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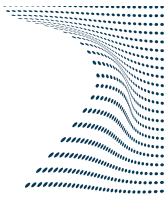

Doctoral Dissertation
Doctoral Program in Energy Engineering (34^{th} cycle)

Tritium transport modelling and experimental validation in liquid metal nuclear power plants

PhD Thesis Summary

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Turin, September, 2022

Summary

This PhD work is focused on the item of tritium management in fusion and fission reactors, with special attention to the fusion reactors ITER and DEMO and to the sodium fast reactor ASTRID, respectively.

With regard to modelling, new tritium modelling tools were developed and extensive verification and validation activities were performed. One of the most important results of the modelling activity is the description of the tritium transport in the smallest functional unit of the WCLL breeding blanket of DEMO, taking into account the MHD and buoyancy effects as well as the chemical reactions in the water, which makes this model one of the most complete available in the literature so far. From an experimental point of view, extensive R&D activity was performed on the Gas-Liquid Contactor in the packed-column configuration and the first qualification of this technology as Tritium Extraction Unit of ITER was performed in an industrial scale facility, TRIEX-II. In this framework, hydrogen isotopes permeation sensors were adopted and the obtained results were used as a benchmark for the transport code. Then, the Sieverts' constant was measured in the experimental facility HyPer-QuarCh II, whose design and upgrade were object of this work. For the first time, the same values were determined using the two different measurement methods adopted in the literature. All these aspects are are resumed in the following main items:

- Hydrogen isotopes permeation sensors;
- Tritium modelling and V&V activities;
- Tritium extraction technologies;
- Sieverts' constant measurement.

New tritium modelling tools were developed and extensive verification and validation activities were performed. One of the most important results of the modelling activity is the description of the tritium transport in the breeder unit of the WCLL breeding blanket of DEMO, taking into account MHD, buoyancy effects and chemical reactions in the water. From an experimental point of view, extensive R&D activity was performed on the Gas-Liquid Contactor in the packed-column

configuration and the first qualification of this technology as Tritium Extraction Unit of ITER was performed in an industrial scale facility, TRIEX-II. In this framework, hydrogen isotopes permeation sensors (HPS) were adopted and the obtained results were used as a benchmark for the transport code. Then, the Sieverts' constant was measured in the experimental facility HyPer-QuarCh II, whose design and upgrade were object of this work. For the first time, the same values were determined using the two different measurement methods adopted in the literature. The experience gained in the fusion framework allowed to develop a design for the HPS suitable for fission applications (sodium fast reactor ASTRID). Here, one of the most important issues was the selection of the material. To this end, a thorough literature review was conducted and nickel and tantalum were selected as possible materials. In particular, a sensor design with nickel was proposed for qualification in the French sodium facility Superfennec. The design with tantalum, on the other hand, is able to guarantee higher permeation fluxes and has been proposed for ASTRID primary and secondary circuits.

Future research can be summarised as follows. Concerning HPS, in 2022-2023 an experimental campaign is foreseen in the frame of ITER in order to better characterise the sensors from the point of view of the performance indicators, i.e. accuracy, precision, linearity, response time and sensibility. For ASTRID, between the end of 2022 and 2023 the HPS will be qualified in a dedicated device to be built in ENEA Brasimone for gas phase operation and in Superfennec loop at CEA for liquid phase operation. Concerning tritium modelling, the model presented in this work will be updated taking into account a pulsed plasma operation. From the point of view of the TEU, a new experimental campaign will be conducted by the end of 2022 in order to qualify the GLC for additional operative conditions in order to confirm and increase the first results obtained within this thesis. Finally, in 2022 it is foreseen to complete the measurement of the Sieverts' constant considering two additional temperature points.

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