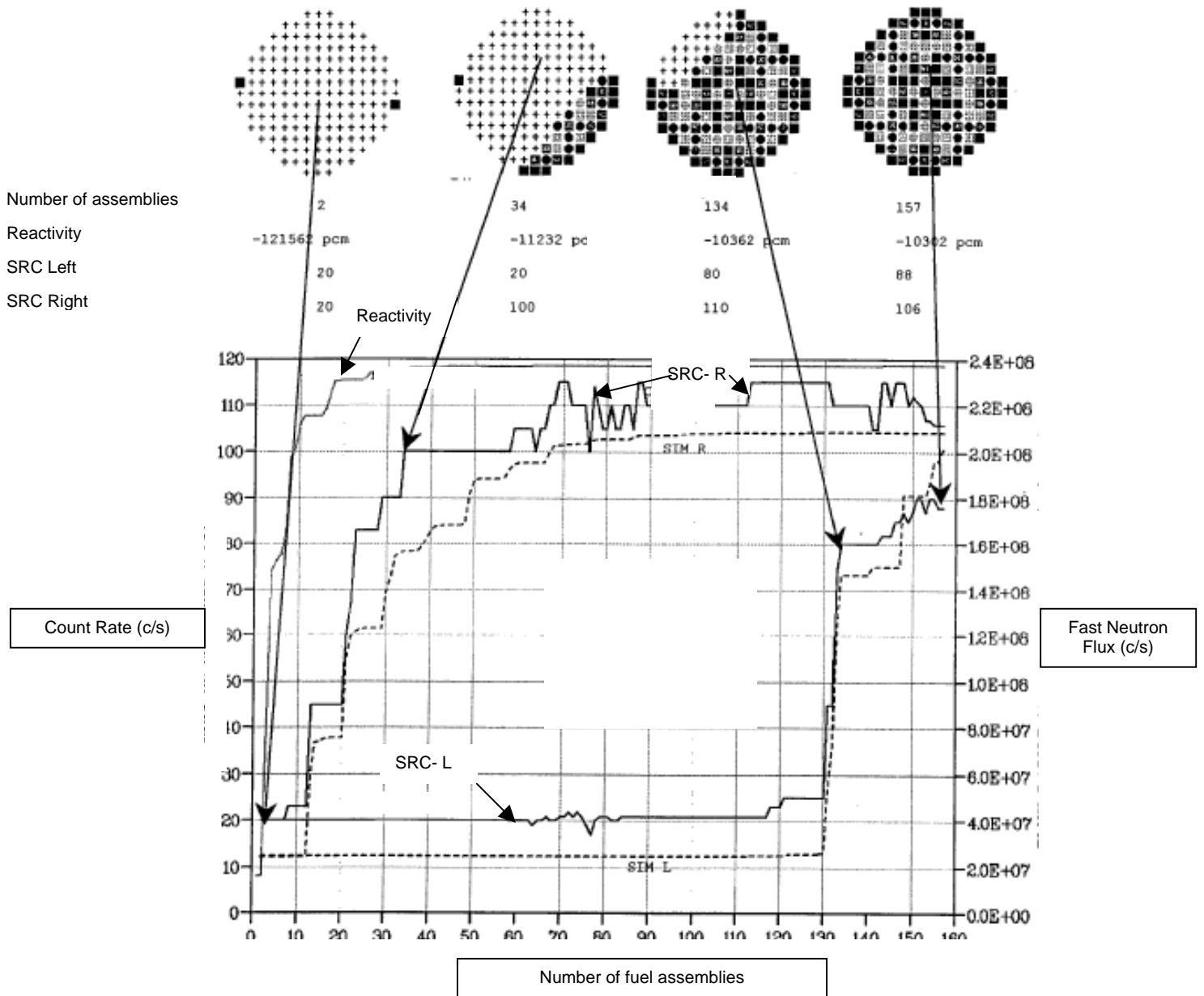
In each assembly :

- 1,2,3,4 : UOX 1st, 2nd,3rd, 4th cycle
- 11 : MOX 1st cycle
- 12, 13 : MOX 2nd, 3rd cycle

Step number



Erroneous Refuelling



Tricastin Unit 3 Campaign 19 : Comparative evolution of the SRCs count rates (SRC-L ; SRC-R) and of the simulations (SIM L and R) - Reactivity evolution along the refuelling

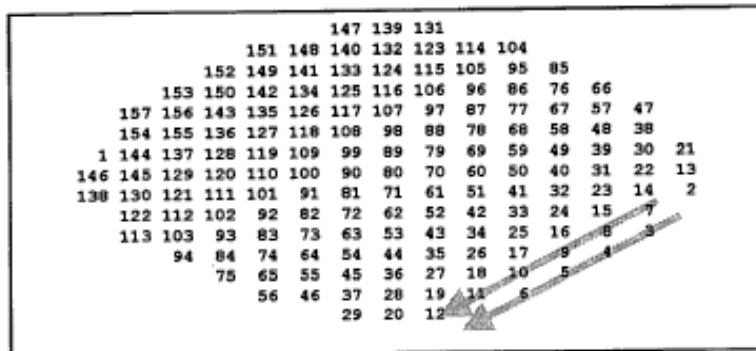
One can notice that along the refuelling, the SRC-L count rate has firstly been only under the influence of the first fuel assembly loaded, located on the R7 isolated position and this, until the introduction, at steps n° 131 and n°133, of the fuel assemblies on R8 and R9 locations close to SRC-L.

As the refuelling progresses from the south east side of the core towards the north west side, the SRC right indicates a significant evolution only in case a fuel assembly is loaded near this detector.

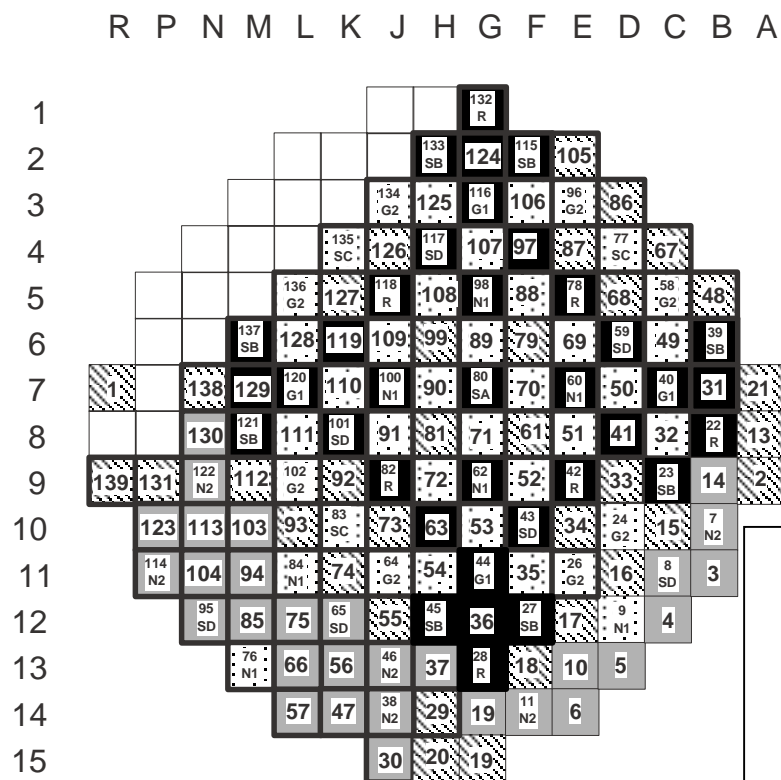
Furthermore, this figures allows to draw the conclusion that the increases of the SRC count rates and the reactivity increase are not correlated.

Moreover, it appears that the calculations can be considered as an indicator able to evaluate the global SRCs count rate evolutions.

3.2.2.2 Refuelling on Dampierre Unit 4 Campaign 18

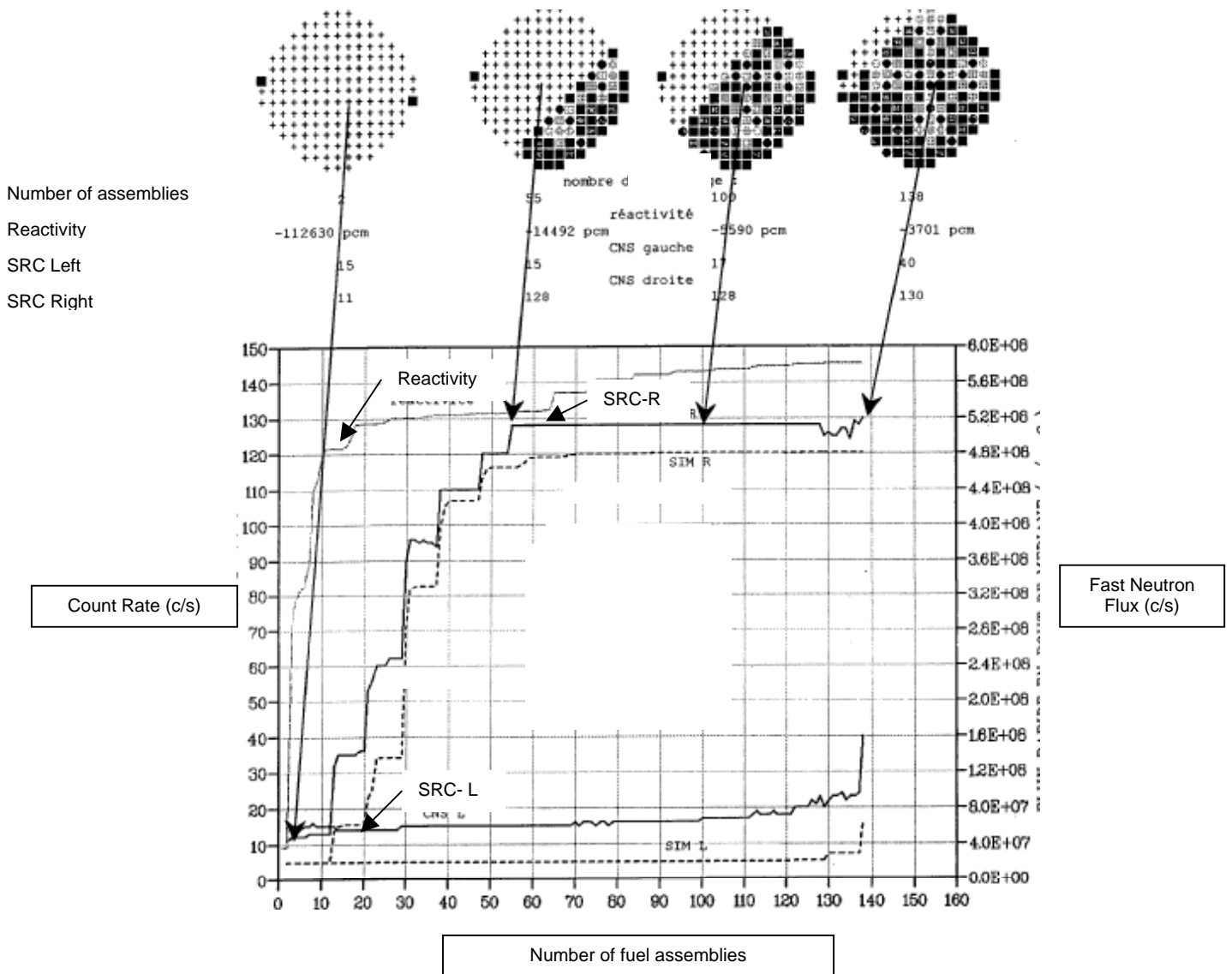


Method of « Diagonal » Refuelling carried out in Dampierre



Core loading pattern due to the erroneous refuelling on Dampierre Unit 4 Campaign 18

125 R	Step number Rod cluster name
□	Step error
■	First cycle assembly
▤	Second cycle assembly
■	Third cycle assembly
▥	Fourth cycle assembly



Erroneous refuelling on Dampierre Unit 4 Campaign 18 : Comparative evolution of the SRCs count rates (SRC-L ; SRC-R) and of the simulations (SIM L and R) - Reactivity evolution along the refuelling

As the graph above shows, the evolution of the count rates of SRC-R and SRC-L along the incidental refuelling of Dampierre Unit 4 have not been influenced whereas the reactive group of fuel assemblies was in progress, between steps n° 60 and 130. As observed for the normal refuelling on Tricastin Unit 3 campaign 19, the SRC count rates have only been significantly increased at the time when the irradiated fuel assemblies were introduced near the detectors. As a matter of fact, the count rate generated by the SRC-R has been sharply increased at step n° 30, from a value of 62 to 90, because of the loading of a MOX irradiated fuel assembly instead of a 1st cycle UO₂ assembly due to the loading error at step n°25. However, this abnormal evolution is not significant enough to detect a handling error, since similar changes in count rate evolutions have been observed independently from that type of incident.

Concerning the SRC-L, the most significant increase is connected with the introduction of the second fuel assembly in the vicinity, namely step n°139 in R9 position.

3.2.2.3 Conclusion

The analysis of these two cases of refuelling operations shows that the SRC count rates during a refuelling (with or without handling error) are mainly influenced by the type of the fuel assemblies loaded close to the detectors, without connection to the effective reactivity level. Moreover, although the results of the calculation remain rough indications compare to the feedback experience results, they allow to indicate the trend of the evolution of the SRC count rate.

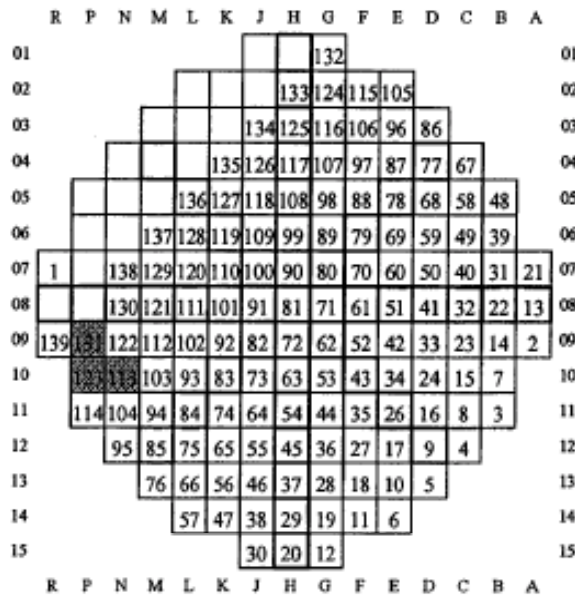
3.2.3 Simulations of divergence occurrences in case of abnormal refuelling

3.2.3.1 Characteristics of the cases considered

The simulations are expected to check the ability of the SRCs to detect the approach of the divergence as the erroneous refuelling progresses. Three cases of unexpected divergence on a non-irradiated core, representative of the Dampierre Unit 4 incident, have been considered, each characterised by a specific boron concentration to study the impact of the distance between the detectors and the fuel assembly location causing the divergence.

Boron concentration	Reactivity level before the loading of the fuel assembly causing the divergence	Step of divergence	Reactivity level after the loading of the fuel assembly causing the divergence
1900 ppm	- 71 pcm	113 (112 th fuel assembly loaded)	+ 465 pcm
1977 ppm	- 78 pcm	123 (122 nd fuel assembly loaded)	+440 pcm
2027 ppm	- 87 pcm	131 (130 th fuel assembly loaded)	+136 pcm

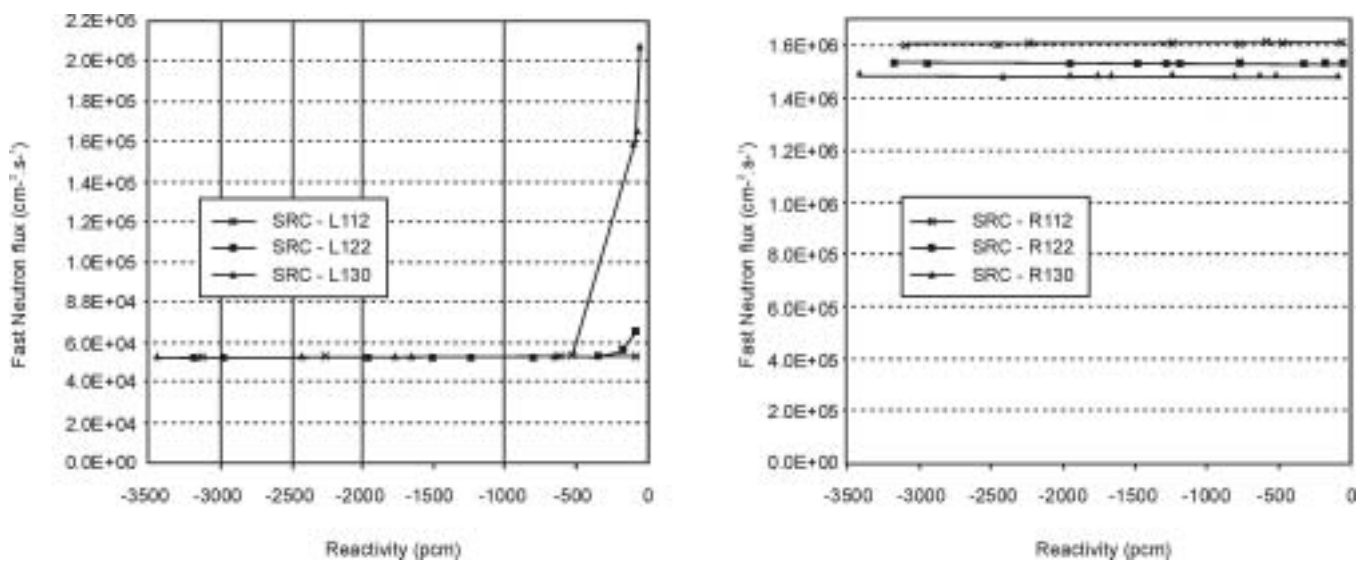
As shown on the figure below, the step n°25 has been omitted to restore the Dampierre Unit 4 conditions.



Comparative evolution of the SRC responses

Simulation of the divergence occurrence successively on 3 steps : 113,123 and 131

In order to evaluate the influence of the location of the fuel assembly causing the divergence on the ability of both SRCs to detect the divergence, the responses of SRCs left and right have been plotted while the loading progresses towards the SRC-L, as shown on the figure below.



As the previous graph shows, it is noticeable that the indications of SRC-R, which is the farthest from the reactive group, remain unchanged wherever the location of the divergence takes place and whatever the core reactivity level reached. Concerning the SRC-L, a slight increase in count rate occurs at the time of divergence on fuel assembly n°122, following by a significant increase when loading fuel assembly n°130, which indicates that the ability of the SRC to detect the divergence, as it approaches, is depending on the distance between the SRC and the location of the reactive group.

Furthermore, it is noticeable that the sharp increase in the SRC-L count rate when loading the fuel assembly n°130 is responsible for the alarm actuation, and thus the detection of the divergence, independently of the value effectively reached by the SRC-L count rate : actually when the divergence occurs, at step n° 130, the SRC-L count rate remains under the SRC-R count rate value, and below the count rate reached at the end of a normal refuelling. During the refuelling, the alarm liable to be actuated is the “high flux on shutdown” alarm, set to three times the flux on the previous count on the SRC concerned.

3.2.3.2 Analysis of the results

At the beginning of a refuelling, the SRCs are influenced by the irradiated fuel assemblies loaded in their vicinity. In a normal configuration, the increase in the SRCs count rates is correlated with the increase in the global core reactivity level. However, the Dampierre configuration is characterised by a low neutronic coupling between the highly reactive group under progress due to the handling error, composed of first cycle fuel assemblies, and the irradiated fuel assemblies located close to the SRCs. As a consequence, the global core reactivity is mainly given by the reactive group, without being detected by the SRCs. The three simulations reported above have highlighted that, in the Dampierre configuration, the global reactivity level of the partially loaded core is effectively mainly given by 25 fuel assemblies designed as the “mini core”. In case of a refuelling without any handling error, an area gathering a limited given number of fuel assemblies loaded can also be considered as representative of the global reactivity. However, the main difference between the two situations is that any similar area of the “normal” core is representative of the final reactivity, whereas for an abnormal refuelling, only the 25 fuel assemblies, identified as the reactive group or “mini core”, are representative of the final value. As a summary, one can say that the “mini core” is associated to a high heterogeneity of the local multiplying properties. Due to the difficulty to evaluate the actual level of reactivity as the refuelling, following an handling error, is in progress, the IRSN safety analysis results have identified the need to consider a potential modification of the Technical Operating Specifications to require as a minimum primary boron concentration the value imposed in the refuelling water storage tank, that means 2425 ppm with regard to Garance fuel management.

3.2.4 Lowest detectable level of power at divergence time

The previous observations have shown that the SRCs are not capable, unless the reactive group is built near the detector, to detect the approach of the divergence. The objective is now to evaluate the minimum level of power reached at time of the divergence. To this end, a simulation has been performed considering the divergence occurs when loading the fuel assembly n°112, the farthest from SRC-L. In order to be as conservative as possible, the boron concentration has been fit to increase the subcriticality level of the core loaded with 111 fuel assemblies (- 413 pcm). In this situation, the results of the simulation point out that the level of power reached after the loading of the 112th fuel assembly is 0,082% NP. At the time of the divergence, the SRC right and left signals are respectively multiplied by a factor of 53 and a factor of 6615. Furthermore, the SRC count rate is 50 times the level reached during a normal refuelling, thus in any case the alarm threshold should be reached. Consequently, if the criticality is reached, the critical state would be diagnosed and confirmed by the SRCs as from the significant power level of 0,1% rated power.

3.2.6 Simulation of the refuelling error on Dampierre Unit 4 under less favourable conditions : boron concentration = 2000 ppm ; burn-up = 0 GWj/tU

The objective of this simulation is to check, in case of the refuelling error incident on Dampierre Unit 4 under less favourable conditions consistent with the Technical Operating Specifications, if the SRCs would have been able to detect the approach of the divergence.

The boron concentration (2000 ppm) is consistent with a slight subcritical level at step n°112.

	Number of Fuel Assemblies	
	80	112
Keff (2D)	0,97054	0,99799
SIM SRC-L (c/s)	5,31E+4	5,46E+4
SIM SRC-R (c/s)	1,55E+6	1,55E+6

The results show that the signals on SRC-L and SRC-R, after the loading of 112 fuel assemblies, have been respectively multiplied by 1,03 and 1.

Consequently, due to the relatively stable level of the count rate on both SRCs, the approach of the divergence would not have been detected in such conditions after the loading of 112 fuel assemblies, firstly because of the distance between the location of the reactive group and the SRCs, and secondly because the first-cycled fuel assemblies loaded are not provided with the inherent neutron sources (only available in irradiated assemblies) which provide the type of neutrons able to influence the SRCs.

3.2.5 Conclusion

As the results of feedback experience and simulations show, the SRC count rate (image of the neutron flux) is not always representative of the reactivity level in the core. In fact, the only situation in which the signals delivered by the SRC are connected to the reactivity level, is at the full loading of the core during the divergence approach by dilution or rod cluster withdrawal, with an homogeneous radial power distribution. During the refuelling (with or without handling error), the signals delivered by the SRC depend firstly on the distance between the reactive group and the detector. Secondly the neutron flux recorded by the SRCs is linked to the presence of the inherent neutron sources in the fuel assemblies loaded and of the neutronic multiplying properties in their environment. That's why if a reactive group, composed with low irradiated fuel assemblies, is built far enough from the SRCs, the detectors remain blind to the reactivity evolution. However, when the reactive group is built near the detector, the sharp increase of the signal has to be considered as the potential indicator of a divergence, independently of the value reached which can remain at low level.

4. OUTCOMES

The potential criticality risk identified at the occasion of this incident points out to the need for investigations related to the efficiency of the source range channels (generation of the high flux on shutdown alarm set to 3 times the flux of the previous count). Considering the refuelling incident on Dampierre Unit 4, in less favourable conditions, the studies have shown that the source range channels would not have warned the refuelling supervisor of an imminent divergence in time to allow him to interrupt refuelling operations before reaching criticality level. Moreover, the results of the investigations on the efficiency of the SRCs during refuelling operations have shown that these detectors provide a count rate (reflecting neutron flux) but would not be able to detect a local increase in reactivity under

refuelling conditions (normal or defective), unless a reactive pattern is formed in the immediate vicinity of one of the two channels.

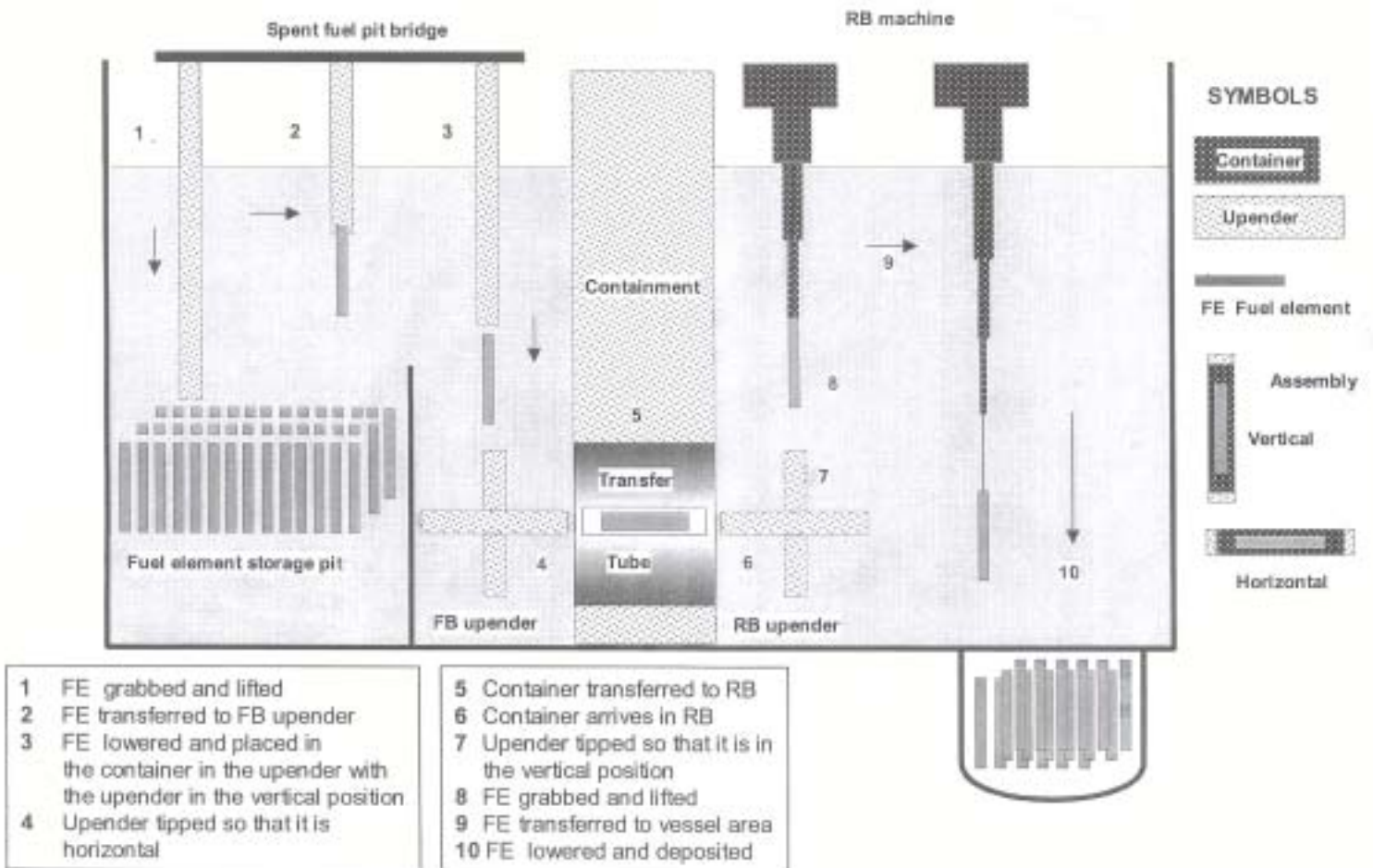
At the light of the previous observations, and due to the fragility of organizational lines of defence and the inadequacy of technical in-depth defence lines, the IRSN analysis has led the French Nuclear Safety Authority to ask EDF to study solutions allowing to detect as soon as possible the refuelling errors to avoid the building up of critical patterns. Actually, the in-depth defence concept with regard to the criticality risk at refuelling has to be based on adequate technical lines of defence notably through efficient neutron flux evolution surveillance during refuelling to detect any abnormal neutron flux evolution. This measure is the only strong line of defence to cope with a significant neutron flux evolution. Consequently, it is necessary to implement technical devices allowing to get a representative signal of the core reactivity from a representative measurement of the neutron flux coming from the reactive pattern under progress, free from any screen effect between the reactive group and the detector.

This incident also revealed that the lines of defence adopted for reactor refuelling operations were lacking in several areas (visual identification of fuel assembly numbers in the FB and RB, communication between the refuelling supervisor in the RB and his assistant in the FB, count rate monitoring). The refuelling operating mode of the Dampierre operator showed that procedures were not strictly observed and revealed an unquestioning approach to operations, particularly concerning the type and the identification of assemblies loaded in the reactor vessel.

Furthermore, this incident draws attention to the need to reconsider the list of operating conditions given in the safety analysis report, particularly for reactivity accidents. Until now, the criticality risk during refuelling has been excluded from this list because of the implementation of redundant lines of defence, which were supposed to prevent occurrence of the risk and to maintain the reactor within the authorized range. In the light of this incident, however, it seems reasonable to look into the possibility of adding this type of accident to the safety study baseline and to consider measures that could be taken to limit its impact.

The IRSN analysis has included his own criticality calculations. These evaluations allowed to calculate the criticality level reached associated with the most penalizing fuel assembly reactive group liable to be constituted following the Dampierre handling error, considering successively the influence of the initial enrichment of the fuel, the fuel management, the boron concentration, the moderator density, and the presence of the core barrel. Moreover, in order to be consistent with the Dampierre configuration, the influence of the reactive group environment (juxtaposition of two reactive groups ; presence of irradiated fuel assemblies on the periphery of the reactive group) has also been taken into account. At the light of the results, the IRSN, taking into account the introduction of new fuel managements of higher enrichments, thus potentially less tolerant with regard to refuelling error due to the increased criticality risk associated, has estimated that it was necessary that EDF extends its studies related to the critical patterns liable to be constituted at refuelling (notably dependant on the fuel refuelling practices), and evaluates in each case the available margin to criticality. This evaluation implies that the computer codes used are qualified with regard to a partially loaded configuration core, this aspect having necessarily to be checked prior to any calculation.

Appendix 1



PWR 900 Fuel Handling Detail of a Refuelling Step