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# Off-gas processing system operations for mercury target vessel replacement at J-PARC

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**Abstract.** An off-gas processing system was installed in the J-PARC spallation neutron source to reduce radioactivity of xenon-127 and tritium contained in a helium cover gas in a surge tank of a mercury circulation system to obey the regulation by law. In addition to this role it has been utilized to a purging process before the target vessel replacement and an air-flow control procedure to minimize uncontrollable radioactivity release during the replacement. An standard and urgent model plans of the off-gas processing system operation were established indicating that 31 days were required at least to replace the target vessel.

## 1. Introduction

The Japanese spallation neutron source (JSNS) [1] in the Materials and Life science experimental Facility (MLF) of the Japan Proton Accelerator Research Complex (J-PARC) started operation in 2008. The intense proton beam of 3 GeV with a power of 1 MW is injected into mercury in a mercury target vessel made by stainless steel. Mercury is supposed to be used until the end of the lifetime of JSNS while the target vessel is replaced periodically. Gaseous radioactivity are accumulated in a cover gas of a surge tank of a mercury circulation system. An off-gas processing system was introduced so that the cover gas including gaseous radioactivity was transferred before mercury draining and a target replacement. The transferred cover gas is kept for 6–12 months for the decay of  $^{127}\text{Xe}$  having half-life of 36.4 days, where tritium in the gas is absorbed by molecular sieve (synthetic zeolite), and then is released to the environment after checking the radioactivity.

The first replacement of the target vessel was carried out in November 2011. At the beginning the radioactivity in the mercury circulation system was reduced by repeating three-step purging process: 1) filling the mercury circulation system with clean helium gas, 2) keeping for a while, and 3) transferring the helium gas to the off-gas processing system. The purging process reduced  $^{127}\text{Xe}$  radioactivity in the mercury circulation system down to 1/100 [2], and then circular specimens were cut out from the head of the target vessel for post irradiation experiments (PIE). The replacement of the target vessel was carried out after the specimen cut-out. During the replacement gas was continuously transferred to the off-gas processing system to form inflow air aiming at reducing the tritium release. The amount of tritium released from the start of cutting process to the end of the replacement was 150 GBq [3], which was 25% larger than 120 GBq, the design value of annual tritium release from MLF. The proton beam irradiation of



450 MWh before the first target vessel replacement was only 9% of 5000 MWh, being assumed in the design. The tritium release in the nominal operation of 1-MW was estimated to be 1.7 TBq based on these values. This higher value could give an impact to other scenarios of radioactivity treatment in MLF, efforts to reduce tritium release have been started.

After the first replacement the mercury target vessel was replaced in 2014, 2015 and 2016. A standard model plan of the replacement has been developed to be scheduled during maintenance period. An urgent model plan has been also discussed for the case of the target failure during beam operation. In this paper improvements of processes to reduce radioactivity release in the model plans during the target vessel replacement are described based on real experiences.

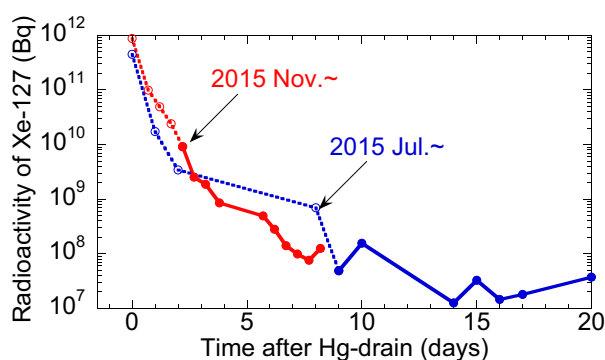
## 2. Improvements of processes to reduce radioactivity release

### 2.1. Purging process

Figure 1 shows the radioactivity of  $^{127}\text{Xe}$  in cover gas and purging gas to compare the effects for different frequency of purging. In July 2015, the purging was performed in a scheduled summer maintenance period. The minimum intervals of the purging was one day. Even in the purging after longer interval, the  $^{127}\text{Xe}$  radioactivity was in the range of extrapolation of daily purging. It was concluded that longer interval than one day brought no benefit.

In November 2015, the purging was performed due to the unexpected target failure. A quick replacement was desired since the failure occurred within one-month operation after a long beam absence from the end of April. Thus, the purging with shorter intervals of 0.5-day was performed expecting to early readiness for the target replacement. Although more purging were carried out in a short period, the duration required to reduce  $^{127}\text{Xe}$  radioactivity was not drastically improved. The goal of  $^{127}\text{Xe}$  radioactivity in the purging gas was determined to be 0.2 GBq not to initiate an alarm of an exhaust gas monitor of MLF assuming gas release of 200 L in 1 minute during the target vessel cutting of replacement processes. The goal was achieved on 9th and 6th day in the July and November 2015 purgings, respectively. The proton beam power at the target failure on November was 500 kW, and the  $^{127}\text{Xe}$  radioactivity was only 28% of the saturated one after a long beam operation. Thus 7.2 times higher radioactivity needs to be taken into account for the nominal operation. Considering these results ten times of purging in 10 days were allocated for the purging process in both standard and urgent model plans of the target vessel replacement.

As a result of transferring the cover gas and the purging gas of ten times, the volume of gas to be stored in the gas holders reached to 3,000–5,400 NL, resulting that 2–3 out of 4 gas holders were occupied. During the target vessel cutting and replacement process, gas in the mercury circulation system needs to be transferred to the off-gas processing system as an air-flow control process, to be mentioned in the next section. At least two, preferably three, gas holders need to be empty to perform the air-flow control during the target vessel replacement. A liquid-nitrogen cooled charcoal trap (CCT) was introduced to separate noble gases from helium



**Figure 1.** Radioactivity of  $^{127}\text{Xe}$  in purging gas, which was reduced by repeated purging. Solid lines and filled circles were obtained by measuring sampled gas by a high-purity germanium (HPGe) detector, dashed lines and open circles were estimated by dose trends of the radiation monitor at the mercury absorber normalized by the results with the HPGe detector.

gas. The gases in the gas holders are circulated through the CCT, and other gases except for helium are trapped in it. The helium gas is released in the environment after the CCT process, and the trapped gas are returned to a gas holder by heating CCT. The volume of the trapped gas were about 600 NL so far. Six days were allocated for the standard model plan including a tritium removal process to avoid frost forming, the CCT and the release processes. Four days were allocated for the urgent plan assuming a shift work.

## 2.2. Air-flow control

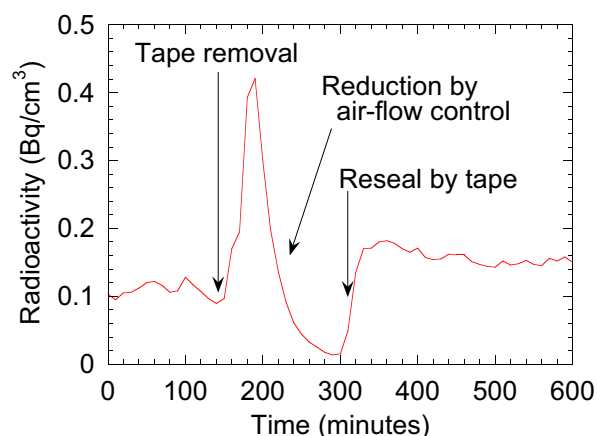
The mercury circulation system was vacuum at the PIE specimen cutting out in 2011. One of the reason why large amount of radioactivity was released assumed that a turbulent inflow might enhance desorption of tritium being trapped in stainless steel of the system. Thereafter we decided to fill the mercury circulation system with dry gas before the cutting for PIE.

The holes after cutting out PIE specimens were sealed with curing tape, but radioactivity was continuously released as shown in Fig. 2. Once the tape was removed, the radioactivity release rapidly increased. Then gas was transferred to the off-gas processing system in order to form an inflow from outside to inside the target vessel. As a result of this ‘air-flow control’, the radioactivity release was reduced down to almost background level. The air-flow control has been carried out frequently hereafter. However the volume of gas holders in the off-gas processing system is limited, silicon-rubber plugs were employed to seal such open holes and mercury flow pipes to minimize radioactivity release and gas volume to be stored in the gas holders.

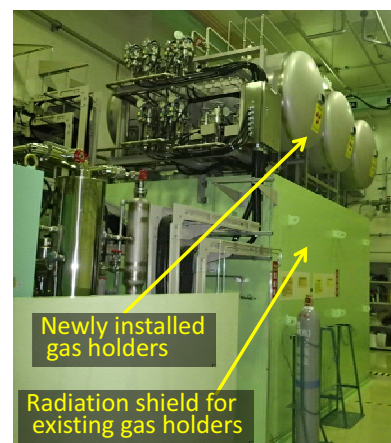
Based on these efforts, three days were allocated in the standard model plan for the cutting for PIE, processing the gas used by the air-flow control, and release of the processed gas. In the urgent case, the cutting would be skipped. Five days were allocated in the both model plans for the target vessel replacement, and processing the air-flow control gas, and release of it assuming that three gas holders were occupied by the air-flow control gas.

## 3. Model plans of target vessel replacement and further upgrade

The improvements and estimations of gas processing procedures have been carried out, and the standard and the urgent model plans for target vessel replacement were established as shown



**Figure 2.** Effects of air-flow control to reduce radioactivity release from the hole of the target vessel head made by cutting out of PIE specimens. Continuous radioactivity release before and after this test indicated that the tape could not seal the hole well.



**Figure 3.** Photograph of newly installed gas holders on the shield of existing gas holders.

**Table 1.** Required time of model plans of target vessel replacement

Process	Standard (days)	Urgent (days)
Cooling/Cover gas transfer/Purging/Process & release	7/1/10/6	0/1/10/4
Cutting for PIE/Process & release	1/2	0/0
Target vessel replacement/Process & release	1/4	1/4
Leak-check/Hg-loading (both incl. Process & release)	6/6	6/5
Total	44	31

in Table 1 including processing of gas used in the leak check after an installation of new target vessel and that used to pressurize a drain tank for mercury loading. The urgent model plan was verified through the target replacement after the target failure occurred in November 2015, which took 32 days except for delays due to other non-technical reasons. There were some delays in the cooling and the process of purging gas. It was not easy to decide to replace the target vessel just after the failure. Four days for discussions and checking the situation were counted as the cooling time. Extra 2 days were used for a tritium removal process in the process of purging gas in order to convert HT gas to HTO by using a catalyst loop. The extra days were not necessary if the first tritium removal process was carried out with the catalyst loop. There were also some advances in the purging, the process of gases used in the air-flow control during the target vessel replacement and that used in the mercury loading due to the lower proton beam power and shorter operation time before the failure than those assumed for the model plan.

Upgrades of the off-gas processing system has started in order to shorten the time of the target vessel replacement. New gas holders (2.4 m<sup>3</sup> for each) were installed in March 2017 as shown in Fig. 3, and to be used after the next target vessel replacement. With the new holders, the whole volume of gases of the mercury loading can be transferred to the off-gas processing system. It will reduce 4 days from the model plan by making it possible to start beam operation without finishing the process and release of the gas used for the mercury loading. Parallel processing modes, in which carrying out two processes at the same time, will be fully added until March 2018 aiming at further reduction of 5 days from the model plans.

#### 4. Summary

The off-gas processing system in JSNS was given the role of reducing the radioactivity release at the target vessel replacement in addition to that defined in the initial design. The model plans in the standard and the urgent cases of the target vessel replacement utilizing the off-gas processing system were established. The urgent model plan of the target vessel replacement needs 31 days, and will be reduced by 9 day after the undergoing upgrades of the off-gas processing system.

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