UKAEA-CCFE-PR(23)99

M Glugla, B. Butler, S. Ciattaglia, C. Day, D Demange, A. Perevezentsev, N. Taylor

Tritium Technology for Fusion Devices - Status and R&D Needs

Tritium Technology for Fusion Devices - Status and R&D Needs

M Glugla, B. Butler, S. Ciattaglia, C. Day, D Demange, A. Perevezentsev, N. Taylor

This is a preprint of a paper submitted for publication in Nuclear Fusion

REVIEW ARTICLE - proposal

Tritium Technology for Fusion Devices - Status and R&D Needs

M Glugla[1], B. Butler[2], S. Ciattaglia[3], C. Day[4], D Demange[5], A. Perevezentsev[6], N. Taylor[7]

[1]MJG Consultancy, Im Kummetsbrüchle 26, 76703 Kraichtal, Germany
[2]UKAEA, Culham Science Centre, Abingdon, OX14 3DB, UK
[3]EUROfusion Programme Management Unit, Boltzmannstr. 2, 85748 Garching, Germany
[4]Karlsruher Institut für Technologie, Institut für Technische Physik, Hermann-von-Helmholtz-Platz 1, Germany
[5]ITER Organization, Route de Vinon-sur-Verdon, 13067 St. Paul-lez-Durance (France)
[6]Rullion Engineering Culham Centre for Fusion Energy, Abingdon, OX14 4DB, UK
[7]UKAEA, Culham Science Centre, Abingdon, OX14 3DB, UK

Abstract.

The DT fuel cycle is rather different to other nuclear fusion topics: it involves handling of a very precious and radiotoxic gas, i.e. tritium, together with deuterium, processing of gaseous, liquid and solid hydrogen isotopologues, treatment of deuterated and tritiated species, and removal and recovery of deuterium / tritium from water and other chemical species. Breeding of tritium from lithium is needed, supported by neutron multipliers.

Fusion devices for electricity production or with inventories and neutron productions beyond TFTR (US) or JET (UK) are likely to be subject to some kind of nuclear regulations, with corresponding consequences on safety, availability and redundancies, formal qualifications, and in any case with the requirement to process tritium and tritiated species at unprecedented inventories and throughputs. Nearly all systems of a fusion power plant - in one way or another - will have interfaces to tritium. Awareness of the need for implementation of such interfaces is key for safety.

This article reviews the current status of tritium technologies for nuclear fusion devices, the maturity levels of components for unit operations, identifies challenges and issues, and provides new insights through discussion of potentials for resolutions and recommendations future for R&D.

To be submitted to: *Nucl. Fusion*
Version of: 02 August 2021

Proposed contents

1. Background

- Increasing number of fusion devices are under design, construction and/or operation, publically funded as well as in the private sector, and are considering to use tritium as fuel, either in campaigns or even continuously to produce electricity;
- Experience from hands-on handling of tritium is becoming rarer and rarer;
  - Involvement of industry right now is more or less limited to replacement of components failed during tritium service;
    - A new facility (H3AT, UK) is in its early design phase, using previously established technologies;
  - Only minor R&D on fusion technologies using tritium currently ongoing in tritium facilities (e.g. Tritium Laboratory Karlsruhe, Germany, Tritium Processing Laboratory Tokai, Japan);
- Tritium breeding has quite a number of unresolved issues;
  - Large gap between mathematical modelling and breeding blanket system design proposals, and availability of experimental data for validation, even only based on hydrogen or deuterium instead of tritium;
  - Uncertainties in breeding efficiencies directly translate into inaccuracies in tritium inventories;
  - Test blankets at ITER can provide data on breeding ratios, performance of extraction and maybe on removal, however not on recovery as the scale of the test blankets are by far too low to test e.g. DEMO proposed technologies;
  - Tritium permeation into breeding blanket cooling loops requires tritium stripping from cooling fluids;
- Tritium confinement requirements and need for buildings compartmentalization aggravate development of remote handling;
  - Servicing large volumes by atmosphere detritiation systems not only involves corresponding throughputs capabilities, but also increased requirements on diesel backed-up power supply;
  - Safety authority requirements on overall fusion facility lifetime dose to staff are challenging.

2. Introduction

- Outline of generic tritium technology requirements on the basis of the three tritium loops (direct recycle, fuel processing, breeding) of a fusion device;
  - Low burn fraction and extraction of bred tritium requires loop operations;
  - Assumptions such as plasma operation using DT, with minimum need for isotopic tailoring;
- General issues and comparatively large uncertainties in breeding system technologies;
- Very large step on both inventories and processing rates when going from TFTR/JET to ITER, and even going beyond considering e.g. DEMO;
- Challenges in confinement and material control (fusion power measurements, breeding efficiency, material in process).

3. Tritium technology unit operations and their maturity, future R&D

- 3.1. Vacuum pumping and gas transfers;
- 3.2. Fueling and other material supply to the plasma chamber;
  - Disruption mitigation;
  - Consequences to tritium processing when using neutral beam heating;
- 3.3. Hydrogen isotope purification;
  - Issues when using trapping technologies such as cryogenic molecular sieves;
- 3.4. Processing of tritiated gaseous impurities;
  - Highly tritiated water, ammonia, radiochemical reactions;
- 3.5. Processing of tritiated water (low and medium tritium concentration);
  - Limits to process large volumes, and general constrains to treat water at very low tritium contamination levels;
- 3.6. Hydrogen isotope separation;
  - Different technologies for different requirements;
  - Isotope separation processes are typically more suitable for enrichment, depletion of one isotope, particularly down to very low levels, is generally much more challenging;
- 3.7. Atmosphere Detritiation
  - Once through and recycle;
  - Humidifier loop upstream of wet scrubbers.

4. Tritium Breeding

- Issues on tritium extraction and removal from breeders, unit operations maturity;
- Challenges on recovery of bred tritium, and transfer to fueling loops;
- Recommendations and potentials to overcome breeding issues;
- Tritium concerns on reuse of breeding material upon change of blanket modules (Li-6).

5. Tritium material management and control

- Limits in accuracy on overall inventories, inventory distribution;
- Tritium is not on the trigger list of the NSG (but tritium technology is);
- Contamination of tritium exposed materials (including catalysts, zeolites, etc.) and potentials for detritiation of redundant components (hot cell tritium technologies).

6. Tritium safety and confinement

- Hydrogen safety, need for compartmentalization, building layout criteria;
- Control of airborne tritium, C1 to C4*** zoning, human access limitations, even with PPE;
  - Putting contamination levels into perspective, and awareness of interfaces to tritium safety in fusion devices;
- Safety methodologies, propagation of requirements, safety classifications, requirements from licensing authorities and need for formal qualification of tritium systems.

7. Conclusions and outlook

- Summary on challenges, open issues, potential mitigation measures, opportunities, recommendations for future R&D, availability of tritium.