ANTICIPATING TRITIUM IMPACT AND TRANSFER IN FISSION AND FUSION POWERPLANTS

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1. CONTEXT AND GOALS OF THE STUDY

The TITANS project (Tritium Impact and Transfer in Advanced Nuclear ReactorS) [1], supported by Horizon Europe, was established to provide cross-cutting activities between fission and fusion programs to improve knowledge on tritium (T) emission management. Operation of fusion devices and future fission reactors will generate higher amounts of T than existing facilities. Safety and social acceptability require to tackle potential permeation and T release in the environment at each step of the T life cycle: develop T release mitigation strategies, improve waste management and refine knowledge in the fields of ecotoxicology, radiotoxicology and dosimetry. Progresses were obtained on 3 main objectives:

- **Tritium handling**: enhancement of permeation barriers is crucial to limit contamination of materials and dissemination in the environment, therefore upgrading of potential solutions (notably via surface treatment) along with validation in T environment has been studied. Another dissemination source concerns tritiated particles produced during dismantling phases: feedback from practical T decommissioning activities [2] has been carried out in parallel with binder matrix development to immobilize T metallic dust with minimal T release. Last but not least, management of tritiated water is anticipated via the design of a mobile water detritiation facility.
- **Tritium control**: T measurement and modelling are of crucial importance for real-time safety monitoring in future devices. Advances in T measurements are tackled through the development of gas chromatography, autoradiography, and novel measurements techniques in tritiated solid, dusts and aerosols using Nuclear Reaction Analysis [3], along with solutions to measure T in liquid metals. In parallel, benchmarking of various fusion and fission T transport codes from system to detail level has been carried out to adequately estimate T inventories in future setups.
- **Tritium protection**: dosimetric studies tackled accidental exposure to T steel or cement dust by discussing the behaviour of T aerosol in the environment, the biological effects in a mussel's population of T particles exposure, the bio kinetics of T particles ingress through skin and the risk assessment of genotoxic effects on human macrophages. These data will be key to establish a radiation dose-response relationship for various biological models.

T metallic dust represent a key inventory and exposure source during operation, maintenance and dismantling for fusion devices: one scientific achievement for each theme is detailed below.

2. Qualification of a binder matrix for tritiated metallic dust

Evaluation of confining properties of cement mortars with respect to hydrogen (H)/T release from metallic tritiated dust was carried out via an integrated test on mock-ups of waste package at intermediate scale, simulating the T source by H production through cement interstitial water radiolysis under gamma irradiation. AISI316L dusts with different sizes were used to account for H production from the alkaline corrosion of metal and the impact of a dedicated H absorber was studied. H absorber efficiency is very high: more than 99.8% is trapped, compared to the production rate without absorber. This effect is confirmed even in presence of steel dusts: the contribution of alkaline corrosion does not seem to have a sensible impact on the H absorber efficiency. Quantitatively, we observed that the absorber capacity is largely sufficient to trap the whole H production, with only 0.05% of incorporated absorber consumed.

3. Improvement of Ion Beam Analysis (IBA) towards the robust on line measurements of tritium in LLW (Low Level Waste) materials.

Confirm and improve T profilometry measurements, especially at low T inventory, is key to using IBA as a T characterization technique. Differential cross-sections for two decay channels of the nuclear reaction between ^{3}He and T were measured and evaluated in the energy range between 0.6 MeV and 3.4 MeV [3]. The cross-sections were measured at three different scattering angles: 125°, 135°, and 155°: good agreement was found with the literature. Using the obtained cross-sections, the ^{3}H depth profile was evaluated on a thick tungsten target. The obtained T depth profile is in good agreement with the deuterium depth profile on a sample that underwent the same irradiation and loading procedure, but with a ^{2}D exposure gas. It was estimated that with the present differential cross-section data, we can obtain T depth profile information down to 3.5 μm in tungsten, hence providing a much needed complementary tool to surface analyses like autoradiography.

4. Risk assessment of genotoxic effects on human macrophages after tritium particles exposure

Previous work in TRANSAT [4] on the impact of steel and cement particles on human epithelial lung cells [5] is carried on by evaluating genotoxic effects for the lung immune system, THP-1 macrophages . The aim is to determine if there are any genotoxic effects and if these effects are linked to the particles themselves, to the T contained in the particles, or to metabolites induced by T radiation. The evaluation of the genotoxicity of hydrogenated particles has been performed and highlighted that these particles did not impact cell viability but induce genotoxic effects, linked with their internalization by macrophages (cf Fig. 1). The evaluation of the genotoxicity of tritiated particles is currently underway, along with dosimetry reconstruction to relate with the efficient dose to the cellular material.

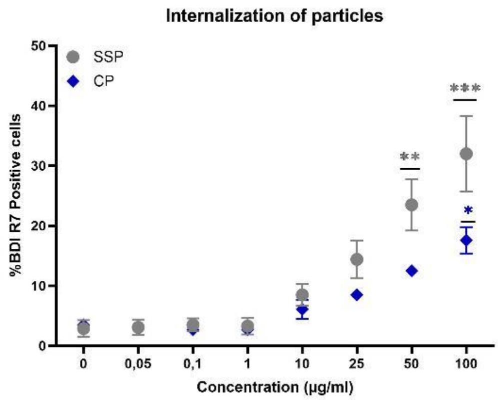

Fig. 1: Uptake of stainless steel and cement particles (SSP and CP) by macrophages observed by flow cytometry.

We will conclude with the key outcomes of the project and the perspectives to carry on the effort towards dissemination in the fusion and fission scientific communities, to reinforce knowledge and prevent T issues to become Achilles heel for future nuclear solutions to the energy transition.

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