ESS Target Station Ventilation - Managing Radiation Hazards

To cite this article: A Polato et al 2018 J. Phys.: Conf. Ser. 1021 012043

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Abstract. The ESS spallation target undergoes a scheduled irradiation period of 5 years. After this time, the Target assembly (wheel and shaft) is transported to ESS Active Cell where a series of mechanical operations are foreseen in order to dismantle the target and sort the wastes before their disposal. The nature of the dismantling operations – mainly performed with sawing and shear cutting tools – generates activated aerodispersed particles (aerosols and gas) contributing to high contamination levels inside the Active Cell. The function of the HVAC is to ensure the dynamic confinement of the airborne contamination and to collect it, through filtration system, to a specific point before the release.

In this paper, the study of the HVAC system is focused on the fire event case. This situation, among others involving the Active Cell, can jeopardize the dynamic confinement hence creating the potential for a radiation hazard for workers and public. With reference data coming from existing literature, the study shows that a controlled operational mode of the HVAC ensures, at the same time, the protection against the fire spread and the dynamic confinement of the airborne contamination for the entire duration of the postulated fire.

1. Introduction
The current lifetime of the ESS target is set today at 5 years of full power beam time. After this time, a new target has to be installed in the target Monolith while the old target has to be removed from here and disassembled. The Active Cell constitutes a process enclosure (total volume of nearly 4000 m³) devoted to the dismantling operations of irradiated components coming from the target Monolith. It hosts, in its premises, a process cell where the effective dismantling is performed, a maintenance cell and a series of storage pits to temporary host the waste before their final disposal.

Airborne contamination inside the Active Cell is the result of the dismantling operations occurring on a complete target assembly and, in particular, from activated dusts and gases from stainless steel shaft and shroud plus eroded tungsten from the target (Figure 1).

The levels of contamination were evaluated on the base of the estimated debris produced during dismantling (cf. [1]) combined with radioactive inventory present in the components (cf. [2] and [3]). In addition to this, a series of coefficients were considered to put in relation the total produced activity during dismantling with the quota of it that results airborne by effect of local phenomena (presence of a local extraction, suspension of dusts due to the air stream, suspension of particles with sufficiently small aerodynamic diameter). These coefficients are derived from experience on the same kind of operations in existing nuclear facilities. Figure 2 and Table 1 give an overview of the coefficients used.
Figure 1. Detail of the target shroud with shown a tungsten sector

Figure 2. Airborne release coefficients

Table 1. Airborne release factors of the total produced activity during dismantling operation

| Airborne fraction of the cutting debris \( F_{\text{ActCell}} \) | Efficiency of local extraction device \( C \) | Resuspension of floor dusts due to ventilation \( F_{\text{HVAC}} \) | Resuspension of floor dusts due to fire \( F_{\text{fire}} \) |
|-------------------------|---------------------------|---------------------------|---------------------------|
| 1E-2                    | 9E-1                      | 1E-6                      | 1E-2                      |

The contamination levels were finally evaluated for different kind of situations [4] and the main results are recalled in Table 2 where the different ratios between total and specific activities are due to the different source terms considered for the different situation (normal, accidental, fire).

Table 2. Active Cell airborne contamination figures

|                           | Total Activity | Specific activity | Derived Air Concentration (DAC) |
|---------------------------|----------------|-------------------|---------------------------------|
| Normal conditions         | 7.92E+10 Bq    | 1.47E+07 Bq/m³    | 1164.0 DAC                      |
| Accidental conditions*    | 7.41E+11 Bq    | 1.47E+08 Bq/m³    | 6558.5 DAC                      |
| Fire conditions           | 2.18E+11 Bq    | 4.04E+07 Bq/m³    | 7376.3 DAC                      |

*The dismantling performed in absence of local extraction device \((C=0\) in Table 1) was considered as the reference accidental condition.

If not confined, leaks through the Active Cell structure would cause dose received by public and personnel working in the adjacent areas. As a consequence, a ventilation system is foreseen to ensure the dynamic confinement of the enclosure.

2. Active Cell HVAC system configuration

The contamination levels of Table 2 classify the Active Cell as a C4** containment area according to [5], which suggests also the implementation of a ventilation system architecture of the type IIIB (Figure 3). Also, the Active Cell being a fire cell, fire dampers are foreseen on the supply and extraction ducts.

In normal conditions the HVAC system supplies a total airflow of 6500 m³/h (1.8 m³/s) to the Active Cell and ensures, via the extraction flow (about the same flow as the supply), a negative pressure with respect to adjacent areas hence ensuring the dynamic confinement.
Figure 3. Active Cell HVAC configuration with indicated fire dampers on the Active Cell perimeter, filters, extraction fans stack. It is possible to notice a bypass on the first level of filtration and the redundancy on the last level of filtration as well as on the extraction fan.

3. HVAC system operations during a fire event

The particular operational mode of the HVAC, during a fire event, is in line with what is described in [5] for areas presenting a high inventory of dispersible radioactive material. It is obtained via closing the supply fire damper upon fire detection, while the extraction fire damper remains open. In this configuration, the extraction can continue at a regime that is sufficient to keep the Active Cell at a pressure value that is lower than the adjacent rooms (ensuring the dynamic confinement). Additionally, the stop of the supply flow reduces the amount of oxygen delivered to the fire.

The goal of the analysis is to demonstrate that, during a fire event, it is possible to keep the ventilation extraction running for the entire duration of the postulated fire without compromising the fire sectorization of the building, ensuring the dynamic confinement of the volume and keeping the filtration at the same time.

The postulated fire is the one described in [6] with a maximum heat release rate of 320 kW and a total duration of 800 seconds. Reference [6] describes an additional fire (sensitivity analysis fire) with a maximum heat release rate of 1000 kW and a total fire duration of 1200 s. In Figure 4 and Figure 5 temperature and flow profiles connected to the fire scenarios are shown.

Figure 4. Temperature profile in the Active Cell during postulated (green) and sensitivity analysis (purple) fires. The red curve describes the adiabatic fire.

Figure 5. Flow increase due to air density variations during postulated (green) and sensitivity analysis (purple) fires. The red curve describes the adiabatic fire.

4. HVAC system behaviour during the fire event

4.1. Effect of increased temperature

The continuous extraction during fire implies that air at a higher temperature circulates through the ducts with the potential of damaging them and in conclusion jeopardize the fire sectorization and possibly spread contamination within the facility (i.e. dynamic confinement function lost).

Temperature profiles of Figure 4 show that the maximum temperature in the Active Cell reaches 40°C for the postulated fire and around 75°C for the sensitivity analysis fire (similar values for the adiabatic fire). These temperatures are compared with the resistance of the HVAC components (for
which a temperature resistance of 200°C for 2 hours was required) that in conclusion are not affected by the higher temperatures for the entire duration of the event.

4.2. Effect of the fire flow

The continuous extraction configuration has to take into account the increased flow result of reduced air density during a fire. If the HVAC is not capable to handle the increased flow, pressure inside the Active Cell can increase compromising the dynamic confinement of the airborne radioactivity.

The HVAC configuration described in Section 2. has, as a first action at the detection of a fire, the closing of the supply fire damper. This has an impact on the extraction flow that is reduced from the initial value of 1.8 m³/s to the sum of the leaks through the Active Cell structure (0.014 m³/s or class 3 according to [7]) plus the flow increase, shown in Figure 5. In this situation, the flow reaches approximately peak values of 0.5 m³/s and 0.8 m³/s for the postulated and sensitivity analysis fires respectively (similar values for the adiabatic fire). Given the maximum flow capacity of the system described in Section 2. the HVAC system can therefore handle the fire flow for the entire duration of the fire without an effect on the confinement function.

4.3. Effect of soot and dust on filters

One of the main concerns of the HVAC configuration of Section 2. is the clogging of filters due to deposition of soot on the filtration media. In this case, an elevated resistance can considerably reduce the extraction flow with repercussions on the dynamic confinement.

Assuming a heat of combustion of 34 kJ/kg with a soot production rate of 0.1 g/g (defined in [6]), the estimated quantity of soot is of 427 g and 1754 g for the postulated and the sensitivity analysis fires respectively. A dust amount of 100 g was added to these quantities to take into account the airborne dust already present in the Active Cell (cf. [4]) for a total of 527 g and 1854 g.

The filters selected for the Active Cell (HEPA filters specifically designed for nuclear applications) present filtrating media surfaces of 80 m² and 120 m² for the first and the second levels of filtration respectively (Figure 3) based on the airflow.

The variation of resistance as a function of the mass of filtered aerosols described in [8] sets at 10g/m² the maximum limit after which the resistance of a filter increases in a non-linear way. The same value was considered in the study as the extreme operating value for the Active Cell filters. After, filters were considered not functional anymore.

It is possible to see that in the case of the postulated fire soot and dusts can be deposited on the first level of filtration without this reaching its functional limits (500 g on 80 m² with a final value of 6.6 g/m²).

For the sensitivity analysis fire, a two-step clogging takes place. In a first stage, the first level of filtration gets progressively clogged until the 10 g/m² is reached (total of 800 g ashes deposited). At this point, the bypass present on the system of Figure 3 opens, the extraction continues passing on the second level of filtration that progressively gets clogged. Of the initial amount of dust, 1054 g deposit on the 120m² for a mass of filtered aerosol of 8.8 g/m² confirming that the extraction can continue for the entire duration of the fire without the soot and dust compromising the resistance of the filters and in conclusion allowing the dynamic confinement function.
5. Conclusions
The study shows that the radiation hazard connected with a fire event in the Active Cell can be
managed via a controlled operational mode of the HVAC system. This ensures, for the entire duration
of the postulated - and the sensitivity analysis - fire, the respect of the fire sectorization and the
dynamic confinement of the Active Cell.

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