Fuel decontamination at Ringhals 1 with the new decontamination process ICEDEC™

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Abstract

The new fuel decontamination technique ICEDEC™, which has been developed by Westinghouse, is based on abrasion of fuel crud with ice particles. A mixture of ice and water is led continuously through the fuel assembly, which is placed in a specially designed fuel decontamination container connected to a closed loop recirculation system. The ice particles scrape off the loose crud from the fuel surfaces and a mixture of crud and water from the melted ice is then led to a filter unit were the crud is separated from the water.

In this paper results of fuel decontamination tests of two-year-old and spent fuel assemblies during spring 2001 at Ringhals 1 are presented.
The fuel crud was only released when ice particles passed through the fuel assembly and stopped within ten seconds after the feeding of ice particles had ceased. The activity release from the fuel could thus be performed in a controlled way making the process easy to manage and survey.
Activity measurements confirmed that about 50 % of the loose crud was removed from the fuel surfaces of the two-year-old assembly. Fuel inspection after the decontamination process showed no influence on the fuel integrity.
Furthermore, no enhanced personnel radiation dose was involved with the fuel decontamination compared to normal fuel services.

INTRODUCTION

One of the major concerns in operating a nuclear power plant is to minimize the radiation exposure to the personnel. The last decades a lot of efforts have been made for that purpose. Among all different kinds of measures to reduce the mandoses in LWRs fuel decontamination is the only one that directly attack the origin of activity buildup in the power plant – the fuel crud.

In the core the fuel crud elements are neutron activated forming radioactive nuclides. Radioactive (and inactive) nuclides - especially those in the outer layer of the crud, the loose crud - are to some extent released to the reactor water and subsequently distributed to different system surfaces of the power plant causing activity buildup. By removing the loose crud from the fuels surfaces in a controlled way by a fuel decontamination technique such as ICEDEC™ there will be less nuclides left in the loose crud that are able to release. Hence, there will be less activity buildup in the plant. For that purpose the fuel decontamination method ICEDEC™ was developed by Westinghouse Atom, Sweden.

The development of the ICEDEC™ equipment and decontamination procedure was performed in several steps; feasibility studies, laboratory tests, full scale test of fuel dummies with synthetic crud and recently, decontamination tests of spent and two year old fuel assemblies [1,2]. In this paper results from the full-scale tests of the spent and the two year old assembly are presented.

THE ICEDECÔ EQUIPMENT AND PROCEDURE

The ICEDEC™ equipment consists of a closed loop recirculating system as sketched in Figure 1. The system contains three units; a decontamination unit for decontamination of the fuel assemblies, a filtering unit which filters the removed crud and a control unit for monitoring and control of the decontamination process.

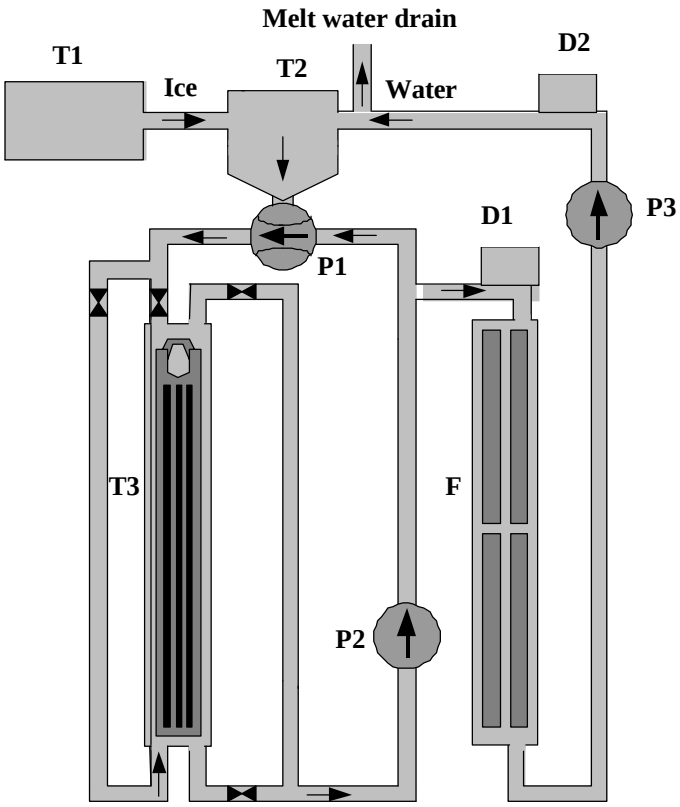

Figure 1*. Sketch of the ICEDEC™ equipment.*

The decontamination unit contains a conventional ice machine connected to an ice tank (T1), an ice/water mixing chamber (T2), an ice/water pump P1, a decontamination container (T3) for the fuel assembly, a circulation pump (P2) and an auxiliary circulating pump (P3) for recirculating water. In addition, there are valves and a number of temperature, pressure and activity gauges.
The maximum flow of the circulation pump is 20 kg/s, which corresponds to the maximum flow through an assembly in the reactor. The ice particles are made from deionized water and are 3-5 mm in size. In the mixing chamber T2, the ice particles are mixed with filtered water, recirculated via P3. The ice/water slurry thus created is then introduced into the decontamination container, T3, either downwards or upwards through the assembly. Before entering the decontamination container the slurry is passing a net with the hole diameter of 3.7 mm, hence maximizing the ice particles to this size.
Fuel crud is then removed by abrasion when the ice particles are scraping the fuel surfaces. One part of the slurry, now consisting of removed crud and water, is led to the filer unit (about 25 % of the flow) and the rest back to the decontamination container.

The filter unit, which is designed to withstand highly radioactive crud, separates the crud from the water. One part of the filtered water is recirculated in the ICEDEC™ system and another part, i.e. the same amount as is introduced to the system via the ice machine, is transported to the pool drain when the activity in the water is below a certain limit.
During the decontamination procedure continuous measurements of total gamma activity is performed by means of BGO scintillation detectors. The detector heads are placed in lead shielded water proof tubes of aluminium, which are mounted in the flow direction at the inlet of the filter unit and at a position after the filter unit, respectively (D1 and D2 in Figure 1). At D1 the water is flowing continuously and at D2 the water is collected in a tank. When the activity at D2 is below a certain limit the residual water is led to the pool drain, otherwise the water is recirculated until the activity has decreased to a value below the limit.

The filter unit contains a stand with room for five filter modules, tubes and valves. The filter modules are dimensioned for more than five kg crud. Four filter modules are arranged in parallel. Each of these contains two sections with the poor size 10 μm and 1 μm, respectively. A fifth module with a poor size of 0,5 μm used for polishing the process water, is connected in series with the others. Each filter module has external dimensions as a BWR fuel assembly. This means that they can be handled with the same equipment and in the same way as the fuel. In addition, it is possible to connect an ion exchange module with ion exchanges resins to the filter unit.

One of several benefits of ICEDEC™ compared to other fuel decontamination methods is that ICEDEC™ is a non-chemical decontamination technique; only deionized water is used. Hence the risk of intergranular stress corrosion cracking or corrosion due to chemical interaction with the cladding and spacer material is reduced.

DECONTAMINATION TESTS AT RINGHALS 1

Decontamination trials of the spent (five-year-old) fuel were primarily performed as process verification tests and to optimize different parameters (flow, flow direction pressure drop, temperature etc.) of the decontamination procedure. Later on these optimized process parameters should be practiced for decontamination of a two-year-old fuel assembly

The decontaminations continued for about 10 minutes. Thereafter the ice feeding was stopped and the decontamination container was purged with water during five minutes. When the activity in the system was sufficiently low the equipment was turned off and the fuel was removed from the decontamination container.

When the decontamination tests were completed the ICEDEC™ equipment was system decontaminated with ice and with the decontamination container empty. Before dismounting the equipment activity measurements of different ICEDEC™ components were performed.

During the decontamination procedure on-line measurements of gamma activity from the released crud were performed at positions both before (D1) and after (D2) filtering. Also the temperature and the pressure drop in the decontamination unit was measured. In addition, water samples were taken at positions before and after the filter unit. From process data thus obtained the decontamination fraction DF and the filter efficiency was estimated.
DF was determined from the total gamma activity data at D1 (see Fig. 1) as:

$$DF = (A_{before}-A_{after})/A_{before} \quad (1)$$

Gamma activity measurements of water samples taken at positions before and after the filter unit were used for estimation of the filter efficiency as:

$$\text{Filter efficiency} = (A_{before} - A_{after})/A_{before} \quad (2)$$

Crud sampling

Crud sampling on rods before and after decontamination was carried out with Westinghouse Atoms equipment consisting of a remotely controlled underwater sampling unit connected to a poolside sample receiving unit and a control unit. The aim of the crud sampling was to determine the amount of loose crud on the fuel and to determine how much of the crud that is removed by the ICEDEC™ procedure during decontamination of the two-year-old fuel.
Both brushing with a nylon brush and scraping with sintered Al_2O_3 was performed. The activity of Co-60 was then measured.
Since the activity in fuel crud in LWRs is dominated by Co-60, this nuclide was used for determining the decontamination fraction according to (1).

Gamma scanning

Gamma scanning of filter units was performed after completed decontamination tests of the five-year-old fuel. The gamma scanning procedure involves continuous movement of the object (usually a fuel assembly) to be studied in front of a collimator slit of a high resolution Ge detector. Processing of the large number of nuclide specific gamma spectra thus generated, results in activity profiles of the object.
In addition, gamma scanning of the decayed five-year-old fuel assemblies was performed both prior to and after the decontamination tests.
On the fuel assemblies the scanning was made specifically of Co-60 (since this is the only nuclide from the crud whose activity is large enough to be detected) and of Cs-137.
It must be emphasized that only decayed fuel can be measured since the background radiation from the fuel is too large in newly shut down fuel.

Fuel inspections

The fuel assemblies were inspected both prior to and after the decontamination procedure[1]. The main aim of the inspections was to verify that the ICEDEC™ procedure maintains the fuel integrity.

RESULTS

Decontamination tests

In Fig. 2 the activity of removed crud (measured at position D1 in fig. 1) is shown as a function of time.

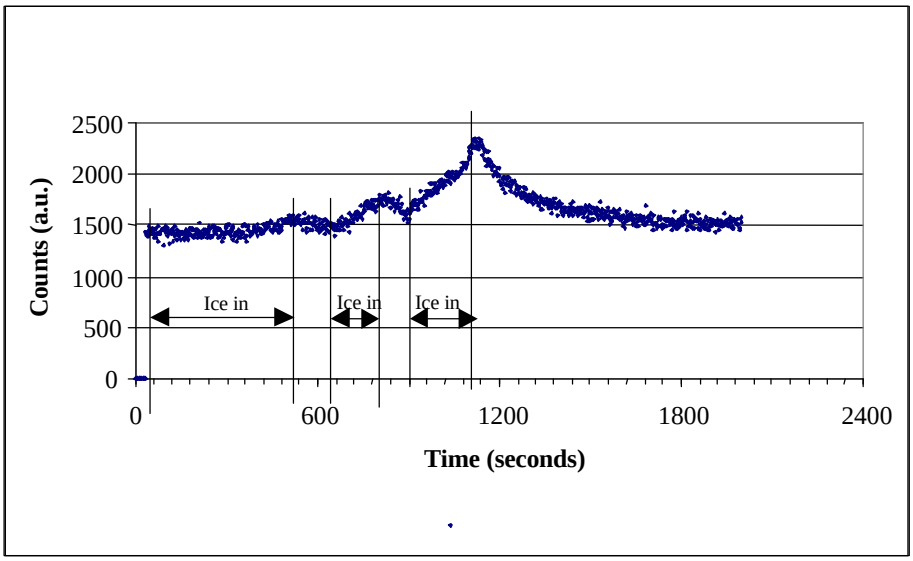

Figure 2*. The gamma activity measured at the inlet of the filter unit during a decontamination test.*

From Fig. 2 it can be seen that the activity increased when ice particles were admitted into the assembly and decreased when the ice feeding was stopped and only water was passing through the decontamination container. In fact, it was observed that the activity started to decrease within 10 seconds after the ice feeding had stopped.
During the ice feeding the temperature in the decontamination container decreased from 20 °C to below 5°C. It was noticed that the activity began to increase when the temperature had decreased to about 6 °C.

From the activity data it was concluded that 34 % of the total activity was removed from the two-year-old fuel. This corresponds to a decontamination fraction of the loose crud of 53 %.

Since the five-year-old fuel assemblies were used mainly as verification of the decontamination procedure there was no relevant data for estimating DF.

When the highest activity was observed at position D1 during the decontamination process the filter efficiency was between 90 and 95 %. At lower activity a lower filter efficiency was estimated. This decrease in filter efficiency with decreasing activity is probably due to the presence of particles of sizes less than 0,5 μm and colloids in the removed crud that pass through the filter modules and ion exchange resin.

In addition to the results from the ICEDEC fuel decontaminations mentioned above it was experienced that the equipment was ease to handle; decontamination and dismountling of the ICEDEC equipment after completed fuel decontaminations proceeded without any complications. Furthermore it was concluded that fuel decontamination with ICEDEC does not involve higher mandoses than fuel services during a normal refuelling outage.

Crud sampling

The percentage of loose crud in the two year-old fuel was determined to about 65 % and in the five-year-old fuel about 8 %.
From scraped crud samples of the two-year-old fuel it was determined that 30 % of the total activity was eliminated by the ICEDEC™ procedure. This corresponds to a decontamination fraction of loose crud of 46 %. The decontamination fraction of loose crud determined from brushed crud samples of the two-year-old fuel was 42 %.

Gamma scanning

Gamma scanning of the filter unit showed that about 85 % of the activity in the filter originated from Co-60. It was also concluded that more than 80 % of the activity from the removed crud was trapped in the 10 μm filter.
Gamma scanning of the decayed (for several months) five-year-old fuel assembly showed that this method can be used for detecting possible displacements of fuel spacers[1]. Owing to the high background radiation from the fuel it is not relevant to use gamma scanning for estimating the decontamination fraction.

Fuel inspection

The conclusion from the tests and inspections of the fuel assemblies was that ICEDEC™ fulfils the main criterion of fuel decontamination, i.e. maintaining the fuel integrity[1]. Only crud was removed from the fuel surfaces and the oxide layer remained intact. The two year old assembly was then put back into the core for further irradiation.

DISCUSSION AND CONCLUSIONS

From crud sampling *loose crud* was defined as the amount of crud that is obtained by brushing with a soft nylon brush. The estimation of the decontamination fraction for the two-year-old fuel assembly from the total activity of removed crud and from the Co-60 activity of crud samples was then based on that definition. The DF varied between 42 and 53 %. It must be emphasized that these results are based on a single assembly, which is too few for drawing any further conclusions.
Questions of great importance that arise when discussing decontamination fractions are: What is the real definition of loose crud if we mean crud that is released from the fuels surfaces into the reactor water and is responsible for the activity buildup in the plant? How much of the crud must be removed by fuel decontamination so that the release of the remaining crud is minimized? There are no answers to these questions yet but experiences from future fuel decontaminations will most likely contribute to the understanding of this subject.

From the ICEDEC fuel decontaminations tests of the spent five-year-old fuel and of the two-year-old fuel it was experienced that:

- ICEDEC fulfils the criterion of maintaining the fuel integrity
- Only crud is removed by ICEDEC – the oxide remains intact
- The fuel decontamination procedure is easy to control
  - crud is only removed when ice is introduced to the fuel assembly
  - the removal of crud ceases within 10 seconds after the ice feeding is stopped
- Fuel decontamination with ICEDEC does not involve higher mandoses than fuel services during a normal refuelling outage
- The equipment is easy to clean and dismount after completed fuel decontamination.
- The filter efficiency was between 90 and 95 % at the highest activity.

REFERENCES

1 L von der Burg, E Fredriksson, R Ivars, A Rosengren, "Fuel decontamination – One way to drastically lower mandoses in LWR", Trans. ENC'98, World Nuclear Congress, October 25-28,1998, Nice, France.

2 L von der Burg, E Fredriksson, R Ivars, A Rosengren, ", "Fuel decontamination – One way to drastically lower mandoses in LWR", Proc. Jahrestagung Kerntechnique, Annual Meeting on Nuclear Technology, May 1999, Germany.

3 E Fredriksson, R Ivars, A Rosengren and G Granath "Inspection of fuel assemblies decontaminated with the ICEDEC™ technique", To be published in Jahrestagung Kerntechnique, Annual Meeting on Nuclear Technology, May 2002, Germany.