Review Of The Operating Experience With The Periodic Testing Issues Of Passive Autocatalytic Recombiners In NPP Krško

Violeta Čalić, Stanko Manojlović
Nuclear Power Plant Krško
Vrbina 12, 8270 Krško, Slovenia
violeta.calic@nek.si , stanko.manojlovic@nek.si

ABSTRACT

Passive Autocatalytic Recombiner (PAR) system was installed in NPP Krško to mitigate design basis (DBA) and design extension condition (DEC) accidents by minimizing the risk of containment damage due to hydrogen deflagrations. The mitigation strategy is based on the catalytic oxidation of hydrogen (H2) using oxygen (O2) from the containment atmosphere and a noble metal palladium (Pd) as catalyst.
Every 18 months the periodic testing of PAR cartridges is performed. The purpose of the PAR cartridge surveillance test is to verify the system operability and assess the need for cartridge regeneration. The testing of the PAR cartridges has shown fluctuations in the results, which could have been caused by testing method sensitivity to environmental conditions, impurities in the containment atmosphere and/or material properties (e.g., amount of catalyst, surface area of reactants, heat addition, etc.).
The issues with the periodic testing had no impact on the system performance. It has been shown that the selection of the testing parameters and the test device design have not been correctly defined. This is confirmed by the results of various tests performed in the period 2015 - 2021. Additionally, operating experience from different PAR users and suppliers indicated the conduction of test at elevated temperatures. NPP Krško insisted, with the supplier of the testing device to solve these issues. The joint approach was to increase the test temperatures to those, which are closer, yet still conservative, to accident conditions (approx. 40 ºC). Under accident conditions the temperature of the containment atmosphere would be much higher than the normal ambient containment temperature. Testing performed at elevated temperatures reduces the impact of the known environmental influences on reaction start-up time.
Numerous tests and design modifications of the test device itself have been made, with the aim of performing the tests at elevated temperature.
The paper reviews NPP Krško's operating experience with the testing of PAR system and the activities performed in order to eliminate difficulties with the surveillance testing.

Keywords: *passive autocatalytic recombiners, PAR, periodic testing, DBA, DEC, PAR testing device, hydrogen*

1 INTRODUCTION

NEK installed PARs in the outage of 2013. This system provides passive combustible gas control for design basis accidents (DBA) and for severe accidents – Beyond Design Basis Accidents (BDBA). As such only 2 PAR units are required to mitigate DBA while additional 20 were installed for BDBA scenarios.
NEK's PARs originated from Siempelkamp NIS Ingenieurgesellschaft mbH (NIS). NIS-PARs have been largely installed worldwide and have a very good operating experience in many plants.

PARs are constructed from a stainless-steel box like element which is open at the bottom and the top. 44 recombiner cartridges, which hold the catalyst, are located at the bottom of the device. After recombination of hydrogen (H2) and oxygen (O2) on the surface of the catalyst, heat and steam are produced. By natural convection water vapour, air and unreacted hydrogen flow through the device, same to a chimney effect.

Cartridges in which the catalyst is encased have stainless steel frame which allows them to be removed. The catalyst itself is palladium (Pd) which has been coated on aluminium oxide pellets. This allows gases to pass through the pellet filled plates, where oxygen and hydrogen are recombined into steam.

Figure 1: An example of the PAR unit installed in NEK

2 ORIGINAL TESTING PROCEDURE

During an outage sample cartridge are removed from different PAR units in order to test and to verify the operability of the PARs for the next cycle. The following steps performed initially were:

1. Collection of one cartridge from each of the two safety-related PARs and from four non-safety related PARs
2. Placement of the cartridges in the testing device, where it is exposed to a mixture of H2 and air at room temperatures.

Acceptance criteria for the test are either:

a) temperature increase of at least 10 °C in 20 minutes or
b) temperature increase of at least 20 °C in 30 minutes.

3. With the test completed successfully, the cartridges are returned to the PARs.

However, a cartridge not fulfilling the acceptance criteria requires all cartridges from the affected PAR to be removed from the device and treated by the PAR cleaning (regeneration) device. After regeneration, two randomly picked treated cartridges from each regenerated unit must have successful functional testing. If acceptance criteria are met, all the cartridges are reinserted back into the PAR units.

The tests have been performed with the NIS test device. The following parameters were used:

- Room temperature: 16 to 22 °C
- Hydrogen (H2) concentration: 3% (± 0.25 abs) vol % in air
- Flow rate: 1500 l/h

- Test gas pressure: 1.5 bar

Figure 2: The original NIS testing device

3 TESTING RESULTS AND METHODOLOGY DEVELOPMENT

During the refueling outages from 2015 to 2021, most of the randomly selected PAR cartridges did not pass the periodic testing at room temperature. According to NEK procedure, in these cases all cartridges have to be regenerated followed again by a test in the test device to demonstrate the success of the regeneration. This was a demanding work in hours and resources.

In order to resolve these testing results fluctuations and to determine if there is a common root cause, NEK (and supplier) performed multiple tests over the years. The test evaluated the following aspects:

- Investigation of the PAR soiling source
- Repeatability of Test Results,
- Definition of Temperature for Testing,
- Qualification of NIS Test Device for Testing at Elevated Temperature,
- Potential Relaxation of Requirements for Regeneration,
- Tests with Cartridges being inside Containment for 1 and 2 Cycle,
- Potential Additional Tests to Support an Issue Analysis,
- Pre-testing of cartridges at 65 °C,
- Test Regarding Potentially Different Behaviour of Different Batches,
- Test Regarding Operability of RTD’s on TD.

The cause analysis of the test failures identified a multi causal situation with increased testing sensitivity due to use of lower band of testing temperature, sporadic oil release into the containment as well as potentially other volatile organic compounds and other uncontrollable contributor to a delayed start-up at low temperatures as e.g. moisture adsorption. Additionally, throughout the investigation successful test results were observed in only one batch of the catalytic material (NEK is using three different batches) [1] [2] [3].

The tests also showed that for testing of PAR cartridges on elevated temperatures new-modified testing device is required since there was difficult manipulation of the heated cartridges, the decrease of temperature which is to be expected by the transport of the heated cartridge from oven to TD is varying, depending on ambient temperature and in what way the person is handling the cartridge and placing it in TD, testing temperatures and repeatability are depending on manipulation of cartridges and in-situ thermocouples, a testing method and system should be isolated and not influenced by human performance and ambient conditions.

Non-regenerated cartridges pass the test on elevated temperatures (45, 50, 55 and 65 ^{o}C), while none have satisfying result at RT (measurement for 5 min only). The results confirmed that even when the cartridges were not passing the test at room temperature, they would still fulfil their intended function during an accident, since higher containment temperatures were expected.

4 VERIFICATION IF ELEVATED TEMPERATURE IS ACCEPTABLE

According to NEK's Updated Safety Analysis Report (USAR) [4] the double-ended pump suction guillotine (DEPSG) is the design basis worst case Loss of Coolant Accident (LOCA) scenario. Therefore, the design analysis for "Determination of the Number of Passive Autocatalytic Recombiners Required for Design Basis Accidents (DBAs) at Krško NPP" is based on this scenario. Additionally, it is more appropriate to operate test in the temperatures which may be expected during DEPSG event. Figure 3 shows the containment temperature in case of DEPSG scenario.

According to Figure 3, the containment temperature reaches 80 °C about 1s after the beginning of transient. Thus, the containment temperature is always significantly higher than 70 °C after beginning of any hydrogen generation. After the start-up of the catalytic reaction, the catalytic surface of the PAR will stay hot until all H2 is consumed.

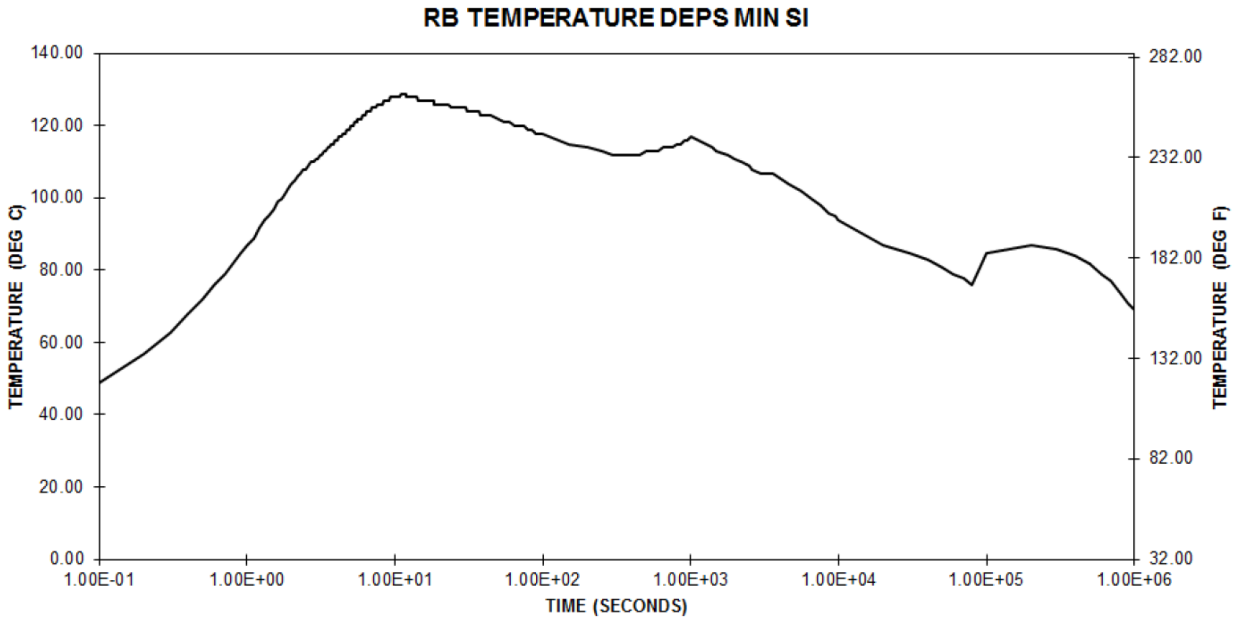

Figure 3: DEPSG temperature development as a function of time

It was therefore shown that sufficient safety margins remain if the initial temperature during surveillance test is up to 50 °C. The selected elevated start temperature considers the following aspects: catalytic reaction rate is temperature sensitive, test preformed at lower temperature compared to temperatures under accident conditions (safety margin) and that elevated test temperature shall keep safety margin which covers all uncertainties and guarantees the operation of the PARs under accident condition during the next complete operation cycle.
All other parameters remained the same and acceptance criteria also remained unchanged.

5 MODIFICATION OF PAR TESTING DEVICE AND TESTING PROCEDURE

NIS PAR testing device was returned to the supplier to modify the testing device in such a way, to allow test being performed at elevated temperature and enable more advanced monitoring of temperatures.

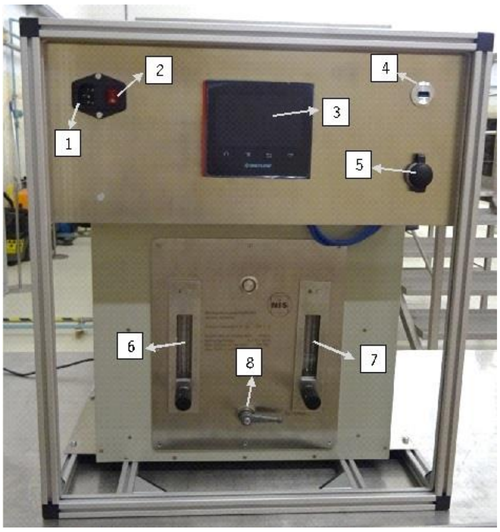

Figure 4: Modified PAR Testing device - the front side of the device (1 - AC power support; 2 - AC power switch; 3 - Watlow F4T screen display; 4 - USB port to obtain Watlow F4T data; 5 - LAN port far programming of Watlow F4T; 6 - Flowmeter - left test channel; 7 - Flowmeter - right test channel; 8 - Isolation valve)

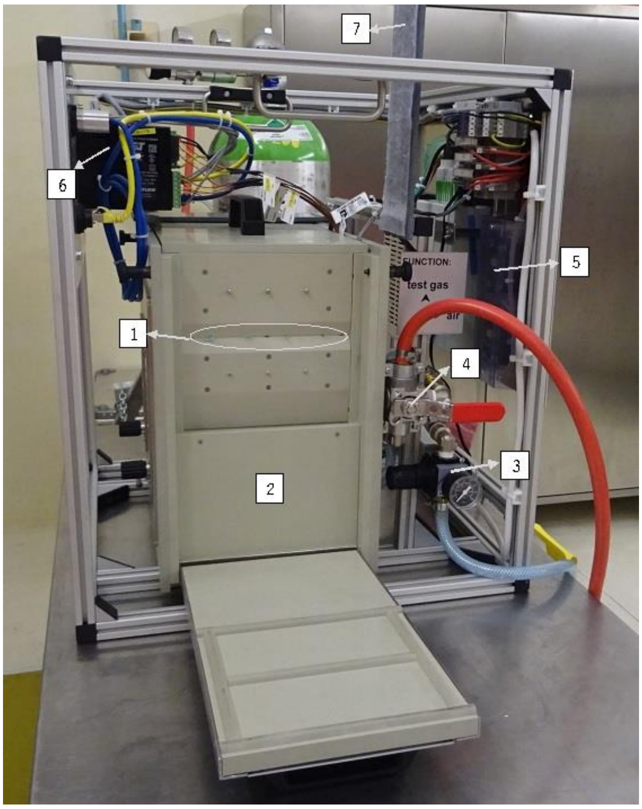

Figure 5 Modified PAR Testing device - the right side view of the device (1 - 4 thermocouples (Ahlborn) in test channel; 2 - Heating block inside the device; 3 - Pressure reducer for compressed air; 4 - three-way valve for switching from compressed air to the test gas; 5 - Solid-State Relays of the PAR-TD; 6 - Watlow F4T controller and input/output signal wires; 7 - Open hinge-joint top plates)

Figures 4 and 5 show the modified testing device. The front of the device provides an analogue flow measurement and a digital display to monitor device heat-up and temperature measurement. The testing device can also be connected to a personal computer to allow easier data collection and plotting.

An additional heating element had to be installed in order to provide initial elevated temperatures (shown on Figure 6). The heating block is a resistive heating element which regulates its output according to the thermocouples in order to provide an elevated temperature of up to max 50 °C.

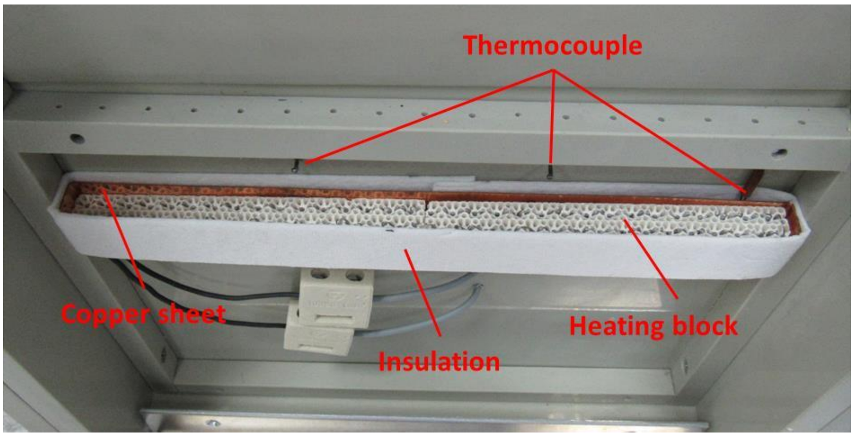

Figure 6: Heating block on the PAR testing device (detail 2 in Figure 5)

For the results to be valid and clearly measurable a PAR cartridge is inserted into the testing device. The cartridge is then heated up to the elevated temperature using compressed air without hydrogen. After temperature stabilization the hydrogen gas is released and an increase of outlet temperature must be registered.

This process is clearly visible from the Figure 7 below. In the initial stages the device is preheated as can be seen at time 00:00 from the figure. When inserting a cartridge into the testing device, a temperature drop is visible at time 2:30. The device is closed back up and the cartridge gets heated to the new elevated temperature at approx. 40 -45 °C. Approx. 40 °C is also typical containment atmosphere temperature during normal plant operation. The temperature stabilizes at about 14:24 when the hydrogen gas is released through the cartridge. A sharp temperature rise of 12 °C can be seen within a span of 2 minutes. Finally, the hydrogen mixture is shut off and the test completed.

The temperature increase shown is sufficient to pass the acceptance criteria of a temperature increase of at least 10 °C in 20 minutes.

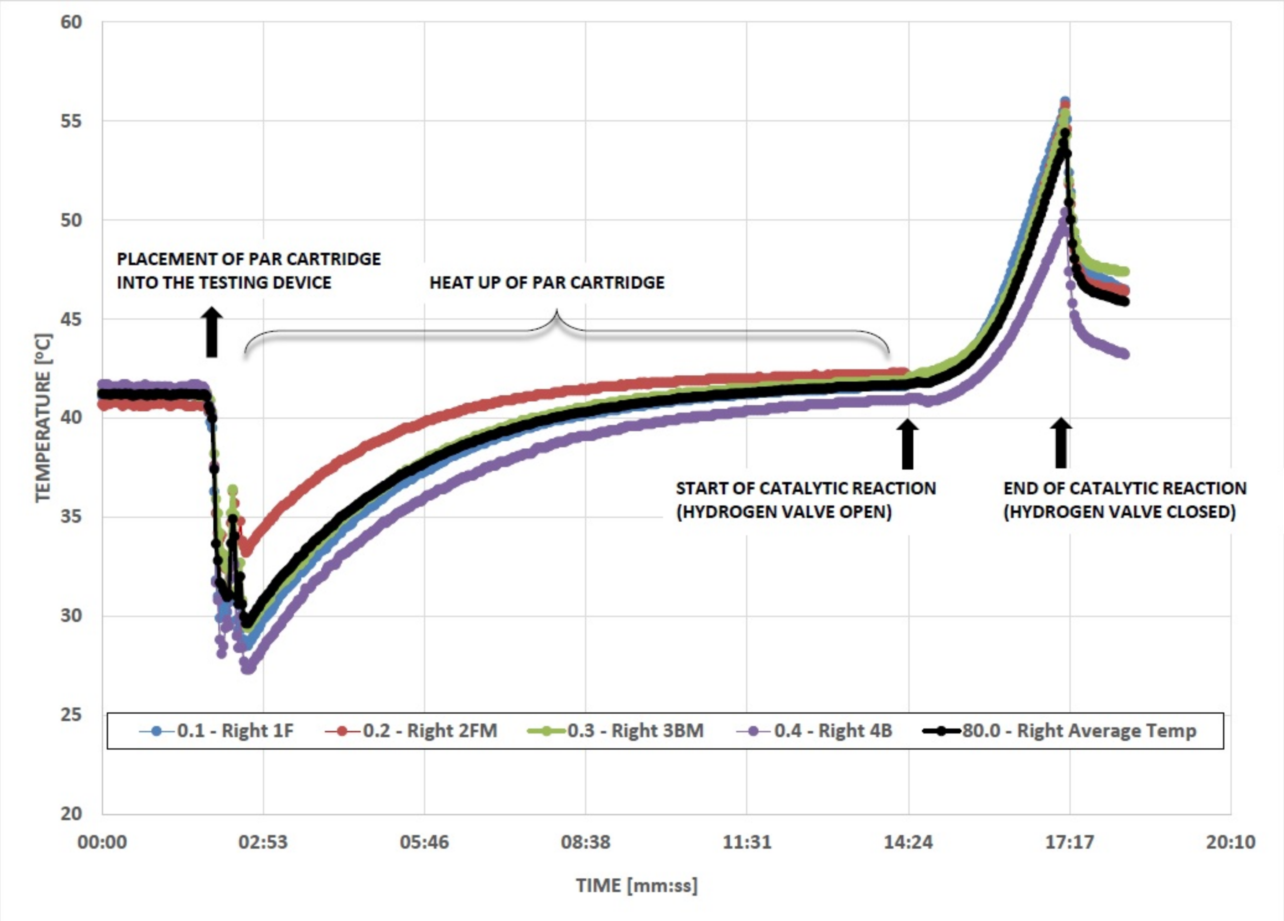

Figure 7: Typical test at elevated temperatures

6 CONCLUSION

The issues with the periodic testing had no impact on the system performance. It has been shown that the selection of the testing parameters and the test device design have not been correctly defined. This is confirmed by the results of various tests performed in the period 2015 - 2021. Additionally, operating experience from different PAR users and suppliers indicated the conduction of test at elevated temperatures.

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Since the implementation of these changes to the testing device and the testing procedure all PAR cartridges have passed the acceptance criteria.

REFERENCES

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