ABSTRACT

During the 2013 refuelling outage in the Krško NPP several fuel assemblies with open defects were found. The Slovenian Nuclear Safety Administration (SNSA) diagnosed open fuel cladding defects from reactor coolant activities since July 2012, 14 months before the outage 2013. During the 2013 outage the SNSA inspectors onsite followed closely the inspection findings and actions performed by the fuel provider and the Krško NPP. The authorized institutions (TSOs) that supervised the Krško NPP activities involving fuel assemblies prepared a special expert opinion on findings. The SNSA reviewed fuel inspection results, assessed fuel conditions and provided an opinion on causes for fuel damage and proposed corrective actions. The SNSA reviewed operational experience with fuel damage and recommended introduction of restricted limits for the fuel leakage in the next fuel cycle. The SNSA also provided information to public and NGOs in Slovenia and internationally.

1 INTRODUCTION

The regulatory body of Slovenia, the SNSA, regularly follows the conditions of fuel cladding integrity through a system of safety performance indicators. Open fuel cladding defects were already diagnosed from reactor coolant activities since July 2012, 14 months before the outage 2013. In meetings with the Krško NPP staff, the SNSA reviewed the inspection findings of leaking fuel assemblies in previous fuel cycles and corrective actions that were proposed by fuel provider Westinghouse. In October 2013 the refuelling outage started in the Krško NPP. During inspection of fuel assemblies unloaded from reactor core several fuel assemblies with open defects were found as well as other fuel assemblies with tight defects. During the outage 2013 onsite SNSA inspectors followed closely activities by the fuel provider and the Krško NPP personnel that included inspections of damaged fuel, identification of damage mechanisms and implementation of corrective actions. The SNSA formed a group of experts to review fuel inspection results, assess fuel conditions and provide an opinion on conclusion of Krško NPP determination of causes for fuel damage and proposed corrective actions.

2 REGULATORY PROCESSES FOR OVERSIGHT OF NPP OPERATION

The SNSA performs regulatory oversight of nuclear and radiation facilities in Slovenia according to the Ionising Radiation Protection and Nuclear Safety Act (ZVISJV) and regulations such as Rules on radiation and nuclear safety factors (JV5) or Rules on operational safety of radiation or nuclear facilities (JV9). The regulation JV9 defines the
reporting criteria for the NPP operator and these reports provide adequate information for the SNSA processes for regulatory oversight of the Krško NPP:

a) Oversight of NPP operation and outage activities by SNSA Inspection
b) Assessment and licensing of NPP design modifications (changes)
c) Monitoring of NPP safety performance indicators
d) Supervision of NPP outages and fuel cycles [3]
e) Analysis of operational events
f) Review of foreign operational experience and regulatory requirements
g) Reporting to international databases for operational experience and reporting of events (IRS\(^1\) and INES\(^2\))

In above listed processes a) and b) the role of TSOs is very important. During refuelling outages the TSOs closely follow the maintenance, tests and inspections and thus assist the SNSA inspection in oversight of the outage. The TSOs findings and recommendations for improvements are summoned in an expert opinion of outage activities [11]. The other process is licensing of changes that are significant for radiation or nuclear safety where an expert opinion from a TSO has to be attached to the application for the change.

3 THE SNSA ASSESSMENT OF THE EVENT

3.1 Oversight of NPP operation in previous outages and last fuel cycle

In 2013, the SNSA monitored a set of 37 safety and performance indicators that help to identify possible problems that can have an influence on nuclear safety very early. The indicator that shows the activity of the primary coolant is presented in Figure 1 where the trend in the leak from the fuel assemblies is shown long before the outage in 2013.

![Figure 1: Activity of the primary coolant – fuel cycle 26 and part of fuel cycle 27][6]

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\(^1\) International Reporting System for Operating Experience (IRS)

\(^2\) International Nuclear and Radiological Event Scale, [http://www-news.iaea.org/](http://www-news.iaea.org/)
The plant has operated in its 26\textsuperscript{th}, 18 month long fuel cycle since May 2012. First indication of the leaking fuel appeared very early in the 53\textsuperscript{rd} day after the start-up. The primary coolant activity gradually increased during the cycle. The activity of the primary coolant reached 3\% of the technical specification limit.

The fuel assemblies leakage has already occurred in previous fuel cycles (see Figure 2) and root cause analysis of the fuel assemblies damage was prepared by fuel provider Westinghouse [9]. The identified cause for fuel leakage in previous fuel cycles was mainly grid to fuel rod fretting and possibly debris induced fretting. In meetings with the Krško NPP staff the SNSA reviewed the inspection findings of leaking fuel assemblies in previous fuel cycles and corrective actions that were proposed by fuel provider Westinghouse such as increased inspection of fuel assemblies and primary coolant system components.

![Figure 2: Number of leaking fuel assemblies found by fuel inspections during outages [6]](image)

### 3.2 Oversight of NPP outage activities

In October 2013 the refuelling outage started in the Krško NPP. The SNSA inspectors and the TSOs performed oversight of outage activities. During transfer of fuel assemblies from the reactor to the spent fuel pool a 50 cm long unknown object was found on the bottom of fuel transfer channel (see Figure 3) that was later identified as a part of a broken fuel rod. The event is described in detail in INES [4] and IRS reports [5].

The SNSA required the Krško NPP to analyse the event and perform appropriate corrective actions prior to the restart of the plant [8]. The SNSA formed a group of experts to review fuel inspection results, assess fuel conditions and provide an opinion on conclusion of Krško NPP determination of causes for fuel damage and proposed corrective actions. To expand the knowledge base of Slovenian experience with damaged fuel, the SNSA reviewed databases of operational events involving fuel damage in foreign NPPs and contacted also the regulatory body of the USA, the country of origin of the Krško NPP and its fuel assemblies.

An event in the Cattenom NPP in 2001 [13] resulted in 28 leaking fuel assemblies. The cause of the fuel damage was fretting. Vibrations of fuel rods inside the grid cells caused wear of the cladding. Ingress of water into the perforated cladding and hydriding of the zircalloy cladding material ruptured the fuel rods. The fuel failure at the Cattenom NPP was not caused by the same root cause as the event in the Krško NPP but the IRS report was useful to
determine interim corrective actions to prevent recurrence of open fuel defects in the next fuel cycle (introduction of restricted limits for the fuel leakage, see 3.3).

The Krško NPP reported on the event analysis according to the requirements of the regulation JV9 and included results of inspection of fuel assemblies [14]. The SNSA reviewed the documentation and prepared a list of safety relevant questions that ought to be resolved prior to restart of the plant. Two special meetings of the SNSA with the Krško NPP management were organised to discuss causes of the event, the condition of the fuel assemblies and the corrective actions that could prevent the recurrence of such fuel damage in next fuel cycle. The SNSA findings were included in the Analysis of the outage activities [3].

The SNSA relied also on special expert opinion of TSOs that supervised the Krško NPP activities involving fuel assemblies [12]. The TSOs assessed the fuel inspection findings and proposed additional ultrasonic and visual inspections to confirm the integrity of those fuel assemblies that were reloaded into the core for the next fuel cycle. The TSOs also confirmed that the interim corrective actions were appropriate to allow the operation of the Krško NPP in next fuel cycle.

Figure 3: The broken part of a fuel rod found in the fuel transfer channel (the broken rod is enlarged in the inset on the right side of the Figure) [5]

3.3 Causes for fuel damage and corrective actions to prevent event recurrence

The cause of open failure of fuel cladding was vibrations due to baffle jetting at the core baffle plate locations (Figure 4). The causes of tight fuel rods defects were grid-to-rod fretting and debris and were already well known from previous operation of the Krško NPP, e.g. fuel cycles 20-26. The detailed description of causes for the event and corrective actions implemented or planned are described in the IRS report [5].

The Krško NPP and Westinghouse proposed some interim corrective measures that were reviewed and confirmed by the TSOs and the SNSA before their implementation. Armouring of fuel assemblies in locations subjected to baffle jetting was performed to prevent recurrence of open fuel defects in new fuel cycle. All of the damaged fuel assemblies were eliminated from the new core design. The broken fuel rod segment was picked up from the bottom of fuel transfer channel and stored in the spent fuel pool. To perform such extended inspections and implement immediate corrective actions [5] the refuelling outage had to be extended beyond the original schedule.
Based on reviewed foreign operational experience [13] and regulatory approach to such events (e.g. US NRC, ASN) the SNSA recommended to the Krško NPP management to introduce restricted limits for the fuel leakage in the next fuel cycle with associated actions in case of degradation of fuel assemblies integrity [8]. These stricter requirements were included in new revision of the Krško NPP Failed Fuel Action Plan [14] and both the Krško NPP and the SNSA regularly follow the fuel integrity conditions in the 27th fuel cycle. The fuel provider Westinghouse prepared a root cause analysis of the event and proposed long-term corrective actions to be implemented during the next refuelling outage in 2015 [9] such as implementation of upflow conversion to eliminate the coolant jets that cause fuel failure due to baffle jetting. An independent evaluation of root cause analysis [10] confirmed the conclusions of root cause analysis and appropriateness of proposed corrective/preventive actions.

### 3.4 Informing the Slovenian and international public and NGOs

The SNSA performed a major task of providing information on all activities and fuel conditions to the Slovenian [8] and international public [1]. Since this event had a large following in public, the SNSA director also attended evening news on national television and presented information on the event and its safety impact for the local population near the Krško NPP [8]. The European nuclear safety regulators inquired on the event and therefore the SNSA prepared a report for the WENRA with detailed clarification of circumstances [7]. An extensive discussion with Slovenian NGOs such as Greenpeace was held and the written correspondence with NGOs is published on the SNSA website [8]. The SNSA staff prepared a report with assessment on safety relevance of the event according to the INES scale [4] (the event was rated as level 0) and a report to the IRS database [5] that included description of...
causes for the event and corrective actions implemented or planned. The SNSA reported on the event to the Government of Slovenia regularly in the scope of the Annual Report on Radiation and Nuclear Safety [6]. The regulatory body of neighbouring Croatia was invited to a meeting at the SNSA and was given extensive information on the event with all the details as well as justification of INES rating that determined the safety significance of the event.

4 CURRENT SITUATION AND FUTURE ACTIVITIES

Following the restart of the plant after the outage both the SNSA and the Krško NPP closely monitor the conditions of the fuel assemblies through trending and analysis of reactor coolant activities [6]. These measurements are regularly reported to the SNSA in weekly reports of the Krško NPP according to the requirements of the regulation JV9. The activity of iodine isotopes in the reactor coolant is rather high due to the contribution of isotopes from tramp uranium (the dispersed fissile material from open fuel cladding defects of previous fuel cycle). The SNSA evaluated fuel conditions and assessed efficiency of corrective actions in new fuel cycle and reported this information internationally [2]. Currently, past the mid-cycle 27, there are still no open fuel defects in the reactor core observed.

The root cause analysis of the fuel provider Westinghouse [9] recommended a design modification with reactor vessel upflow conversion, which would decrease or eliminate the effect of vibrations due to baffle jetting. This modification is to be performed during the next refuelling outage and it shall reduce the pressure difference and possibility for jetting. This modification will involve major changes to the Krško NPP Safety analysis report and such changes need to be approved by the SNSA prior to implementation according to the requirements of the ZVISJV and the regulation JV9. Other proposed improvements aim to improve the robustness of the fuel assemblies to the grid-to-rod fretting and debris fretting fuel damaging mechanisms [10].

5 CONCLUSIONS

During the regular outage 2013 at the end of cycle 26, regular SNSA inspection was carried out in cooperation of SNSA inspectors, other SNSA experts and representatives of TSOs. The SNSA closely followed all activities involving fuel inspections and fuel assemblies reconstitution during the outage. The analyses to determine causes for fuel damage were all reviewed and safety aspects were discussed with the operator. Prior to the start of the cycle 27, based on the SNSA recommendations the Krško NPP Failed Fuel Action Plan was upgraded to comprise actions in case of observed open fuel defects. Every action level includes corrective and preventive actions in the event of the degradation of fuel assembly conditions and in the event of open defects in the fuel rods, as observed in fuel cycle 26. The implemented corrective actions successfully addressed the identified cause of open fuel defects and fuel conditions in the core are currently still without any open cladding defects.

The event of fuel damage in the outage 2013 was a challenging task for the operator and the fuel provider especially in the tight schedule of numerous outage activities. However, with joint effort of the operator, regulator and the TSOs and including also exchange of information with foreign regulatory bodies, the fuel conditions in the reactor core were brought under control. A long term solution is in preparation phase and this should eliminate the cause of open fuel cladding defects. Extensive information of Slovenian and international public by the SNSA have regained the trust of the public as well as the NGOs in the safe operation of the Krško NPP. Further activities will involve fuel assemblies inspection in
future outages as well as licensing and implementation of design modifications that will eliminate fuel damage due to baffle jetting.

REFERENCES


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[13] Serious fuel cladding failures at Cattenom 3, IRS report Number 7540, February 2003 (Restricted)