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Absorber Rigs - a Better Concept than Burnable Poison.

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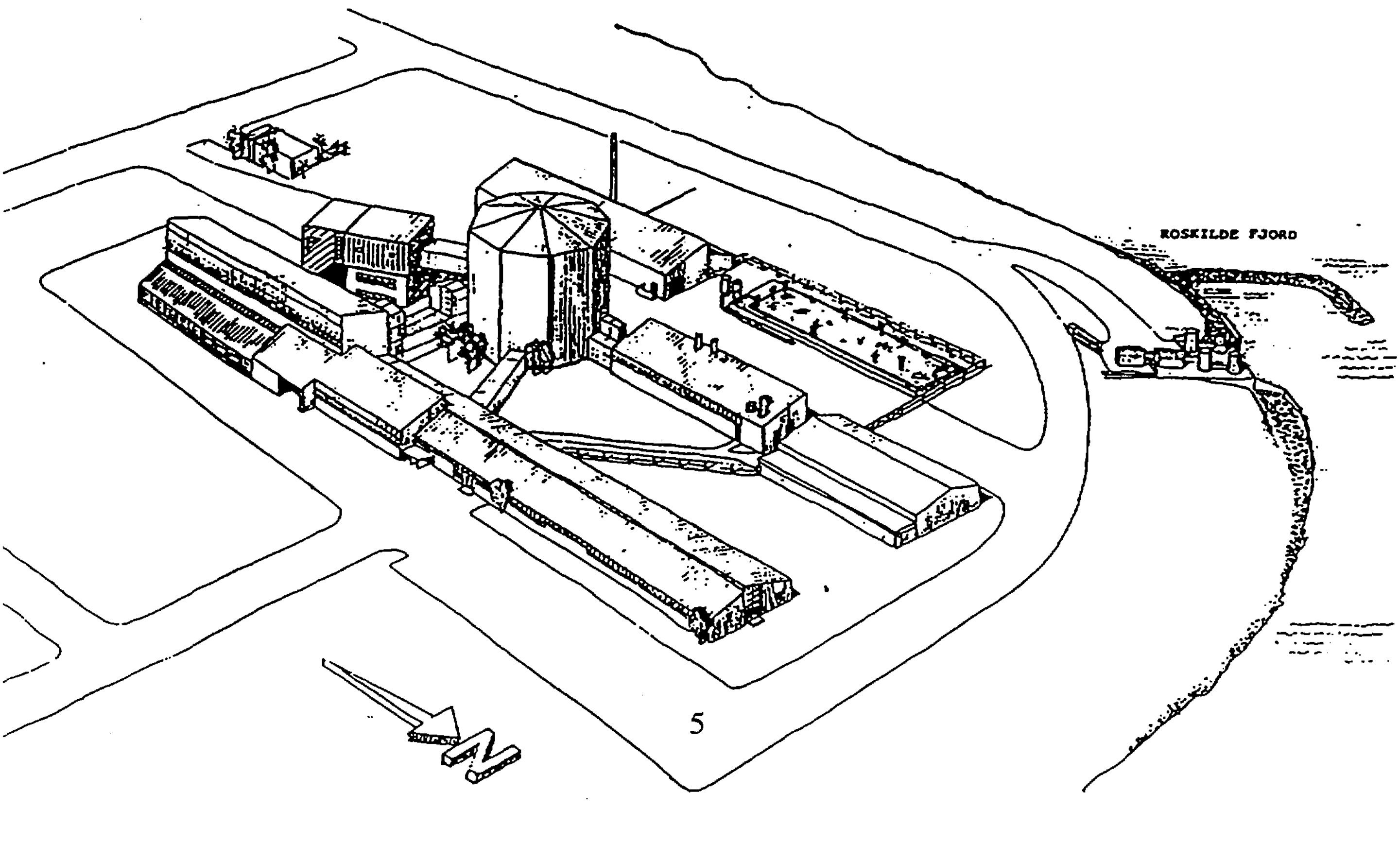


Introduction.

The reactor, DR 3, at Risø National Laboratory in Denmark is a 10 MW heavy water cooled and moderated research reactor. DR 3 is of a design similar to the British "PLUTO" type. DR 3 reached criticallity for the first time January 15, 1960, and its regular operation at power began in November 1960.

The reactor is controlled by seven coarse control arms (CCA's), which move like signal arms between the rows of fuel elements. In addition, there are one fine control rod (FCR) and two safety rods (SR's) situated in corners of the core.

The reactor core consists of 26 fuel elements, each one containing four concentric Aluminium-clad fuel tubes, which are arranged to provide a 5 cm. centre hole for experiments. In 1988 the conversion from HEU (High Enriched Uranium) to LEU (Low Enriched Uranium: U_3Si_2/Al) started. Since December 1990 DR 3 has run on a full LEU core.

The operation cycle is 4 weeks of which 23½ days is continious operation and 4½ days is shut down. Operational statistics have been extremely good, with a utilization exceeding 80%.

DR 3 is originally built as a Material Testing Reactor, but today it is used as a Multipurpose Research Reactor. With a cold neutron source, six three-axis spectrometers and a small angle neutron scatter instrument DR 3 is appointed as a Large European Beam Facility and these neutron beam instruments are intensively used by researchers from Risø and from the other EEC-countries. The main production activities are Silicon doping, isotope production and activating analysis.

Irradiation Facilities.

DR 3 has a large production of Silicon irradiation - almost 30 tons in 1994. There is one 5-in. horizontal facility and another similar is just about to be built. Vertically we have five 3-in. facilities in the Graphite, two 4-in. heavy-water cooled facilities and one 5-in. light-water cooled facility.

To improve the conditions for the Silicon production and the experiments it would be desirable to be able to control the flux distribution in the core radially as well as axially.

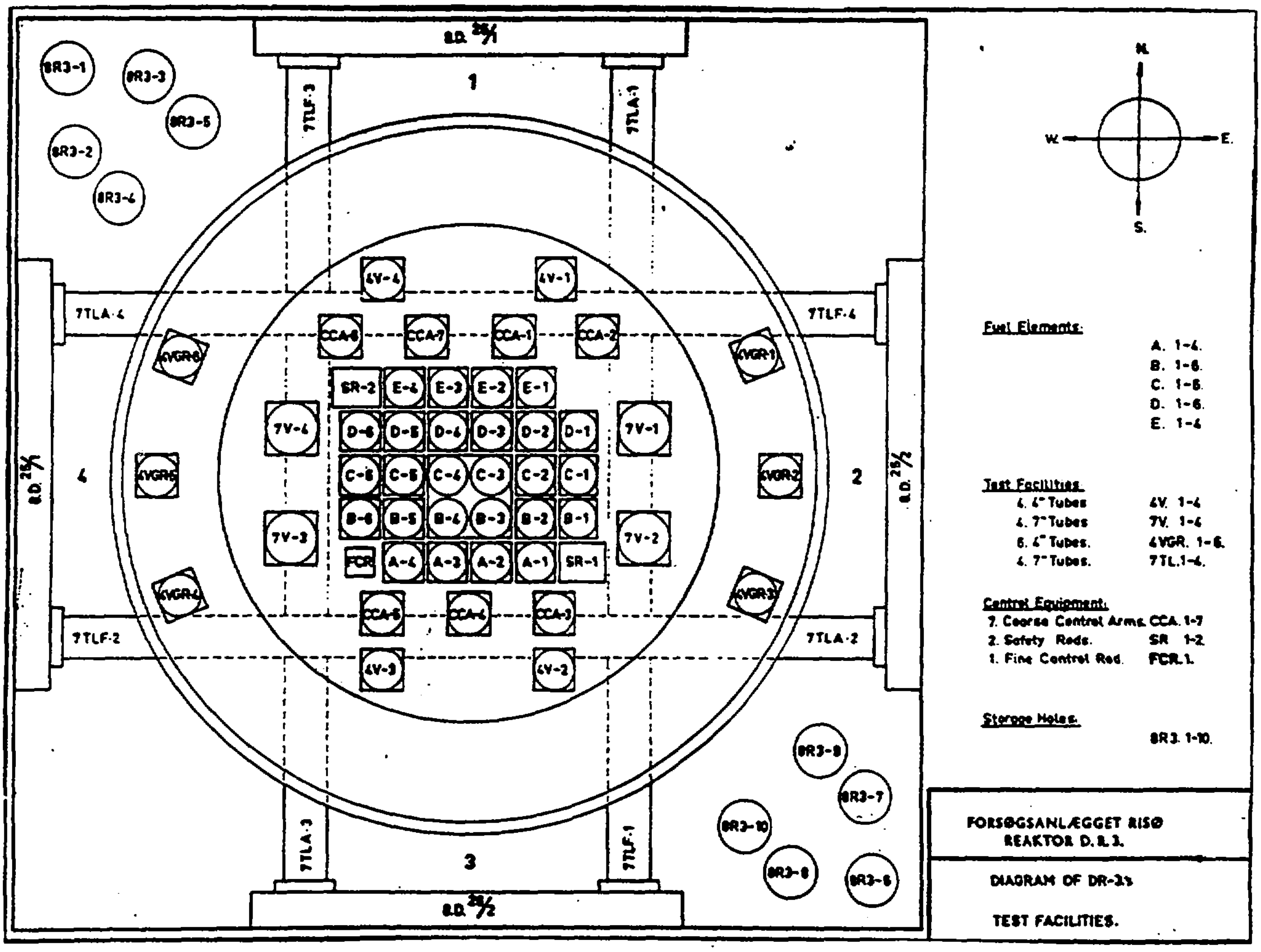


Figure 1: Test Facilities at DR 3.

During a normal reactor run the position of the CCA's will vary from about 17° to about 28° on account of burnup. These variations affected the flux distribution considerably, not only between the upper and the lower half of the core, but radially as well. Changes of up to 80% had been seen for the neutron flux in the tops of the

A-row and E-row elements. This variation was especially causing problems with uniformity of Silicon-irradiation. Often parts of the reactor period could not be used for irradiation due to this effect.

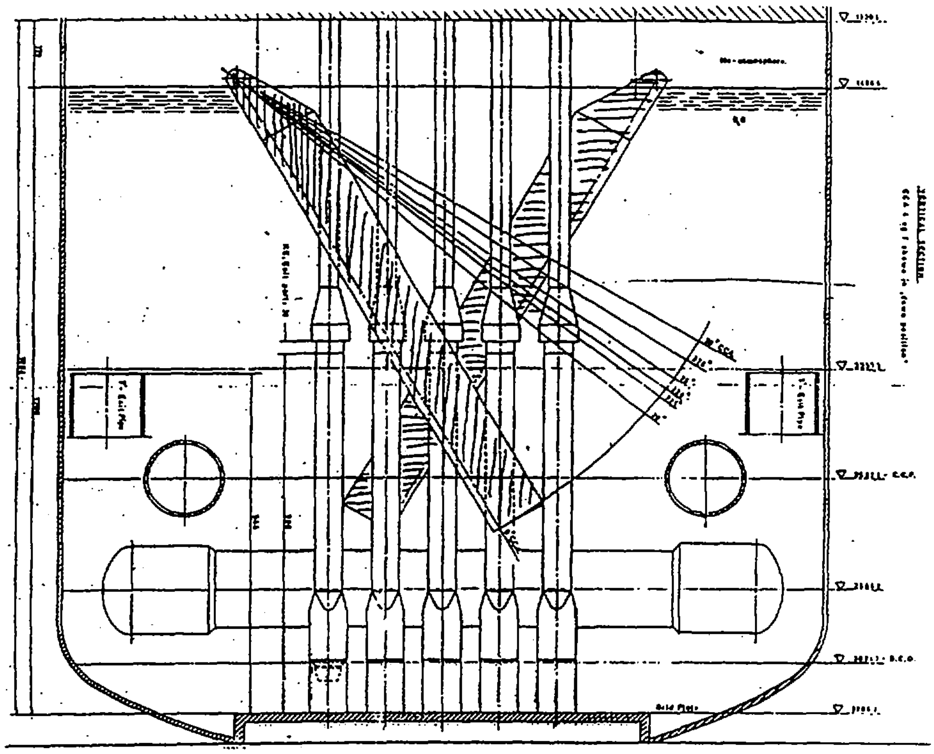


Figure 2: Various positions of the CCA's.

Disadvantages regarding burnable poison.

Burnable poison is a more common way of controlling flux distribution in the core. But it has some disadvantages compared to absorber rigs:

- Burnable poison is a once through method, and it has a limited effect - only one running period.

- Burnable poison will reduce the thermal flux inside the new fuel elements where it is already low.

- Using burnable poison will not allow control of the radial fluxdistribution without interferring with the refueling-program.

- Burnable poison makes it impossible to carry out measurements of reactivity changes caused by fuel element replacements and burnup.

Controlling the flux distribution by means of absorber rigs.

To improve the research facilities in DR 3 we have constructed some movable absorber rigs positioned in all those fuel elements that have no experiments installed. Thereby we obtain a constant CCA angle during a reactor run and thus a steady flux distribution in the core. In addition, we get the possibility of raising the flux exactly where it is needed.

Using movable absorber rigs opens up to new ways of controlling the fluxdistribution in the core - radially as well as axially.

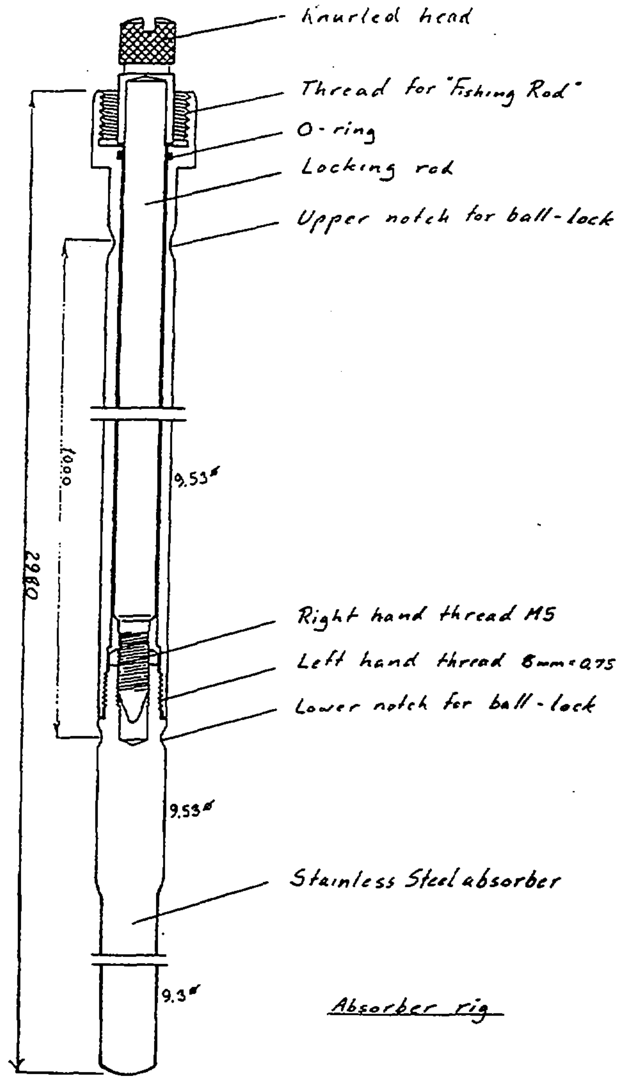
The axial effect of movable absorber rigs is to enable us to maintain an almost constant, high CCA-angle throughout the reactor cycle (Fig. 3). A CCA angle of 22° has been chosen as the most ideal position for the CCA's concerning Silicon irradiation. At 22° the CCA-group turn out of the top of the A- and E-row, and consequently the neutronflux is not reduced so much any more by the presence of the CCA's between the fuel elements.

The radial effect is gained because it becomes possible to lower the flux in the center positions and raising it in the outer fuel elements. Another possibility is to straighten a wry flux distribution.

In case an experimenter wants it, the absorber rigs gives us the opportunity of making a fluxtrap in an area of the core by positioning the absorber rigs in the opposite side of the core.

Description of the absorber rig.

The whole arrangement with the absorber rig has been made to replace a normal flux scan rig, a condition that has been decisive for the design. Consequently that leaves only very little space - less than 1 cm.



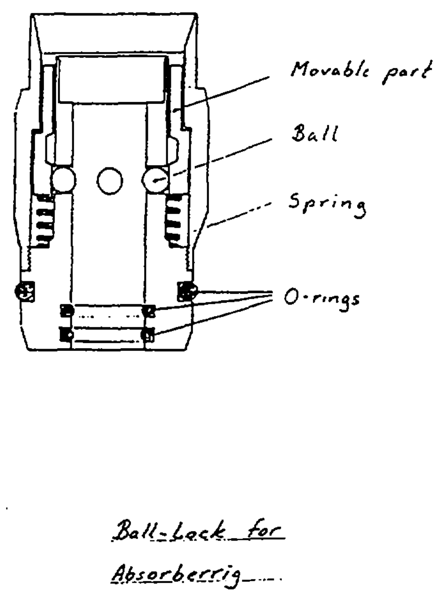


Figure 3: The absorber rig and the ball lock.

An absorber rig is made up of 3 parts (Fig. 3):

- An upper part, made entirely of stainless steel, which is removable.

- An under part with a stainless steel absorber rod which can be parked in two positions: Either in the core ("down"-position) or above the core ("up"-position).

- A ball-lock to keep the absorber in position.

The connection of the under-part to the upper part is effected by means of threads in the two parts. The inner locking rod is used to make a lock that will prevent the two parts from loosening caused by vibrations. For this purpose the main joint has left-hand thread whereas the locking rod has a normal right-hand thread.

When the two threads are tightened against each other they form an effective lock, because a tendency for one joint to come loose is counterbalanced by a tendency for the other joint to become tighter, and vice versa. An O-ring in the top together with a double O-ring in the ball-lock provides friction to the locking rod, which is desirable, when the parts are to be unscrewed. The O-rings also makes the arrangement Helium-tight. The parts of the absorber rig will provide shielding upwards in the "up"-position as well as the "down"-position.

<u>The choise of absorber material.</u>

In the original concept the absorber itself was an 8 mm. Titanium rod. The reasons for this choice were firstly that it had the right magnitude of absorption, secondly that neutronirradiated Titanium has a reasonably short halflife so that it should be possible to handle an irradiated absorber rig after a reasonable cooling time.

However, after measuring an irradiated prototype rig, it turned out that it contained rather longlived isotopes so that handling would be out of the question anyhow. With no longer any reason for using the very expensive Titanium we looked for a simpler solution, and calculations showed that a 9.3 mm. stainless steel rod would have the same absorption.

Handling the absorber rigs.

When the absorber is to be retracted from the core, the ball-lock is activated and the whole absorber rig is lifted by means of a "fishing rod". It is lifted until the ball-lock engages the lower locking notch (on the under part). A "click" indicates, that the absorber rig has been locked in position. It is only possible to operate one absorber rig at a time, because there is only one piece of tool (fishing rod).

When the lower part thus is locked securely in retracted position, first the locking rod and then the upper part will be unscrewed and removed. The absorber is now lifted 1 m. and is entirely out of the core. At the same time nothing is protuding upwards from the fuel element plug which would otherwise interfere with the shielding plugs.

The handling of the absorber rigs is done manual. Experiments have shown that there is no need for a motordrive for this purpose. It is possibel to avoid reactor trip with a retracting speed of 5 cm/s, but it will cause minor effect changes, as the FCR is not capable of compensating at that speed. In stead a retracting speed of around 2 - 2.5 cm/s is suitable and it is no problem keeping that speed using handpower.

Operation.

In two of the fuel elements we have experiments placed permanently. In addition there are four movable irradition rigs at the moment, which are running during some periods. That leaves us at least 20 positions, in which we are able to place absorber rigs.

A schedule is made for each reactor period showing the needed absorber rigs in the concerned cycle and the sequence in which the absorber rigs are retracted during the period. Fig. 4 shows the order of retraction of the absorber rigs to get a smooth flux distribution.

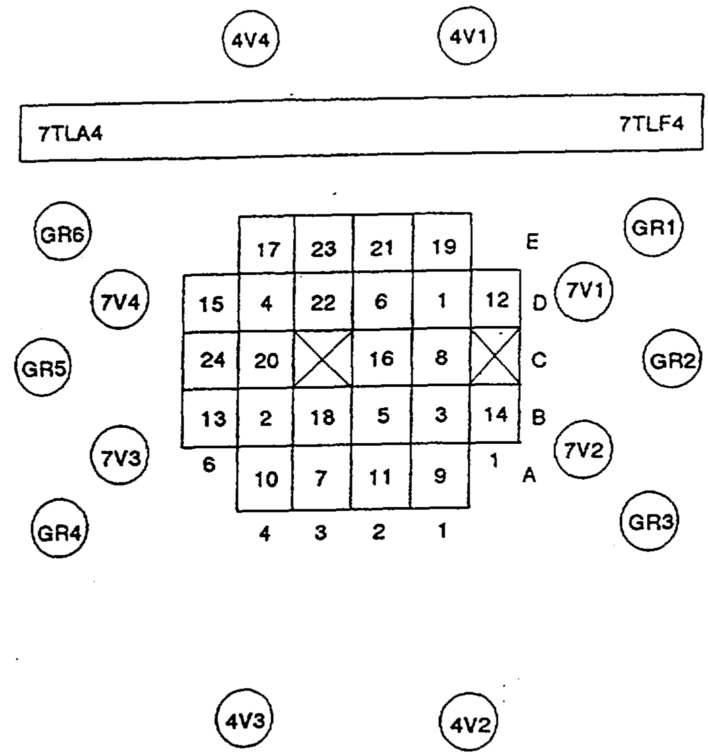


Figure 4: The order of retracting the absorber rigs.

The lowest number of absorber rigs needed is 17, but it depends on the fuelling and the CCA start-up-angle. The effect of an absorber rig depends on the core position and vary from 0.07 (B6) to 0.25 (C3).

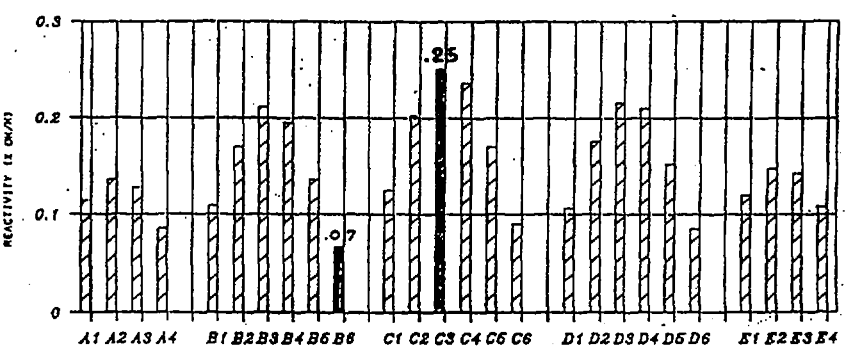


Figure 5: Reactivity worth of absorber rigs in different core positions.

Fig. 5 shows the reactivity worth of the absorber rigs in the different corepositions. During a running period the reactivity worth of burnup is around 2.8 % dk/k. 24 absorber rigs placed in the core will absorb 3.53 % dk/k, which is more than enough to compensate for the burnup.

At the beginning of the reactor period the needed absorber rigs will be in their "down" positions. When the Xenon equilibrium has been established after 30-40 hours, the CCA angle will have exceeded 22°. When the FCR reaches an upper limit of 40 cm. it is time to retract the first absorber rig. During this retraction the FCR will compensate and it should end close to its lower operating limit (6 cm.) with the absorber rig in the "up"-position. (The reactivity worth of the FCR in this 40 - 6 cm. interval is 0.35 % dk/k which is more than the worth of an absorber rig in a center position). Likewise the rest of the absorber rigs are to be retracted one by one, so the CCA angle is kept at approximately 22° throughout the reactor run.

Fig. 6 and fig. 7 show the reactivity loss by increasing burn-up with and without absorber rigs.

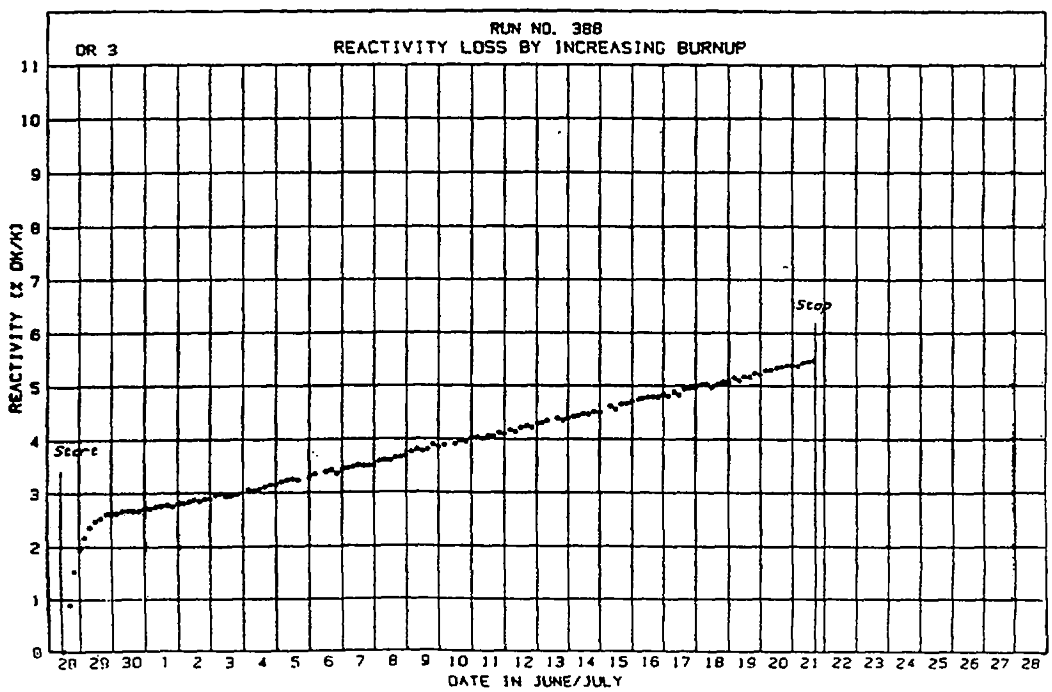


Figure 6: Reactivity loss by increasing burn-up. Without absorber rigs.

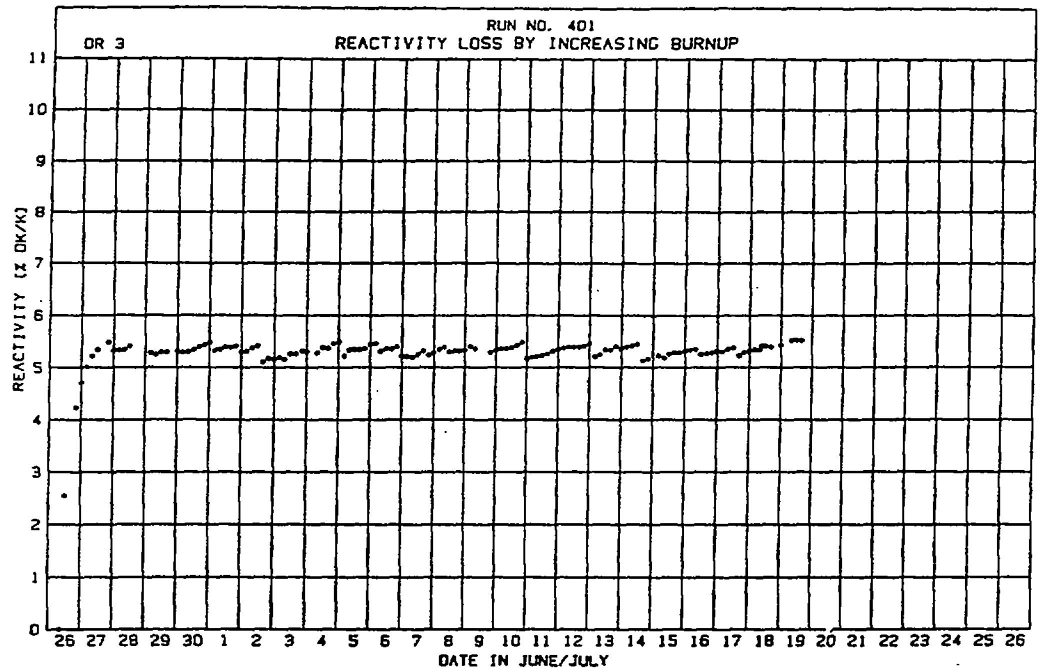


Figure 7: Reactivity loss by increasing burn-up. With absorber rigs.

Operations Experiences.

During the last four years we have used movable absorber rigs succesfully at DR 3. We have made some minor modifications, but basically they have performed very well. Of course there were some difficulties when we took the absorber rigs into use.

During the mechanical test of the absorber rig a minor problem occured. Descenting the absorber, it "caught" an edge in the flux scan rig. But when we had to make a number of new flux scan rigs anyway, this konus was just made bigger. Thereby this problem had been taken care of.

At the first test of the absorber rig at full power it was ascertained that the absorber was hanging in the O-rings in stead of being locked in position by the ball lock. By falling down the absorber would cause a reactor trip as well as a Helium leakage in the topvoid. A potential unpleasant situation but with no safety significance. The situation occured because of lack of instruction of the operator and his lack of familiarty with the construction. Now the operation procedure has been changed and extended. The "fishing rod" has been marked to indicate where the locking positions are. This event has not happened since.

Handling of absorber rigs during a reactor trip.

During an undesired reactor shut down the risk of getting a Xenon poisoning is larger with the absorber rigs in the core. The procedure is then to retract the absorber rigs from the "down" position. Though it depends on how many absorber rigs is left in the core and how long the trip is estimated to last. Moving all absorber rigs takes around half an hour.

There will always be at least 2 hours from reactor trip until the latest startup time before Xenon poisoning occurs. If the trip is estimated to be of short duration i. e. caused by a power failure or so, the remaining absorber rigs stay in the core during the trip. If the trip is caused by a more severe failure, which requires repair of some components, it is possible to gain some time by retracting the remaining absorber rigs to the "up"-position.

According to the moment of the operation cycle there is more or less time to gain. A full running period is 561 hours. In the tables below (Tab. 1 and Tab. 2) the signification of the absorber rigs in the core during reactor trip is shown.

100 hours 15 absorbers	Absorber rigs in the core	Absorber rigs out of the core	Gain
Before Xenon poisening	2.0 hours	3.5 hours	1.5 hours
During Xenon poisening	29.0 hours	23.0 hours	5.0 hours

Table 1: Trip after 100 hours of running. 15 absorber rigs in the core.

400 hours 5 absorbers	Absorber rigs in the core	Absorber rigs out of the core	Gain
Before Xenon poisening	2.0 hours	2.5 hours	0.5 hours
During Xenon poisening	28.5 hours	27.0 hours	1.5 hours

Table 2: Trip after 400 hours of running. 5 absorber rigs in the core.

Safety analysis.

- Break of the absorber rod or the upper part: The absorber rod will fall down to the bottom of the thimble of the flux scan rig. The reactivity worth will not change if the break occurs in the "down"-position. But if the break occurs in the "up"-position, the reactor will shut down for two reasons: Because of adding absorber material to the core, as the absorber rod falls down and trip will occur due to a negativ period.

- Exceeding pressure in the reactor tank: During normal operation the absorber rigs are locked in the "down"-position by the ball lock. It has been ascertained that even if the ball locks fail, the rigs are sufficiently heavy that even a pressure rise, caused by a transient, to the maximum allowable pressure for the reactor vessel, 0.6 bar, can not cause the rigs to be shot out of the core, which would aggravate the transient.

- Distortion of the flux distribution in the core: It is not possible to provoke this, as the total reactivity worth of absorber rigs in all 26 core positions is 3.8 % dk/k, which corresponds to normal operation.

- Momentary retraction of one absorber rig: The maximal permissible step-change in reactivity is 0.5 % dk/k. This operational limit is established on the basis of the ability of the core to resist transients without any risk of melting a fuel plate. The maximum reactivity worth of one absorber rig is 0.25 % dk/k, which is only half of the permitted change, so this is not a problem.

As a conclusion of the safety analysis we can say that the absorber rigs are not able to cause any risk for the reactor safety even in case of a glaring blunder.

Healthphysical aspects.

At the same time as testing the absorber rigs, radiation measurements have been done with the absorber in both positions. The levels were found to be quite normal. The rig provides satisfactorily shielding under all circumstances. The two O-rings make the absorber rig totally Helium-tight.

Handling of the removable upper part can be done without special precautions as it is only insignificant activated.

The absorber rod made of stainless steel becomes very activated due to the contents of Cobalt. However that is not a problem as the absorber rigs are handled inside the fuel elements.

Decommissioning.

The lifetime of the absorber rods is very long. The stainless steel contains 73 % of Iron which form 64 % of the relative absorbtion effect. Iron has the longest lifetime: 124 years. The weighed burn-up time for one absorber rod is thus around 100 years. Consequently there will be no need for making new absorber rigs.

So far we have taken two absorber rigs out of operation. They are stocked but we hope to be able to fix them. At the moment they are stored in a storage hole in the external storage block. When time comes for decommissioning, we plan to cut the absorber rigs into small pieces and put these into a container for permanent storage.

References.

1. P. R. Winstrøm: Experience with absorber rigs at DR 3. April 1992. 18/M 2287.

2. P. R. Winstrøm: Absorber Rigs for Reactivity Control in the Core of DR 3. May 1990. 10/M 2177.

3. P. R. Winstrøm and K. Haack: Beskrivelse og design-vurdering af bevægelige absorberrigs i DR 3's brændselselementer. June 1991. 18/M 241a.