

Multiscale integral analysis of a HT leakage in a fusion nuclear power plant

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Abstract. The present work presents an example of the application of an integral methodology based on a multiscale analysis that covers the whole tritium cycle within a nuclear fusion power plant, from a micro scale, analyzing key components where tritium is leaked through permeation, to a macro scale, considering its atmospheric transport. A leakage from the Nuclear Power Plants, (NPP) primary to the secondary side of a heat exchanger (HEX) is considered for the present example. Both primary and secondary loop coolants are assumed to be He. Leakage is placed inside the HEX, leaking tritium in elementary tritium (HT) form to the secondary loop where it permeates through the piping structural material to the exterior. The Heating Ventilation and Air Conditioning (HVAC) system removes the leaked tritium towards the NPP exhaust. The HEX is modelled with system codes and coupled to Computational Fluid Dynamic (CFD) to account for tritium dispersion inside the nuclear power plants buildings and in site environment. Finally, tritium dispersion is calculated with an atmospheric transport code and a dosimetry analysis is carried out. Results show how the implemented methodology is capable of assessing the impact of tritium from the microscale to the atmospheric scale including the dosimetric aspect.

1. Introduction

The transfer of tritium from the IRC to the environment is conservatively assumed to occur when the IRC is operating with a single enclosure scheme through the tritium plant power conversion system (intermediate heat exchangers and helium blowers). Tritium loss is mainly caused by HT and T₂ permeation and simultaneous primary coolant leakage through the Heat Exchangers. Primary coolant chemistry appears to be the most effective way to control tritium permeation from the breeder into primary coolant and from primary coolant through Heat Exchangers by H₂ flux isotopic exchange or steel (EUROFER/INCOLOY) oxidation. A leakage at a NPP primary to secondary heat exchanger is considered for the present coupling example. Both primary and secondary loop coolants are assumed to be He. A leakage is set to happen inside the one of the HEX, leaking tritium in HT form to the secondary loop where it permeates through the piping structural material to the exterior. HVAC removes the leaked tritium towards the NPP exhaust. The HEX is modelled with system codes and coupled to CFD to account for tritium dispersion inside the NPP and site environment. Finally, tritium dispersion is calculated with an atmospheric transport code and a dosimetry analysis is carried out. Tritium environmental release rate limit are assumed to be ~ 1 g-T/y . This limit determines the key parameters for the tritium IRC (with HT and HTO as dominant molecules, and T₂, T₂O as marginal one). The mechanism of transfer to the environment is assumed to be through leakages or permeation at the exchange system of the power plant (primary to secondary loop). Hence, chemical process optimization of the primary system is a key factor that needs to be reanalyzed in terms of radiological impact. It is necessary to consider all the pathways of tritium from the reactor to the



atmosphere and to model the transport phenomena adequately. Early and chronic doses, which have been evaluated for the Most Exposed Individual (MEI), have been calculated at particular distance bands from the release point.

2. Integral multiscale analysis example

1.1. Integral multiscale analysis. Primary to secondary leakage analysis

Different time and space scale calculation have to be carried out to perform an integral analysis of tritium dispersion from a leakage in a NPP. In the present work, an example for a HT leakage in a HEX is presented. Primary and secondary loop calculations are carried out with MELCOR[1] and GOTHIC[2] System Codes (SC) while larger scale calculation involving the NPP rooms and site are performed with ANSYS® Fluent® [3] CFD code. Atmospheric transport is calculated with UFOTRI Code [4]. Codes are coupled in order to achieve a best-estimate calculation with conservative parameters.

1.2. Tritium atmospheric and dosimetric analysis

For selecting the boundary conditions in the Tritium atmospheric dispersion at the macro scale, conservative parameters are used to define the input of the coupling with the data calculated with the CFD code. The methodology used for the calculation of the doses is probabilistic. The secondary phase in the tritium dispersion requires a coupling in the dispersion outputs and the tritium transport in all the body intake enclosures. In this phase, all mechanisms should be established where the deposition and incorporation in the environment can result in absorbed dose, including the oxidation of tritium in the case of HT.

3. HT leakage results

In the present work a leakage at a HEX is selected as an example to show the integral and multiscale analysis. As an example a 2.5 GWth fusion power plant with three power loops is simulated with MELCOR and GOTHIC, coupled to ANSYS® Fluent® CFD code and atmospheric transport up to 1 km. The HEX primary pipe breaks and HT leaks to the secondary loop. Note that this is a hypothetical accident scenario designed to clearly show how different codes can be coupled to achieve an integral and multiscale analysis.

3.1 HEX MELCOR and GOTHIC results

MELCOR and GOTHIC have been used as system codes for the simplified example in order to analyze the behavior of a leakage at a HEX and to show its coupling to ANSYS® Fluent®. A small leakage, through a hole in a primary pipe, with a section of $7.5 \times 10^{-5} \text{ m}^2$ is set to happen 1000 s after the system reaches the steady state. Results, shown in Fig. 1, present a leakage maximum mass flow rate of 0.82 kg/s. Tritium leakage is assumed to be only in form of HT and with a mass fraction of a 0.001. Note that permeation has not been calculated. The ratio of permeated tritium is set to be more than ten times that of a leakage at ambient conditions. The resulting GOTHIC data present a slightly larger (more conservative) leakage mass flow rate than that of MELCOR as shown in Fig. 1. Tritium in the secondary loop permeates to the environment. GOTHIC results are set as a time dependent BC at the considered room in the NPP. A simplified generic geometry for a fusion reactor site has been considered including a simple HVAC to the exhaust. A transient case has been run until the plume reaches its steady state and analyzed for surface concentrations (see. Fig. 2)

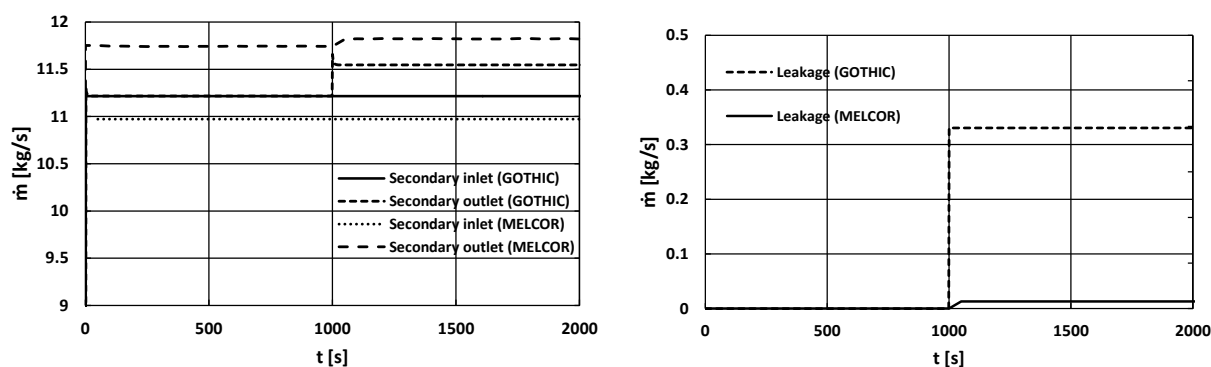


Fig. 1. MELCOR (at the left) and GOTHIC (at the right) HEX model secondary mass flow rate evolution.

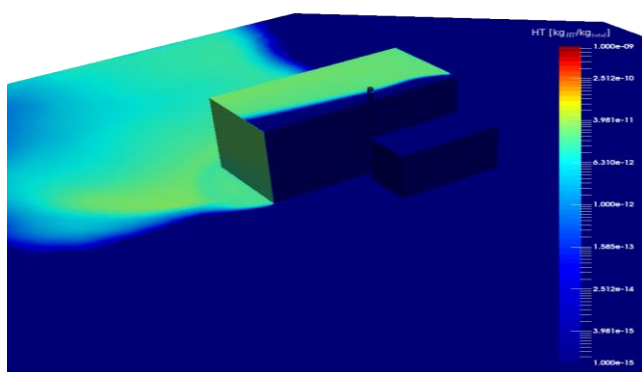


Fig. 2. HT mass fraction on the site surface including buildings.

3.2 Atmospheric and Dosimetric analysis

The environmental conditions of the primary phase of tritium emission are factors that determine the intake concentrations by biological agents. Atmospheric processes have an important role mainly in the primary phase where tritium is not deposited in soil and plants in the environment. The accident takes place at 30 m high stack and the rate of emission into the atmosphere is of 1.032 gram/s. The meteorological variables after the accident are also measured every 10 minutes of day 181 (the first of June). At that moment there is a contamination in the crops and therefore a dose by ingestion. The major chemical forms of tritium, HT and HTO, are strongly dependent on their velocity of deposition, **¡Error! No se encuentra el origen de la referencia..** This parameter determines the concentration of tritium released to the atmosphere as HTO and the amount of tritium that penetrates into the lower layers of the soil below 5 cm from the surface, [5]. We have considered different releases, HT and HTO, for comparing the different chemical forms of tritium. But elemental tritium is observed. The doses resulting from inhalation are considered from two different perspectives: on one hand tritium enters the body from direct inhalation of the plume passage, and, on the other hand from (the plume) re-emission. For calculating the intake doses, the assumption made is that all of food consumed is produced locally and it is considered a compartment which is divided into an organic part and an inorganic part. The dose by ingestion of contaminated foods constitute the 97% of the contribution to doses in emissions to the atmosphere of elemental tritium when the crop is under development and the vegetal growth is ongoing. Concerning the contribution to the total dose due to inhalation, it has different components, one due to inhalation by the direct pass of the tritium contaminated plume and the dose by re-emission of HT oxidized to HTO, from the surface of the soil. In the case of HT the dose due to tritium re-emission is a factor 3 higher than the dose due to inhalation

directly from the tritium contaminated plume. This produce an increment of the atmospheric amount of HTO, therefore the dose due to inhalation of HTO constitute a 44.8% of the total dose.

Table 1. Most Exposed Individual, MEI, (Sv) values with downwind distance.

Distance (m)	HT (Sv)	HTO (Sv)
145	1.85E-04	3.88E-04
180	1.76E-04	3.60E-04
320	1.25E-04	2.54E-04

CONCLUSIONS

An integral and multiscale methodology application for Tritium leakages has been presented, showing that different techniques can be coupled to determine tritium transport at different time and space scales. All tritium transport phenomena have been assessed from a conservative point of view. A MELCOR and GOTHIC SC calculations together with a CFD analysis has been used to show how a detailed scale simulation can be coupled to atmospheric transport calculations. Plume and site concentrations can be analyzed at a micro scale giving valuable insight on the behavior of HT leakages. In any case the maxima dose overpasses the 1 mSv stipulated by the guidelines of regulation. This is due to the quantity of tritium deposited into the soil, which is lower than the atmospheric tritium in the first 200 meters of the accident where the tritium concentrations are always higher. The values of HT minor than the values of HTO are due to Dose Conversion Factor for a person older than 17 for HT is 4 orders of magnitude minor than HTO. The difference of doses for HT and HTO emission is due to the contribution to total doses by re-emission, which is important at short distance but not at large distances, because 95% of the HT deposited on the surface is returned to the air as HTO, increasing the atmospheric levels of this molecule. The HT contribution to MEI in the worst case (near to the point of emission) is a factor 3 lower than the correspondent HTO contribution.

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