TRANSAT

Research and Innovation Action (RIA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 754586.

Start date : 2017-09-01 Duration : 54 Months

2nd Summer School Proceedings

Authors : Dr. Sabina MARKELJ (JSI), Mrs. Delphine Meyer (LGI)

TRANSAT - Contract Number: 754586

Project officer: Project Officer: Angelgiorgio IORIZZO

Document title	2nd Summer School Proceedings
Author(s)	Dr. Sabina MARKELJ, Mrs. Delphine Meyer (LGI)
Number of pages	49
Document type	Deliverable
Work Package	WP05
Document number	D5.5
Issued by	JSI
Date of completion	2021-08-04 18:45:11
Dissemination level	Public

Summary

In this deliverable the objectives, the program of the second Tritium School and summary of the program and attendance are given together with all the abstracts of the talks presented at the event. The book of abstracts was made available on the web page https://transat-h2020.eu/transat-second-tritium-school/. A summary of the organizational details and information about participant's profiles are given.

Approval

Date	By
2021-08-04 18:45:28	Dr. Sabina MARKELJ (JSI)
2021-08-05 09:21:21	Mr. Christian GRISOLIA (CEA)

Table of contents

Summary

In this deliverable the objectives, the program of the second Tritium School and summary of the program and attendance are given together with all the abstracts of the talks presented at the event. The book of abstracts was made available on the web page https://transat-h2020.eu/transat-second-tritium-school/. A summary of the organizational details and information about participant's profiles are given.

1. Objectives of the school

The Second Tritium School was organized by TRANSAT project (TRANSversal Actions for Tritium). Within the framework of H2020 Euratom research and innovation programme, TRANSAT was built to contribute to Research and Innovation on cross-cutting activities required to improve knowledge on tritium management in fission and fusion facilities. TRANSAT aim is to answer the main following challenges: tritium release mitigation strategies, waste management improvement and refinement of the knowledge in the field of radiotoxicity, radiobiology and dosimetry.

The school comprised of five days of tutorial lectures that cover all the aspects that TRANSAT project wants to address. Experts in the field of fusion, fission, waste management, biology applied to toxicology and dosimetry from around the world held lectures on different topics related to tritium. The addressed topics were very multidisciplinary and went from tritium detection, management, control, retention and waste to radiotoxicity, ecotoxicity and dosimetry of tritium in organisms. Both PhD students and young generation of researchers working in fusion and fission research and development were strongly encouraged to participate.

The lesson learned from the first school was to have more focus on topics like tritium release from facilities, tritium in dust particles and topics related to radiotoxicity and ecotoxicity and we believe we have achieved this objective with the second school. We indeed gave a lot of weight on the waste handling and management of tritium in fission and in fusion devices. The attendees got hands on information about tritium in JET, ITER and tritium production and cycles in next generation fission reactors and future fusion. These subjects turned out to be the hottest topics that got a lot attention and discussion and are important for the future development and research.

2. Venue and context details

Initially hosted by Marseille (France), the second TRANSAT Tritium School was turned due to the Covid-19 Pandemic into virtual school taking place in the afternoon hours from 13:00 to 19:00 in Central European Time from 14th to 18th June 2021. The school started by a warm welcome by Thierry Orsiere from the Aix-Marseille University (AMU), the initially planned host

institution, with an introduction video. The school continued by a welcome by Christian Grisolia (coordinator of the TRANSAT project). Experts in the field of fusion and fission from around the world participated and attended lectures on different topics related to tritium. In total, the second edition of the School gathered 369 participants who attended 28 invited lectures and 5 discussion sessions. As talks were multidisciplinary and covering the different aspects of research and development in the field of tritium in fusion and fusion facilities, the School was aligned with the main objective of the TRANSAT project, that is considering "TRANSversal Actions for Tritium".

A 5-day programme based on tritium

Each day of the School was devoted to several specific topics divided into different sessions The day started with lectures from invited speakers who introduced the topic and state-of-the-art research in the field and then some talks went deeper in the field. Topics that were covered in the school:

- General fission and fusion - tritium: Tritium migration, management, transport, detection, dust, JET activities
- Tritium waste
- Radiotoxicity/ecotoxicity
- Epidemology of tritium
- Tritium dosimetry

At the end of the day, a discussion session was organised to discuss on the questions raised by the attendees and the open questions based on the talks from that day.

3. Program and activities

Abstracts of all the invited speakers are provided in this section as they followed in the program for individual days. The agenda and book of abstracts were provided to the participants on https://transat-h2020.eu/transat-second-tritium-school/ (https://transat-h2020.eu/wp-content/uploads/2021/06/Book-of-Abstracts-SECOND-Tritium-school-VF.pdf) .

We give the detailed program for individual days and the abstracts for individual talks, as indicated in the program context bellow within the indicated pages.

4. Facilitators and staff organization

Organisers:

Sabina Markelj, Jožef Stefan Institute, Slovenia
Thierry Orsière, IMBE, Aix-Marseille University, France
Christian Grisolia, CEA, France
Delphine Meyer, LGI Consulting, France

Programme committee:

Dave Coombs, UKAEA, UK
Ion Cristescu, KIT, Germany
Christian Grisolia, CEA, France
Karine Liger, CEA, France
Véronique Malard, CEA, France
Sabina Markelj, JSI, Slovenia
Carlos Moreno, CIEMAT, Spain
Robert Vale, UKAEA, UK

Editors of the book of abstracts:

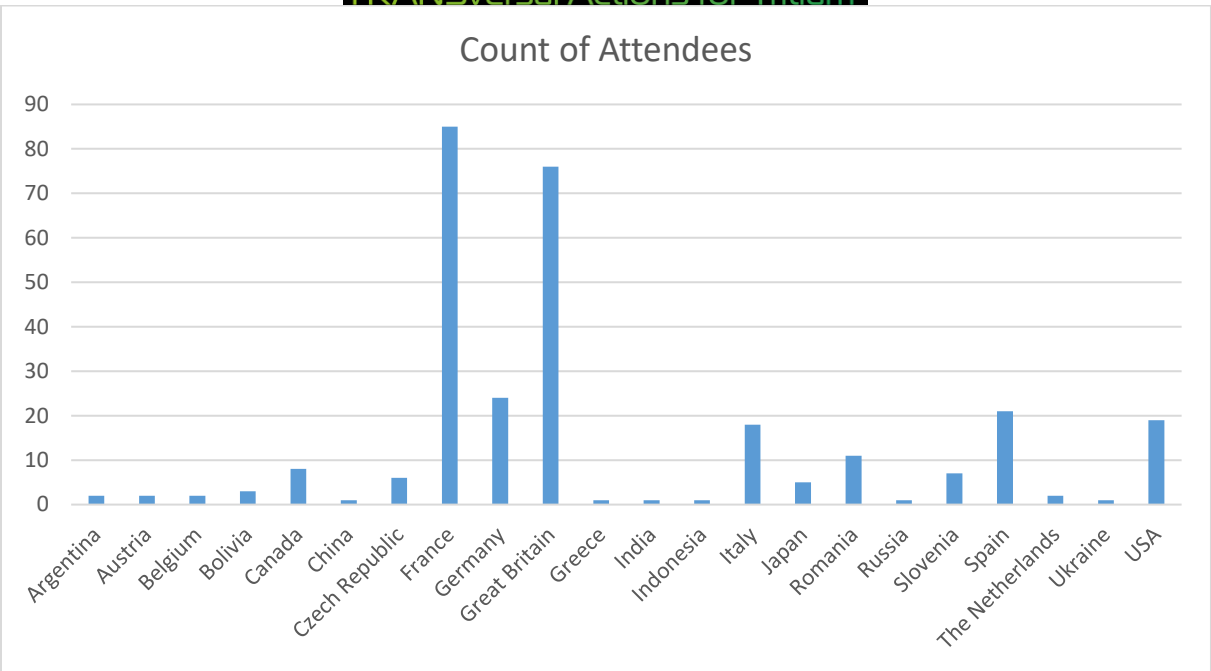
Sabina Markelj, Thierry Orsière, Delphine Meyer and Mya Belden

Front page graphics design for Flyer and Book of abstract:

Mathilde Bazin-Retours and Mya Belden, LGI Consulting, France

5. Profiles of the participants

The School gathered 367 registered participants from different countries such as Europe, USA, Great Britain, Japan, India, China, Indonesia, Argentina etc.. In total 297 of the registered people attended the school virtually during the 5 days. In the graph bellow there is statistics of participation counted by the country of origin.



The profile of participants was: students, pos-docs, technologists, researchers, engineers, etc. Participants were from institutes, universities and other institution and companies such as Jacobs, Commonwealth Fusion Systems, MIT, Nuvia UK Ltd, SHINE Medical Technologies, Frazer-Nash Consultancy, ANDRA, IAEA, RINA Consulting Centro Sviluppo Materiali (CSM), RATEN, ORANO, NUVIA PREVENTION, Comisión Nacional de Energía Atómica, etc.

From the profile of the participants the school did not only attract students but also engineers, scientists and senior scientists that could learn about all the aspects and problems related to tritium.

6. Methodology of the school organization, the format chosen and the main conclusions for each discussion session

In order to organize the tritium school the program committee first suggested the names for invited speakers that are known in the field and in specific topic. There was at least one speaker proposed for each topic that is covered in the TRANSAT project. The invitations to the invited speakers were send out in January 2021 and most of the invited speakers agreed to give a lecture. Since the school was virtual all the talks were planned to be live presented via conference call.

Since we have decided for the school to be virtual the program committee also decided to have only invited speakers and no contributed talks. For this reason, no call for abstracts was announced. Participants only had to register on the web page and the registration was free of charge. The web page for the Second Tritium School became available in December 2020. The announcement about the school was sent to TRANSAT web page subscribers in middle of January 2021. On the web page all the needed information was given together with the names

of the invited speakers and titles of their presentations. The response from public was very positive and the registration numbers were rising very fast from the very beginning of the announcement of the school. At the end we had 369 registered attendees and from this there were28 invited speakers. The attendees had to register through the school web page and the deadline was 15th May 2021.

A 5-day programme based on tritium

For the Second Tritium School we have decided to have a bit different schedule compared to first school not having complete each day of the School devoted to a specific topic but in some cases the topics were intermixed but still being connected to each other. The main topic of the day started with the lectures with invited speakers giving an overview on the subject and then the talks became more and more focused, but still educational enough so that the attendees got deep knowledge and state-of-the-art on the specific topic. There were all high-quality talks with contributions from leaders in specific areas from institutions such as ITER, EUROfusion, JET that are directly connected to tritium handling, management etc. The talks had different duration, some had 40 min time for the presentation and 10 minutes for questions and others had 30 minutes for the talk and 5 minutes for questions. The duration was based on the speakers preferences and the topic that the speaker covered. All presentations were presented live via zoom webinar and there were no problems with connectivity and all speakers were in time for their session/presentation. The questions were given to the lecturers through Questions & Answers option by writing. The chair of the session was reading the questions to speakers and they have then answered them. In case not all questions could be addressed in the allocated time, they were questioned in the discussion session. A discussion session was organised each day after all the talks. The discussions section was meant to discuss on the raised questions during the talks and on the open issues of the specific topics of the day. The attendees could listen to the experts in the field of fission, fusion, nuclear safety, waste and biology. Maximum attendees participating in a session was 181.

The first day was dedicated to tritium migration and management. Attendees could learn about tritium migration and management in fission and fusion devices. The day started with an excellent talk about the fundamentals of tritium handling and continued on the hydrogen and tritium transfer cycles in fission and fusion devices. There was one talk also devoted only to tritium in ITER. The day was finished by a talk on dust in fusion reactors. For that day there were 272 people who joined the school virtually.

The second day focused on tritium migration, transport, detection and waste. First session of the day dealt with plasma wall interaction, how this influences on tritium retention in fusion materials and how it can be modelled to predict tritium inventory. In the second session different tritium detection techniques were presented and one talk was especially devoted to detection of tritium in Joint European Torus (JET) giving an excellent overview on the detection techniques and their capability and detection limitations. Last session was devoted to JET

preparation on DT campaign and waste management in JET. For that day there were 235 people who joined the school virtually.

The third day was addressing tritium migration, management and waste. In the first session we had two excellent talks one about tritium processing in breeding blankets in fusion reactor and second one on radioactive dust from a safety point of view. Second session was devoted to tritium waste and decommission procedures which become more and more relevant in for fission and fusion devices. Last session was devoted to breeding blankets in DEMO and tritium permeation barriers both very important aspects for running the future fusion devices like DEMO. For that day there were 206 people who joined the school virtually.

The fourth day was devoted to radiotoxicity, ecotoxicity, epidemiology of tritium and its dosimetry. In the first session there were two excellent talks that gave an overview human and ecosystem response to tritium. The second session addressed an important issue of epidemiological and ecotoxicological studies on tritium. Last talk of the day was devoted to dosimetry of tritium on human and non-human biota. For that day there were 156 people who joined the school virtually.

The last day dealt with radiotoxicity, dosimetry of tritium and waste management. In the first session the listeners could learn about influence of tritium on aquatic environment and about modelling approached for tritium dosimetry at the sub-cellular scale. The last talk of the tritium school was from the French national agency for radioactive waste (ANDRA) where a broad overview about the waste management in France was presented with focus on the quantity of tritiated waste can be stored based on the material activity. For that day there were 131 people who joined the school virtually.

The format of the program chosen turned out to be really successful and researchers and students could get an overview on the topics related with tritium and the problems that are arising. The field is very much interdisciplinary, from basic physics to biological and chemistry problems, that scientist need to research in order to tackle the possible impact of tritium on energy and its possible impact on the environment. The attendees could download a book of abstract from the web page. After the school most of the presentations were shared with the participants on the web link https://transat-h2020.eu/second-transat-tritium-school-presentation-download/ (password protected – password: TritiumSchool2021), after obtaining the permission of the speakers. The certificate of attendance was sent to participants who asked for it.

7. Promotion of the event (flyer, website, social media, electronic invitations…)

LGI, AMU and JSI worked together to promote the Second TRANSAT Summer School. Firstly, LGI designed **a flyer** (Figure 1) and created **a special page** (Figure 2) on the TRANSAT website to announce and promote this event, including registration, agenda, key dates, posts on LinkedIn https://transat-h2020.eu/transat-second-tritium-school/ .

Figure 2: Flyer for the Second Tritium school

Figure 3: Screenshot of the web page for the Second Tritium school on the TRANSAT web page.

Attendees that participated at the school have obtained on request certificate of participation, figure 4.

Figure 4: A template of the certificate pf participation.

A series of electronic invitations were also designed and distributed to all the contacts who subscribed to the project newsletters and news (GDRP compliant system). An example is shown in figure 5.

Figure 5: Electronic invitation for the Second Tritium school.

On the TRANSAT LinkedIn account, few posts/tweets were published announcing the School. LGI designed a visual to use on social media (Figure 6).

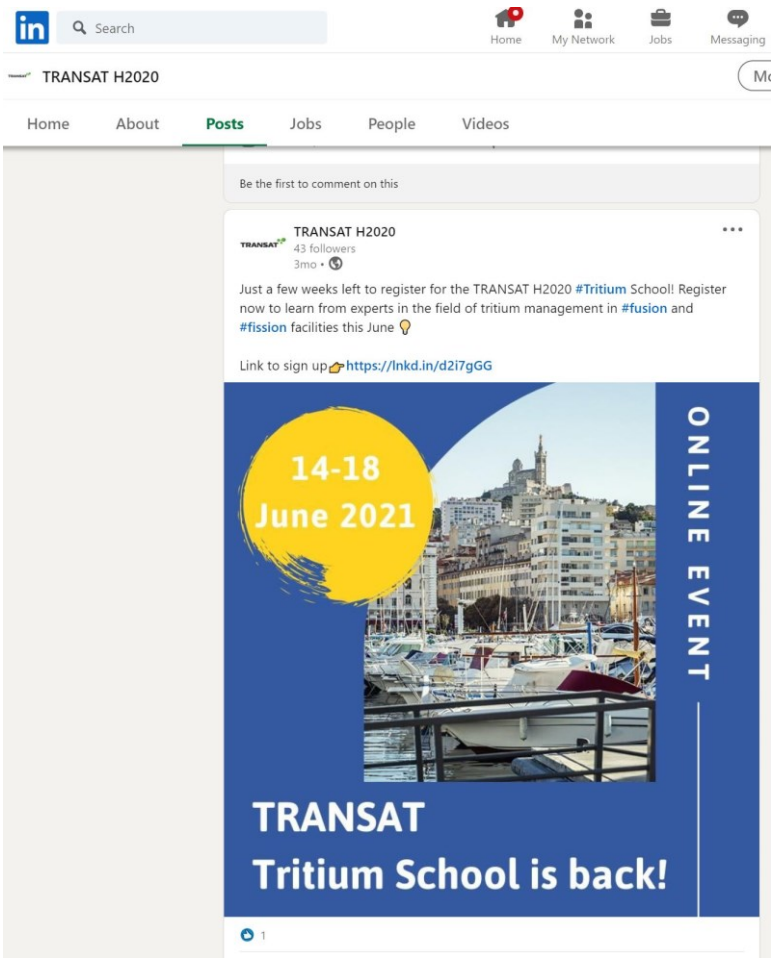


Figure 6: Screenshot of the post about the Second Tritium school on LinkedIn account.

8. Conclusions and expected impacts

The expected impact of the Tritium school is to educate people about tritium from all the aspects related to it, from its birth to its decay. The second impact of Tritium school is to gather the interdisciplinary community from fusion, fission and biology to share the knowledge and discuss about tritium handling, releases and possible hazards of tritium for the environment.

The first Tritium School was a success and we believe we have with the Second Tritium school exceeded our expectation for participation which means the school got good reputation on the quality. The expected impacts were very much achieved at the Second Tritium School being a great success and having 369 participants from around the world, 297 participants also then joining the virtual school. The profile of the participants was students, engineers, scientist and senior scientist. The reason for attracting also experienced researchers shows us that the topics related to tritium are actual (due to use of tritium as fuel in future fusion devices), important and very much interdisciplinary. Namely, in order to get a good overview

over the subject one needs to understand the basic physics how tritium is produced, where it is used and how it could be detected and handled as a waste material and most importantly how it could influence on organisms and environment. This is what the school program provided by gathering scientists and senior scientists to look at the tritium problem from different aspects and to give knowledge to the future generations.

We hope in the future a continuation of the Tritium school will taking place, perhaps under the umbrella of Aix-Marseille university since it is vital to educate the young generation especially with ITER approaching its start-up and the new generation of fission reactors.

9. Annex I: Book of abstracts

Scientific programme, Day 1 – Monday, 14th of June

12:30 - 13:00	***Welcome by Transat coordinator and video about Marseille***	
Session 1	Topic: tritium migration, management	Chair : Christian Grisolia
13:00-13:50 (50 min)	L1 - The fundamentals of tritium handling	Walter Shmayda (Univ. Rochester, US)
13:50-14:40 (50 min)	L2 - Assessment of tritium and hydrogen transfers in new generation fission reactors	Thierry Gilardi (CEA, France)
14:40-15:00	***Coffee Break***	
Session 2	Topic: tritium migration, management	Chair : Carlos Moreno
15:00-15:50 (50 min)	L3 - Tritium Process Technology for Fusion Fuel Cycles	James Klein & George Larsen (SRNL, US)
15:50-16:40 (50 min)	*L4 - ITER and Tritium*	Scott Willms (ITER)
16:40-17:00	***Coffee Break***	
Session 3	Topic: tritium migration, management	Chair : Thierry Gilardi
17:00-17:35 (35 min)	L5 - Tritium circuit	Carlos Moreno (CIEMAT, Spain)
17:35-18:10 (35 min)	L6 - Tritiated dust in fusion reactors	Christian Grisolia (CEA, France)
18:10-18:40 (30 min)	***Discussion***	***Chair:*** Christian Grisolia / Walter Shmayda

Duration of presentations: talk + discussion

40 + 10 min

30 + 5 min

Lecture 1

THE FUNDAMENTALS OF TRITIUM HANDLING

W. T. Shmayda

University of Rochester, Laboratory for Laser Energetics, Rochester, NY, USA, 14623

wshm@lle.rochester.edu

Storage, process monitoring and scavenging form the basis of all tritium handling systems. This presentation will discuss uranium as a storage medium, ionization chambers as the backbone of monitoring tritium movement in process loops and recovery of trace levels of tritium from inert and air bearing streams for emission reduction.

Several factors influence the loading rate of getter beds. These include the host medium, the thermal capacity of the containment, and the gas transmission rate from a vessel to the storage device. The interrelationship of these factors will be discussed with the objective to design responsive storage beds that can reproducibly absorb tritium up to their design capacity. Uranium is the medium of choice against which the advantages and disadvantaged of using other storage media need to be assessed. Pyrophoricity is often raised as an issue of concern. Responses to air ingress accident scenarios will be shown to be benign events in correctly designed storage beds.

Ionization chambers afford a simple and robust technique for monitoring the movement of tritium in process loops. These devices can be integrated directly into process loops without compromising the leak-tightness of the process systems. To first order, ion pair production in these chambers relies uniquely on the concentration of tritons in the carrier stream. However, detailed interpretation of the measurements needs to take into account several mitigating factors: operating pressure, type of gas, impurity content, and surface effects. Additionally, under higher carrier gas flow conditions there may be a need to understand the collection and the precipitator efficiencies of the design.

Emission reduction from facilities relies on the extraction of low concentrations of tritium from effluent streams before they are discharged to the environment. This scavenging depends on the composition of the effluent streams. Non-reactive streams (those that contain negligible quantities of oxygen) are typically passed through getter beds that have ultra-low hydrogen vapor pressures. Hydrogen containing tritium can be released from the getters and collected for tritium recovery if necessary. Air bearing streams rely on catalytic oxidation traditionally known as ‘burn and dry’ schemes. In these cases, tritium containing species are converted to tritiated water which is collected on driers. Once regenerated the condensate can be processed for tritium recovery or can be land disposed. This presentation will discuss both of these approaches.

ASSESSMENT OF TRITIUM AND HYDROGEN TRANSFERS IN NEW GENERATION FISSION REACTORS

T. Gilardi[a]

[a]CEA/DES/IRESNE/DTN, CEA-Cadarache, 13108 Saint-Paul les Durance, France

thierry.gilardi@cea.fr

Due to its high diffusivity in metals and especially for high temperature conditions, the tritium produced in the core of fission reactors is likely to migrate easily through the different circuits. Potential release of tritium in gaseous form, by permeation through pipings and components walls, is also an important phenomena to be evaluated for the control of safe operating conditions and of environmental impact. In the case of new generation Sodium Fast Reactors (SFR), the control of tritium inventories and releases is an important issue due to its higher effective transfer into sodium through stainless steel claddings, and due to its atomic form once dissolved in sodium.

A global review of the different transfer contributions and physico-chemical phenomena to be considered for tritium (and more generally hydrogen isotopes) in SFR is presented as well as the equivalent behavior of stable hydrogen produced in tertiary circuit in the case of classical water/steam cycle (Rankine thermodynamical cycle). Physical models used for the evaluation of the different transfers and phenomena are presented as well as the qualitative influence of major parameters.

Calculation tools developed for the evaluation of Tritium (and hydrogen) transfers and inventories are described. Illustration results are presented in terms of tritium activities and hydrogen concentrations in each circuit of the reactor, but also in terms of transfer fluxes and releases. In addition, the distribution of the various transfer contributions (between primary, secondary and tertiary circuits) is analyzed as well as the typical influence of key parameters.

An application is also presented for the assessment of the potential effect of controlled hydrogen dissolution in secondary sodium in order to propose efficient solution for enhanced tritium trapping in sodium purification systems (cold traps).

Keywords: Tritium migration, Tritium inventory and control

Lecture 3

Tritium Processing Technology for Fusion Fuel Cycles

J. E. Klein and G. K. Larsen

Savannah River National Laboratory, Aiken, SC USA

James.klein@srnl.doe.gov

Fusion energy holds the promise of harnessing energy from fusing atoms together to generate net electrical power. The most commonly studied fusion reaction is deuterium-tritium (DT) fusion which creates neutrons and helium in a magnetically confined and heated plasma. With low amounts of DT in the plasma actually fused and the need to remove the helium "ash", tritium and deuterium must be continuously withdrawn from the reactor and recycled. Since tritium is consumed in the fusion reaction it must also be produced in sufficient quantities to sustain the fusion process.

This presentation will give a high-level overview of the DT fusion fuel cycle, waste gas processing, and tritium stripping and tritium recovery technologies. The importance of tritium recovery technologies within the context of environmental accumulation of tritium from fusion energy will also be discussed.

Lecture 4

ITER AND TRITIUM

R. S. Willms

ITER Organization, Route de Vinon-sur-Verdon - CS 90 046 - 13067 St Paul Lez Durance Cedex, France

Scott.Willms@iter.org

ITER will be a significant scale-up of previous deuterium-tritium burning plasma experiments, and is presently in the construction phase. This presentation will summarize the progress and plans for the tritium processing system.

Lecture 5

TRITIUM IN CIRCUITS

C. Moreno[a], F. Roca[b], T. Gilardi[a] A. Rueda, J. Serna, S. Hendricks

[a]CIEMAT, Fusion Technology Division, Madrid, Spain

[b]CEA, DES, IRESNE, DTN, F-13108 Saint-Paul-Lez-Durance, France

[c]EAI Empresarios Agrupados Internacional, Madrid, Spain

carlos.moreno@ciemat-fusion.es

Tritium as radioactive element and valuable fuel in nuclear fusion reactors requires maximum traceability and containment. One of the problems common to circuits that transport tritium is permeation through materials. Tritium is a light element with an extraordinary capability to permeate through structural materials because of its diffusive properties. For this reason, the main priority in this kind of circuits is how to control the inventory and permeation to the environment.

Different control strategies for tritium leaks in circuits such as anti-permeation barriers, the effect of isotopic co-permeation and chemical balance have been studied both fusion and fission programs. In parallel, techniques such as permeators, getters or cold traps have been used both to control the inventory and to recover the tritium so that it can be reused.

This is where the ability to predict the behaviour of tritium and the development of models to study the transfer phenomena involved becomes particularly important. In this talk, scenarios such as the breeding blankets of nuclear fusion reactors, the lithium loops of the IFMIF-DONES early-neutron source and the balances and inventories of a sodium-cooled fast reactor will be analysed exploring different control techniques applied to their corresponding tritium transport models.

Keywords : tritium, hydrogen, transfers, inventory, releases, modelling,

Tritiated dust in fusion reactors.

C. Grisolia[a], E Hodille[a], E Bernard[a], M Payet[a], M Diez[a], S Peillon[b], F Gensdarmes[b]

[a]IRFM, CEA-Cadarache, 13108 Saint-Paul les Durance, France
[b]Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-RES, SCA, Gif-sur-Yvette, 91192, France

christian.grisolia@cea.fr

During fusion machine operation and due to plasma wall interaction, particles/dust will be created (size ranging from nanometer to tens of micron). Different morphologies of dust are expected to be produced from spherical particles induced by melting of metal after high heat flux interactions (unipolar arcs, ELMs,...) to fractal ones created by accretion. The later point is confirmed by dust collection in a full tungsten (W) environment machine, the WEST tokamak. Indeed, among the collected particles, spherical and complex shape submicron-sized ones are found. Their high specific surface area can be associated with high physico-chemical reactivity.

The first part of this presentation will be devoted to describe the processes of powder creation in fusion machines. It will also be recalled how the production of powders is currently estimated according to the processes involved. A critical analysis of the results predicted for the future fusion machines (ITER and DEMO) will be made, focusing in particular on the creation processes that may have been neglected due to the different plasma operation of the current machines.

In the rest of this presentation, we will focus on the study of relevant W tritiated particles.

Experimental results of tritium loading/desorption carried out on W particles having a wide range of surface topology will be recalled.

These experimental results are reproduced by using a kinetic surface model suggesting that the bulk contribution is very low for such particles. With this approach, the desorption kinetic is explained by the change of the desorption energy with the coverage of the surface by hydrogen which is highlighted by atomistic simulations: on bare surface, the desorption energy is 1.4 eV while for saturated surface, it drops below 0.8 eV.

This approach has numerous experimental consequences that will be described in detail in the presentation.

It will be shown, especially, that W dust placed on the bottom floor of a fusion machine and exposed to tritium gas will be loaded with tritium even at very low in vessel tritium pressure. Surface saturation can be reached rapidly at 1 Pa and 373 K. How the trapping on W massive material can be modified by the presence of fuzzy structure will be also addressed.

However, this saturation can be mitigated by isotopic exchange. Tritiated dust exposed to D_2 or H_2 at 300-373 K will lose their total quantity of tritium as soon as the H_2 or D_2 are the main isotopes in the vacuum vessel. Some consequences of these observations will be discussed in terms of safety for the machine. Especially, we will investigate if this capacity to release tritium modifies the approaches that must be followed in the analysis of a LOVA (Loss Of vacuum Accident). Consequences expected on the measurement of tritium carried by dust and the evaluation of the tritium source term will be also reviewed.

Keywords: Tritium management, Tritium waste, Tritium inventory and control

Scientific programme, Day 2 – Tuesday, 15th of June

12:30 - 13:00	***Connecting***	
Session 4	Topic: tritium migration, transport	Chair : Sabina Markelj
13:00-13:50 (50 min)	L7 - Nuclear fusion, wall loading and materials: on the difficult life of a material close to a thermonuclear plasma	Greg de Temmerman (Zenon, France)
13:50-14:40 (50 min)	L8 - Tritium in plasma facing components in fusion devices: retention and transport	Klaus Schmid (IPP, Germany)
14:40-15:00	***Coffee Break***	
Session 5	Topic: tritium detection	Chair : Klaus Schmid
15:00-15:35 (35 min)	L9 - Non-destructive tritium measurement in solids using beta-ray induced x-ray spectrometry (BIXS)	Yuji Hatano (Toyama univ., Japan)
15:35-16:10 (35 min)	L10 - Tritium detection methods developed during TRANSAT project	Pascal Fichet, Arnaud Bultel & Sabina Markelj (CEA / Coria, France & JSI, Slovenia)
16:10-16:45 (35 min)	*L11 - Tritium analysis of JET plasma facing materials*	Anna Widdowson (UKAEA, UK)
16:45-17:05	***Coffee Break***	
Session 6	Topic: tritium detection, waste	Chair : Anna Widdowson
17:05-17:40 (35 min)	L12 - Preparation for DT campaign in JET	Ben Wakeling (UKAEA, UK)
17:40-18:15 (35 min)	L13 - Solid Waste Detritiation	Dave Coombs (UKAEA, UK)
18:15-18:45 (30 min)	***Discussion***	**Chair:** Sabina Markelj / Christian Grisolia

Duration of presentations: talk + discussion

40 + 10 min

30 + 5 min

Lecture 7

Nuclear fusion, wall loading and materials: on the difficult life of a material close to a thermonuclear plasma

Greg De Temmerman

[1]Zenon Research, 16 rue Séguier, 75006, Paris, France
[2]MINES ParisTech, University PSL, Institute of Higher Education for Innovation and Entrepreneurship (IHEIE), 75006 Paris, France

Nuclear fusion is a promising option for a future low-carbon, dispatchable and abundant energy source. Fusion requires high temperatures to occur and simply speaking, the fusion process consists in heating a gas at 150 million °C in a vacuum chamber and confine it with strong magnetic fields or lasers. In a magnetically confined fusion reactor, power from the hot core plasma is exhausted by the plasma-facing components. This happens mainly in the divertor area, a special area of the plasma chamber where the open magnetic field lines intersect the primary plasma facing components and where the plasma is neutralized and pumped away. The plasma-facing surfaces in the divertor are exposed to extreme heat (>10MW.m^{-2}) and particle fluxes, for extended durations of times.
Being continuously bombarded by energetic particles, together with high energy neutrons from the fusion reactions, the plasma-facing materials need to satisfy stringent demands: minimum erosion to reduce impurity sources and plasma contamination and maximum lifetime; resilience to changes in morphology/composition; minimum retention of tritium (nuclear licensing), good thermo-mechanical properties. Plasma-surface interactions at the plasma boundary also play a significant role in the machine performances.

This talk will first give an introduction to nuclear fusion, and an introduction to the tremendous challenge of materials science under such extreme conditions

TRANSversal Actions for Tritium

Lecture 8

Tritium in plasma facing components in fusion devices: retention and transport

K. Schmid[a]

[a]Max-Planck-Institut for Plasma-Physics, Boltzmannstrasse 2, 85748 Garching, Germany

Klaus.Schmid@ipp.mpg.de

The uptake and transport of hydrogen isotopes HI (Hydrogen, Deuterium and Tritium) in metals used as first wall materials in fusion devices has key implications on their operation: The socalled recycling dynamics of implantation & reflection of energetic HI's and effusion of molecular species at thermal energies from the wall back to the plasma, defines momentum and energy balance in the scrape of layer region of the plasma which is in contact with the wall [1]. The retention of HI's that diffuse deep into the material and are immobilized there via trapping at defects poses two further challenges: Firstly, a large T inventory is a safety concern in current fusion experiments like ITER. Secondly in a future fusion power plant the retained T is no longer available for burn in the plasma core and this loss has to be compensated by increased breeding of T in the blanket. Thus, putting even more strain on the already tight T budget defined by the tritium breeding ratio in a fusion reactor [2]. The first wall of a future fusion reactor will be comprised of the top armor material W and structural materials below like steel or Cu alloys that connect the top plasma-facing surface to the coolant. Therefore, the transport through the whole component from the W armor layer to the coolant needs to be understood: This firstly requires experiments on HIs retention in the different materials (W, steels and Cu-alloys) due to trapping at intrinsic defects and at defects generated due to exposure to the fusion environment: bombardment by plasma species and/or MeV neutrons, formation of transmutation and reaction products like e.g.: Re and He. Secondly experiments on permeation across the interface in between the materials are required to determine the barrier properties of the different interfaces and the influence of typical impurities like O on these properties Finally, since the conditions at the first wall of a fusion reactor are impossible to reproduce in controlled lab experiments, models, benchmarked against the above-mentioned experiments, are needed to make predictions on T-transport and retention. To make calculations on the required length and time scales of mm to cm and months to years respectively, so called diffusion trapping codes are used today [3].
The lecture will first review experimental results on trap formation and its implication on hydrogen transport and retention and then explain the concepts behind diffusion trapping codes and how they are used to extrapolate lab results to future fusion devices.

[1] R. Schneider, et al., Contrib. Plasma Phys. 40 (3-4), 2000 p. 328
[2] G.R.Tynan et al, Nucl. Mat. and Energy Vol. 12, 2017 p. 164
[3] A. H. M. Krom , A. Bakker, Metall. Mater. Trans. B 31B, 2000 p. 1475

Lecture 9

NON-DESTRUCTIVE TRITIUM MEASUREMENT IN SOLIDS USING BETA-RAY INDUCED X-RAY SPECTROMETRY (BIXS)

Y. Hatano[a], S. E. Lee[b]

[a]Hydrogen Isotope Research Center, University of Toyama, 930-8555, Japan
[b]Graduate School of Science and Engineering, University of Toyama, 930-8555, Japan

hatano@ctg.u-toyama.ac.jp

The mamixmum energy of β-rays from tritium is 18.6 keV, and the escape depths of those β-rays are just a few micrometers in low atomic number materials and a few hundred nanometers in high atomic number materials. Hence, it is difficult to measure tritium content in a solid material by β-ray counting. Nevertheless, interactions between β-rays and matters result in generation of bremsstrahlung and characteristic x-rays. Because of far larger escape depths of x-rays than β-rays at the same energy, non-destructive evaluation of tritium content in a solid sample is possible by x-ray measurements. The objective of this presentation is to explain the principle of β-ray induced x-ray spectrometry (BIXS) and show examples of applications.

In most cases, a spectrum of x-rays emitted from a solid sample containing tritium is measured under Ar gas atmosphere by using a silicon drift detector or a Ge detector. Ar(Kα) x-ray is generated by β-rays from tritium atoms present at the sample surface and in the sub-surface region within the escape depth of β-rays. On the other hand, β-rays from tritium in the bulk induce bremsstrahlung and characteristic x-rays of constituent elements of the sample. Because the absorption coefficient of x-rays sharply decreases with increasing x-ray energy, x-ray spectrum varies with a depth profile of tritium; the intensity of x-rays in a high energy region relative to that in a low energy region increases with increasing penetration depth of tritium. A careful comparison between measured spectrum and that constructed by computer simulation allows non-destructive depth profiling of tritium in a solid sample. This technique has been used for evaluation of tritium diffusivity in tungsten at room temperature [1] and tritium implantation depths in Be and W-coated CFC tiles used in JET for ITER-like wall experiment [2,3].

Many alloys have inhomogeneous structure due to presence of second phase precipitates such as carbides in steels, dispersed particles such as Y_2O_3 in oxide dispersion-strengthened alloys, etc. These particls can act as traps against hydrogen isotopes. Becasuse of short traveling distances of β-rays, the intensity ratios of characterestic x-rays of constituent elements show local chemical compositions around tritium atoms in an inhomogeneous structure. If characterestic x-rays of constitutent elements of second phase particles is strong relatively to that of matrix element, it means tritium is strongly segregated in the second phase particles and/or at the boundaries between second phase particles and matrix. Results of our efforts for identification of hydroen trapping sites in alloys using BIXS will be also presented.

[1] M. Matsuyama et al., J. Nucl. Mater. 307-311 (2002) 729-734.
[2] Y. Hatano et al., Phys. Scr. 2017 (T170) (2017) 014014.
[3] S. E. Lee et al., Fusion Eng. Design 160 (2020) 111959.

TRITIUM DETECTION METHODS DEVELOPED DURING TRANSAT PROJECT

P.Fichet[a], A. Bultel[b], S. Markelj[c], M. Payet[a,e], M Dinescu[d], C Grisolia[e]

[a]*Université Paris-Saclay, CEA, , 91191, Gif-sur-Yvette, France*
[b]**Université de Rouen – Normandy, CORIA UMR6614, 76801 Saint-Etienne du Rouvray, France**
[c]*Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia*
[d]*Laseri, PPAM,* **Magurele / Ilfov,** *Romania*
[e]*CEA, IRFM, F-13108, Saint-Paul-lez-Durance, France*

Tritium is a radionuclide very difficult to analyze mainly because of its energy, type of emission (β^-) and its chemical and physical behavior. In all kinds of developments concerning the tritium (dismantling processes, fusion development, environmental control…), it is essential to characterize the radionuclide with high accuracy and a minimum of uncertainty.

In the very near future with the developments of fusion machines such as ITER, that will use Deuterium and Tritium as fuel, controlled production of tritiated wastes and needs to assess the exact inventory of tritium will be crucial.

During TRANSAT project, three innovative techniques have been developed (LIBS, NRA, Autoradiography) and will be presented.

The autoradiography technique, a technique commercially developed for researches in biology is currently developed at CEA France, because of its high potentialities to investigate tritium in situ on solid surface. New developments of this technology called MAUD providing real time results and using new SiPM (Silicon Photomultipliers) detectors, will be presented.

The LIBS (Laser-Induced Breakdown Spectroscopy) is based on the spectroscopic analysis of laser-induced plasmas produced on the sample to be analyzed. This method is currently in development within TRANSAT to test the capacity to derive the hydrogen and isotopes concentrations within ITER-like samples.

A new ion beam analysis method utilizing nuclear reaction analysis (NRA) between ^{3}He and T is being developed. It will enable measurements of trapped T in materials to depths of a few micrometers and is currently being developed within the project. The measurements on tritiated samples are done and an evaluation of the cross section will be performed. Such new technique will enable simultaneous detection of deuterium and tritium in materials.

Keywords: Tritium detection

Tritium analysis of JET plasma facing materials

A. Widdowson[a] and JET Contributors*

[a]*UK Atomic Energy Authority, Culham Centre for Fusion Energy, Abingdon, OX14 3DB, UK*

anna.widdowson@ukaea.uk

Since the beginning of the JET-ILW operations in 2011 an extensive ex-situ analysis programme of JET components removed periodically from the vessel has been completed to provide a detailed insight into material migration and fuel retention. This presentation provides an overview of the tritium analysis results obtained as part of the ex-situ analysis of JET components using different tritium analysis techniques and will compare these with deuterium retention data. In addition, the ongoing assessment of tritium accountancy in JET during tritium operations in 2020 and 2021 will be presented based on the established global deuterium retention picture.

During JET-ILW operations, a substantial amount of analysis has naturally focused on deuterium. Nevertheless, ex-situ analyses of the small quantities of tritium have also been performed and different tritium analysis techniques demonstrated and an overview of will be presented. The source of tritium in JET-ILW is twofold; tritium from deuterium-deuterium reaction ($_2H + _2H \Rightarrow _3He + n$ (3.27 MeV)) and legacy tritium retained in-vessel following 1997 deuterium-tritium experiments (DTE1) when 35 g of tritium was injected into JET. The amount of tritium found in components for the JET-ILW is at least three orders of magnitude lower than for deuterium. For example, using thermal desorption analysis (TDS) the tritium concentration is of the order 10_{13} T atoms/cm_2 on a sample from the beryllium outer poloidal limiter whereas the deuterium concentrations from TDS and ion beam analysis are in the range 10_{16}-10_{18} D atoms/cm_2 on different areas on the same tile [2]. Tritium analysis has also revealed surfaces where deuterium and tritium concentrations do not follow the same distribution patterns. This is notably on JET beryllium limiters where tritium concentrations remain relatively similar across the toroidal length of the tile, whereas deuterium is concentrated in deposits on the ends of tile. These differences could indicate differences in retention mechanisms and highlight the importance of future analysis of components following JET DT operations to benchmark predicted retention.

Based on deuterium analysis data it has been determined that ~0.2% of injected fuel was retained in JET plasma facing and remote surfaces in the 2011-2012 operations [1], with 65% of total fuel inventory being retained in the divertor. From this global deuterium retention distribution an estimation of tritium retention in components during JET tritium operations is underway, making use of tritium injection amounts to date and future tritium injection schedules. These will be presented to demonstrate how the comprehensive ex-situ analysis data from JET components can provide in-vessel tritium accumulation/accountancy and ex-situ waste inventory information. In addition, the impact of vessel heating, cleaning experiments, offgas and venting will also be discussed.

Keywords:Tritium detection; Tritium inventory and control

[1] K. Heinola, A. Widdowson, J. Likonen, E. Alves, A. Baron-Wiechec, N. Barradas, S. Brezinsek, N. Catarino, P. Coad, S. Koivuranta, G.F. Matthews, M. Mayer, P. Petersson, JET-EFDA contributors, J. Nucl. Mater. 463 (2015) 961–965.

[2] L. Avotina, I. Jepu, A. Baron-Wiechec, M. Kresina, A. Widdowson, JET Contributors, Phys. Scr. T171 (2020) 014009.

* See list of authors: E. Joffrin et al, Nuclear Fusion 59 (2019) 112021

Lecture 12

Preparation for DT campaign in JET FOR 2nd TRITIUM SCHOOL

B. Wakeling[a], R.Walker[a], S. Romanelli[a], X. Lefebvre[a], R. Olney[a], T. Huddleston[a], A. Withycombe[a], A. Hollingsworth[a], T. Jackson[s], G. Papadopoulus[a], H. Allen[a], M. Knight[a], M. Kresina[a], N. Platt[a], P. Staniec[a], R. Knights[a], S. Bickerton[a], S. Davies[a], S. Strikwerda[a], D. Kennedy[a], J. Collins[a], R., F. Sanni[a], H. Todd[a], J. Cieslik[a], O. Franklin[a], A. Begolli[a], J. O'Callaghan[a], R. George[a], S. Knipe[a]

[a]H3AT, UKAEA, Culham science centre, UK

ben.wakeling@ukaea.uk

The Joint European Torus (JET) is undertaking a deuterium-tritium campaign during 2021, which will involve reprocessing more tritium through the torus than has been done before. The first deuterium-tritium experiment (DTE1), was carried out in 1997 and involved delivering a 100g of tritium to the torus by recycling an inventory of 20g [1]. This upcoming campaign, will aim to process 1000g through the torus with an inventory of 70g. This talk will discuss some of technical challenges with preparing JET and will focus on the work around the Active Gas Handling System (AGHS), the tritium plant for JET.

Many factors impact the campaign readiness. The JET machine has become more complex over the last 24 years through modifications, for example increasing the number of tritium introduction systems. In addition, the AGHS plant has not been used to supply tritium to the torus for 17 years. The impact of these factors on the preparation, along with unexpected challenges including the failure of the exhaust detritiation system, will be discussed.

In addition, this talk will review the operational experience gained from the first campaign, which identified modifications to reduce the processing cycle time of the tritium plant. The upgrades, critical to the plant performance, were implemented, yet even with this to support the campaign schedule, AGHS is still required to operate at maximum utilisation, 24hrs a day, 7 days a week.

This work has been carried out within the framework of the Contract for the Operation of the JET Facilities and has received funding from the European Union's Horizon 2020 research and innovation programme. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] R. Lasser, et al., Fus. Eng. Des. (1999) 173

Keywords: Tritium Management; Tritium inventory and control

Lecture 13

SOLID WASTE DETRITIATION

D.Coombs[a], R.Vale[a],

[a]UKAEA, Culham Science Centre, Abingdon, Oxfordshire, UK

Tritium is present in radioactive waste generated from fusion and some fission activities and is expected to be a major consideration in future fusion projects. In the UK, it is present in some solid waste generated from the operation of the Joint European Torus (JET). JET was the first device to produce controlled fusion power with deuterium and tritium and holds the world record for fusion power. Waste generated onsite during operations must be appropriately treated, characterised and packaged prior to disposal via environmentally responsible off-site routes for recycling, further treatment or disposal. Government legislation requires that the quantity and impact of waste is minimised through the application of a waste hierarchy and a constant demonstration that 'best available techniques' (BAT) are being used.

This presentation will describe the processes in place for the management and disposal of JET tritiated waste and how BAT has been developed to recover and reuse the tritium present in legacy wastes; thereby closing the tritium 'lifecycle'. Additionally, current work funded by the TRANSAT Programme is leading to a better understanding of the behaviour of tritium in soft waste is described. Representing efforts to develop future characterisation options and to meet fusion waste challenges and further develop BAT.

Scientific programme, Day 3 – Wednesday, 16th of June

12:30 - 13:00	***Connecting***	
Session 7	Topic: tritium migration, management	Chair : Marco Utili
13:00-13:50 (50 min)	L14 - Tritium Processing in Breeding Blankets and Test Blanket Systems in DEMO	Alessandro Spagnuolo (EUROfusion)
13:50-14:40 (50 min)	L15 - From plasma facing components to radioactive dust: A study on the behaviour of tritiated dust in fusion reactors	Samuel Peillon (IRSN, France)
14:40-15:00	***Coffee Break***	
Session 8	Topic: tritium waste	Chair : Dave Coombs
15:00-15:35 (35 min)	L16 - General principles and examples of decommissioning of a facility containing tritium	Aurelie Lis (CEA, France)
15:35-16:10 (35 min)	*L17 - Overview of detritiation processes for solid tritiated softhousekeeping waste*	Karine Liger (CEA, France)
16:10-16:45 (35 min)	*L18 - Learnings from dismantling an obsolete tritium installation and decommissioning tritium laboratories*	Kris Dylst (SCK-CEN, Belgium)
16:45-17:05	***Coffee Break***	
Session 9	Topic: tritium migration, management	Chair : Karine Liger
17:05-17:40 (35 min)	L19 - Tritium breeding blankets for DEMO - Water Cooled Lithium Lead	Marco Utili (ENEA, Italy)
17:40-18:15 (35 min)	L20 - T_2 antipermeation coatings beyond chemical formulas: the key role of microstructure and deposition method	Fabio Di Fonzo (IIT, Italy)
18:15-18:45 (30 min)	***Discussion***	***Chair:*** Marco Utili / Karine Liger

Duration of presentations: talk + discussion

40 + 10 min

30 + 5 min

Tritium Processing in Breeding Blankets and Test Blanket Systems in DEMO

G.A. Spagnuolo[a], L.V. Boccaccini[b]

[a] *PPPT Power Plant Physics and Technology, EUROfusion – Programme Management Unit, Boltzmannstrasse 2, 85748 Garching, Germany*

[b] *Karlsruhe Institute of Technology (KIT), Campus Nord, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany*

alessandro.spagnuolo@euro-fusion.org

Within the framework of EUROfusion activities, two DEMO architectures are being developed.

One is based on the Water Cooled Lithium Lead (WCLL) Breeding Blanket (BB) concept that uses water as coolant and PbLi as neutron multiplier, tritium breeder and carrier. The other one is based on the Helium Cooled Pebble Bed (HCPB) BB concept where Helium is used both as coolant and T carrier (i.e. purge gas), and beryllide (e.g. $Be_{12}Ti$) blocks and solid ceramic (e.g. a mixture of Li_4SiO_4 and Li_2TiO_3) as neutron multipliers and tritium breeders, respectively [1].

As a consequence, the two DEMO variants result in completely different reactor and ancillary system designs. Among the BB interfacing systems, the most notables in the management of tritium are: the Primary Heat Transfer System (PHTS) with the Coolant Purification Systems (CPS), the Tritium Extraction and Removal Systems (TER) and, to less extent, the Tokamak Fueling System that pumps back in the Vacuum Vessel the tritium produced in BB and extracted in the TER. Both R&D and modelling activities are linked to the design of these systems that all together with the BB constitute the DEMO architecture. Therefore, also the definition of the tritium management systems for the extraction and the control of inventories and releases needs to be tuned for each variant [2].

For this reason, it is worth to tackle at an early stage the coordination of different studies among the area involved in order to guarantee that the developed solutions are consistent and the major issues are addressed. This becomes vital in case systems are involved in the management of tritium. As a consequence, the definition of the tritium management systems for the extraction and the control of inventories and releases also needs to be tuned for each variant. Furthermore, dedicated technologies for tritium extraction and removal must be developed and specific working points for the two architectures must be defined [2].

In this talk, an overview of the tritium permeation issues and the applied mitigation measures (e.g. permeation barriers) for the BB and ancillary systems are described. Furthermore, preliminary operating limits in the management of tritium are also reported.

Keywords: Tritium Management; Tritium inventory and control

[1] G. Federici et al., Overview of the DEMO staged design approach in Europe, Nuclear Fusion, vol. 59, no. 6, p. 066013, 2019

[2] G.A. Spagnuolo et al, Integration issues on tritium management of the European DEMO Breeding Blanket and ancillary systems, Submitted to Fusion Engineering and Design.

FROM PLASMA FACING COMPONENTS TO RADIOACTIVE DUST: A STUDY ON THE BEHAVIOUR OF TRITIATED DUST IN FUSION REACTORS

S.Peillon[a], M. Payet[b], T. Gélain[a], F. Gensdarmes[a], and C. Grisolia[b]

[a]Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-RES, SCA, Gif-sur-Yvette, 91192, France
[b]IRFM, CEA-Cadarache, 13108 Saint-Paul les Durance, France

samuel.peillon@irsn.fr

Nuclear fusion reactors based on plasma magnetic confinement and tokamak technology produce toxic and/or radioactive metal (mostly beryllium and tungsten) dust as a result of plasma/wall interactions within the vacuum vessel (VV). In addition to being a factor of pollution of the plasma, these dusts also involve safety issues in case of opening of the machine, maintenance or accidental situation like a break of the confinement barrier. To assess the safety of such nuclear installations and the relevance of the associated radiation protection measures, an important step consists in determining the source terms of dust contamination in normal operation and for different accidental scenarios.

These source terms are commonly calculated using resuspension coefficients which relate the quantity of dust emitted to the initial quantity involved, depending on the scenario considered. However, the behavior of these particles remains difficult to assess, in particular due to a lack of knowledge on the evolution of adhesion forces between the particles and the surfaces on which they are deposited. In addition, radioactive dust can electrically self-charge under the effect of ionizing radiation from the radionuclides it incorporates. The resulting charged particles can be subjected to electrostatic forces that may affect their adhesion or behavior once in the aerosol phase.

The study of the adhesion forces and the resuspension of metallic particles incorporating tritium deposited on surfaces representative of a tokamak environment are the main objectives of the work presented in this lecture. The presentation will begin with a few reminders on the dust production mechanisms encountered in a tokamak environment. On this occasion, I will introduce the experimental device and method used to sample dust inside the WEST tokamak currently in operation at CEA Cadarache. Thanks to this sampling campaign, laboratory experiments on micrometer tungsten particles loaded with tritium could be carried out. In particular, a parametric study using Atomic Force Microscopy (AFM) was completed and adhesion forces, as well as electrical potential, were obtained for neutral or labeled spherical tungsten particles. The sensitivity of this technique allowed us to demonstrate the effect of surface roughness on the adhesion and to measure the electric potential on individual radioactive particles. Finally, resuspension experiments with tungsten particles loaded with tritium were carried out and results obtained will be discussed during the presentation.

These experiments combined with the validation of a dust resuspension model can provide robust data for dust management, safety analysis and definition of radiation protection plans for future nuclear fusion facilities.

Keyword: Tritium inventory and control

GENERAL PRINCIPLES AND EXAMPLES OF DECOMMISSIONING OF A FACILITY CONTAINING TRITIUM

A. Lis[a], F. Legoux[a], S. Lengrand[b], J. Pirmez[a]

[a]DES/DDSD/UARP/SRTP, CEA-Marcoule, 30 207 Bagnols sur Cèze, France
[b]DG/CEA MAR/DUSP/SPR/LRIC, CEA-Marcoule, 30 207 Bagnols sur Cèze, France

aurelie.lis@cea.fr, franck.legoux@cea.fr, sandra.lengrand@cea.fr, jacques.pirmez@cea.fr

In all facility dismantling projects, the first step is the removal of the nuclear source term. The objective is to reduce workers' radiation exposure and dissemination risks during the future operations. In the case of Tritium, the major risk is radiotoxicity when it is in its oxidized form.

A special feature of Tritium is its ability to accumulate inside materials over time, then release gradually or in puffs, for example when heated. When planning dismantling scenarios, it is important to remember its ability to be trapped in water present in its atmospheric environment. Some tritiated water can often be found within the process, particularly in retention zones or low points. During cutting operations, pipe cutting for example, relatively large amounts of Tritium could be released, and represent a danger for operators.

Therefore when a facility dismantling is programmed, it is very important to decrease the source term., To decrease the potential risks for operators, the Tritium should be dried, pumped, and trapped before the dismantling operations begin. Furthermore, the operation instructions must take Tritium's features into account. They must forbid cutting operations involving hot points or water, so as to avoid producing tritiated water, the management and treatment of which are very difficult.

In-depth he knowledge of a facility and the level of the process contamination is indispensable when starting dismantling studies. Full, reliable input data sets enable the appropriate dismantling scenario to be built, with all the measures necessary to work in safety and to avoid the production of special waste.

Keywords: Tritium Management; Tritium waste

OVERVIEW OF DETRITIATION PROCESSES FOR SOLID TRITIATED SOFTHOUSEKEEPING WASTE

K. Liger[a]

[a] CEA, Agence ITER France, F-13108 Saint-Paul-lez-Durance, France

karine.liger@cea.fr

During its operating and dismantling phases, the ITER facility will generate different types of tritiated waste for which suitable management routes must be provided. Whenever required, the current management strategy for ITER tritiated waste involves an interim storage for tritium decay before transfer to a final repository. The opportunity of a detritiation treatment prior storage is also studied as it may have a positive impact on the management routes.

This lecture will focus on the description of detritiation processes that could possibly be used for solid tritiated soft housekeeping waste and will give an evaluation of their technical relevance as a preliminary treatment prior interim or final disposal.

This overview will show that there are a number of efficient detritiation processes and that their performances have effects on parameters with a quantifiable financial impact, such as the storage time, the storage surface area, the volume of waste to be managed after treatment, and the overall discharge levels from the storage facility. It must nonetheless be remembered that all tritium removed from this waste represents a secondary waste to be managed. The entire technical issue of detritiation is thus based on finding the right balance between process efficiency and the production of a minimum volume of secondary waste.

Finally, though technical solutions exist, the implementation and operation of these processes can be costly. Their relevance in the entire waste management system has then to be assessed through a technical and economic study.

Keyword: Tritium waste

LEARNINGS FROM DISMANTLING AN OBSOLETE TRITIUM INSTALLATION AND DECOMMISSIONING TRITIUM LABORATORIES

K. Dylst[a], Bart Gilissen[a], Yves D'Joos[a]
[a]SCK•CEN, Boeretang 200, 2400 Mol, Belgium

Kris.Dylst@sckcen.be

In the last decades two major tritium dismantling / decommissioning projects were started at SCK•CEN. Between 2003 and 2009 two rooms that served as tritium laboratory at SCK•CEN were decommissioned [1]. The tritium laboratories were initially commissioned in 1975 for a tritium inventory of 37 TBq, with a strong focus on handling tritium as HTO. For the first laboratory room, the decommissioning strategy was to free release as much materials as possible. For the decommissioning the second laboratory room a more pragmatic approach was used. At the expense of extra waste generation the decommissioning could be done faster.

In 2017 a dismantling study started for the VNS (Variable Neutron Shield). The VNS installation is located in the reactor building of the BR2 research reactor and is not related to the tritium laboratory. At the start of this dismantling study the VNS installation wasn't been operational for more than 20 years. In this installation substantial amounts of tritium were generated by neutron irradiation of pure He-3 gas. The formed tritium was removed from the He-3 gas flow by sending it through titanium retention traps (or Ti-getters). The maximum retention capacity of each Ti getter was 370 TBq, but the actual tritium content of each of the 5 present Ti-getters was unknown. Three of these Ti-getters were still connected to the VNS installation whilst two others were stored separately in stainless steel containers. Also a tritium containing experimental NaK getter was stored separately. NaK is a liquid metal that can react heavily with oxygen, water or NaK oxides. Also the tritium content of the NaK getter is unknown. A proper characterization together with finding disposal routes for these getters was indicated as an important first step in this dismantling exercise. But this required dismantling getters from the VNS installation.

Sharing the learnings from these projects can provide useful perspectives for decommissioning of tritium installations: from the waste, cost and labour impact of the used strategy to the difference between decommissioning an installation from which operational knowledge is present or not.

Keyword: Tritium waste

[1] Kris Dylst, Frederik Slachmuylders, Bart Gilissen, Comparison of different strategies for decommissioning a tritium laboratory, Fusion Engineering and Design, Volume 88, Issues 9–10, 2013, Pages 2655-2658

TRITIUM BREEDING BLANKETS FOR DEMO - WATER COOLED LITHIUM LEAD

M. Utili[a], D. Rapisarda[b], Ion Cristescu[c]

[a]ENEA Brasimone, 40032 Camugnano, Bologna, Italy

[b]CIEMAT, Fusion Technology Division, Avda. Complutense, 40 Madrid 28040 Spain

[c]Karlsruhe Institute of Technology, Institute for Technical Physics, Tritium Laboratory Karlsruhe, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

marco.utili@enea.it

The eutectic alloy PbLi is the breeder of one of the two Breeder Blankets (BB) concepts candidates for DEMO, the WCLL (Water Cooled Lithium Lead) [1], and of the other two concepts of BB investigated in EUROPE, the DCLL (Dual Coolant Lithium Lead) and HCLL (Helium Cooled Lithium Lead). The analysis of tritium generated into BB, definition of strategy to reduce tritium permeation into PHTS (Primary Heat Transfer System) of the reactor and the design and characterization of the system devoted to extract the tritium generated into the breeder, the Tritium Extraction and Removal (TER) System, are critical issues in the European Roadmap [2]. PbLi also serves the purpose of neutron multiplier and tritium carrier, this last role can only be fulfilled if TER system circulates the alloy through the BB.

Three technologies were investigated for the use in DEMO as TER: Gas Liquid Contactor (GLC), Permeation Against Vacuum (PAV) and Liquid Vacuum Contactor (LVC) [3]. In the GLC a flow of helium plus a small percentage of hydrogen is put in direct contact with PbLi in counter-current and tritium is removed by stripping. The PAV is based on a membrane that separates PbLi from vacuum, the membrane is made with a tritium permeable material, such as α-iron, vanadium or niobium, thus allowing the diffusion of tritium from PbLi to vacuum as a consequence of the concentration gradient. In the LVC tritium atoms are transported from the bulk of the liquid to their outer surface where they recombinate to form T2, which then leaves the liquid metal and is collected by a vacuum line. LVC appeared also as a suitable process, however some uncertainties on the figures of key parameters has to be still solved.

The design of TER system presents several technical issues due to the characteristics of the alloy: opacity, melting temperature of 235°C, density, etc, in order to design the system and auxiliaries, the following issues have to be solved:

- integration of the loops and of the main components in the tokamak building, minimizing the tritium releases and optimizing the efficiency of the systems;
- operation of TER loops, both in normal and abnormal conditions;
- development of barriers to avoid tritium permeation in the PHTS of the WCLL BB;

The management of tritium into WCLL BB of DEMO reactor and the design of TER system and integration in tritium building are reported, together with their secondary systems.

Keywords: Tritium management; Tritium inventory and control

[1] F.Cismondi, G.A.Spagnuolo, L.V.Boccaccini, et. All, Progress of the conceptual design of the European DEMO breeding blanket, tritium extraction and coolant purification systems, Fusion Engineering and Design (157), 2020, 111640.

[2] M.Utili, S.Bassini, L.Boccaccini, et. All, Status of Pb-16Li technologies for European DEMO fusion reactor, Fusion Engineering and Design (146) Part B, 2019, 2676-2681.

[3] D.Demange, R.Antunes, O.Borisevich, L.Frances, D.Rapisarda, A.Santucci, M.Utili, Tritium extraction technologies and DEMO requirements, Fusion Engineering and Design (109–111) Part A, 2016, Pages 912-916.

T2 ANTIPERMEATION COATINGS BEYOND CHEMICAL FORMULAS: THE KEY ROLE OF MICROSTRUCTURE AND DEPOSITION METHOD

F. Di Fonzo

Center for Nano Science and Technology - CNST@PoliMi, Istituto Italiano di Tecnologia, 20133 Milan (MI), Italy.

After decades of research, nuclear fusion is maturing from a scientific dream into a sustainable and safe power generating technology. The International Thermonuclear Experimental Reactor (ITER) will be the last experimental reactor studying plasma physics and fusion ignition. After, fusion will enter the commercialization stage, with the development of demonstrative fusion power plants. This transition is witnessed by the "nationalization" of the programs and the emergence of start-ups (among others General Fusion (CA), Commonwealth Fusion Systems (USA), Tokamak Energy (UK)). Most of these concepts have in common the deuterium- tritium fusion reaction, which implies the production of the latter from Li, in the breeding blanket (BB). In this case, inevitably, T_2 permeation through structural steels emerges as one of the main technical issues to tackle in order to guarantee safety and economy of any future power plant. A definitive solution must be found in order to allow all the above-mentioned concepts of commercial fusion reactor to become reality.

In this lecture we will review the status of the research on tritium antipermeation coatings, highlighting the wide discrepancies, even of several orders of magnitudes, reported often for the same (nominally) coating material (e.g. Al2O3) deposited by means of different techniques. Often overlooked details like coating micro and nanostructure, phase transitions, defect type and density, substrate adhesion, size of the samples will be taken into account in order to explain these discrepancies. Furthermore, the key role of the operative environment on the interaction between hydrogen isotopes and solid surfaces will be considered, differentiating between gas, liquid metal and water environment. Again, in the framework of the holistic approach mentioned above, we will discuss the role of the nuclear, chemical and mechanical stability of the coating material with respect the substrate and the test environment. A detailed case study will be presented on Al_2O_3 illustrating the role of structure (amorphous vs nanocrystalline), porosity, defect density and deposition method.

Scientific programme, Day 4 – Thursday, 17th of June

12:30 - 13:00	***Connecting***	
Session 10	Topic: Radiotoxicity/ecotoxicity	Chair : Veronique Malard
13:00-13:50 (50 min)	L21 - Human exposure to tritium: biokinetic models and health effects – UNSCEAR report	Laurence Lebaron-Jacobs (CEA, France)
13:50-14:40 (50 min)	L22 - The VATO project: development and validation of a dynamic Transfer model of tritium in a grassland ecosystem	Severine Le Dizès (IRSN, France)
14:40-15:00	***Coffee Break***	
Session 11	Topic: Epidemology of tritium and ecotoxicity	Chair : Awadhesh Jha
15:00-15:50 (50 min)	L23 - Epidemiological studies of tritium exposure	Richard Wakeford (Univ. Manchester, UK)
15:50-16:40 (50 min)	*L24 - The ecotoxicology of tritium: effects on fish using several endpoints, from molecule to individual responses – comparison to gamma radiation*	Beatrice Gagnaire (IRSN, France)
16:40-17:00	***Coffee Break***	
Session 12	Topic: Tritium dosimetry	Chair : Giorgio Baiocco
17:00-17:50 (50 min)	L25 - Dosimetry of tritium in humans and non-human biota	Francois Paquet (IRSN, France)
17:50-18:30 (30 min)	***Discussion***	***Chair:*** Veronique Malard / Awadhesh Jha

Duration of presentations: talk + discussion
40 + 10 min
30 + 5 min

HUMAN EXPOSURE TO TRITIUM: BIOKINETIC MODELS AND HEALTH EFFECTS – UNSCEAR REPORT

Laurence Lebaron-Jacobs[a]

[a]Direction of Fundamental Research; CEA de Cadarache; 13108 St Paul les Durance cedex France

laurence.lebaron-jacobs@cea.fr

Tritium is of natural or anthropogenic origin. It is produced as tritiated hydrogen, tritiated water or tritiated organic molecules. As a low-energy beta emitter, tritium is generally considered to be of low radiotoxicity. Tritiated water makes up the majority of tritium releases from nuclear facilities. Its biokinetics in humans essentially involve a retention period of 10 days, which decreases when people drink a lot of water. A small fraction is metabolised and integrated, along with hydrogen, into all biomolecules (proteins, lipids, carbohydrates, nucleic acids). This fraction has a longer half-life of several dozen days. Current uncertainties are limited and marginal in terms of implications for protection standards. The International Commission on Commission on Radiological Protection (ICRP) does the updating of the retention and excretion functions of radionuclides periodically. Tritium is no exception to these revisions, which are taken up by the international radiation protection authorities (IAEA, WHO and EURATOM in particular).

In terms of health, recent syntheses (UNSCEAR report) have highlighted several difficulties and/or uncertainties concerning the assessment of the effects of tritium exposure. The need to reassess the current biokinetic model for intake of tritiated biochemical substrates, the high density of heterogeneous distribution ionisation of tritium, the relevance of the dose, and the lack of data at environmental concentrations do not call into question the low radiotoxicity of tritium, but may eventually lead to review estimates.

The experimental data come mainly from cellular and animal studies after exposure to tritiated water (HTO). Exposure to tritium can induce both deterministic and stochastic effects (cancer or heritable effects), in laboratory mice and rats. However, to date, there is no epidemiological evidence of stochastic health effects being induced by tritium exposure in humans.

THE VATO PROJECT: DEVELOPMENT AND VALIDATION OF A DYNAMIC TRANSFER MODEL OF TRITIUM IN A GRASSLAND ECOSYSTEM

S. Le Dizès[a], C Aulagnier[b], F. Vermorel[b], H. Renard[c], M Rozet[c], D. Hébert[c], C. Voiseux[c], L. Solier[c]

[a]IRSN, PSE-ENV/SRTE/LR2T, CEN-Cadarache, 13115 Saint-Paul-lez-Durance, France
[b]Electricité de France, DIPDE, 154 avenue Thiers, 69458 Lyon, Cedex 06 France
[c]IRSN, PSE-ENV/SRTE/LRC, Rue Max-Pol Fouchet B.P.10, 50130 Cherbourg-Octeville, France

severine.ledizes@irsn.fr

Tritium (^{3}H) is a major radionuclide released in several forms (HTO: tritiated water, HT: tritiated hydrogen) by nuclear facilities under normal operating conditions. In this context, the objective of the VATO project (which ran from 2013 to 2016 for tritium study, and resulted from a collaboration between IRSN and EDF) is to get a more accurate quantification of ^{3}H transfer for a better assessment of the radiological impact of tritiated releases from nuclear facilities. More precisely, a dynamic compartment model with high temporal resolution was developed at IRSN to estimate ^{3}H (and ^{14}C) transfer in terrestrial ecosystems such as grasslands exposed to continuous or intermittent atmospheric ^{3}H releases from nuclear facilities, or combinations thereof [4] [2, 3, 4, 5]. TOCATTA-χ model belongs to the larger framework of the SYMBIOSE modelling and simulation platform which aims to assess the fate and transport of a wide range of radionuclides in various environmental systems [1, 2]. The conceptual and mathematical models of TOCATTA-χ were designed to be relatively simple, minimizing the number of compartments and the input parameters required. At the same time, the model achieves a good compromise between easy-to-use (because it must be used in operational mode), explanatory power and predictive accuracy under various experimental conditions.
As part of the VATO project, the model was tested against three-year-long in situ measurements of ^{3}H activity concentration monitored by IRSN in the air, groundwater and grass, together with meteorological parameters, on a grass field plot located 2 km downwind of the AREVA NC La Hague nuclear reprocessing plant, as had been done previously for the evaluation of transfer of ^{14}C in grass [2, 3, 4]. By considering the fast exchanges at the vegetation-air canopy interface, the model correctly reproduces the observed variability of the activity concentration of TFWT in the grass, which evolves according to the peaks in the atmospheric HTO activity concentration over the previous 24 hours [6]. The average activity concentration of OBT in the grass is also correctly reproduced. However, the model had to be improved in order to occasionally reproduce a high concentration of OBT activity, as observed in December 2013. The introduction of another fast-kinetic compartment (such as TFWT) improved the predictions by increasing the correlation coefficient of 0.29 to 0.56 when it includes this particular point. Additional experimental and modelling investigations were undertaken by IRSN and EDF between 2017 and 2020 under the LEGATO project to better assess (and properly model) the transfer of tritium to leaf vegetables, fruits and roots. The development of a fully mechanistic model was a necessary upstream work for the understanding of the mechanisms and for the proposal of simplifications when possible, leading to the recent implementation of an operational version of the model within the SYMBIOSE platform.

Keywords: Tritium radiotoxicity / ecotoxicity

[1] M.-A. Gonze, et al., ICRER 2011, 19-24 June, Hamilton (Canada) (2011).
[2] S. Le Dizès, et al., J. Environ. Radioact. 105, 48-59 (2012).
[3] C. Aulagnier, et al., J. Environ. Radioact. 112, 52-59 (2012).
[4] C. Aulagnier, et al., J. Environ. Radioact. 120, 80-93 (2013).
[5] S. Le Dizès, et al., J. Environ. Radioact. 124, 191-204 (2013)
[6] S. Le Dizès, et al., J. Environ. Radioact. 171, 83-92 (2017)

ABSTRACTS 23: EPIDEMIOLOGICAL STUDIES OF TRITIUM EXPOSURE

R. Wakeford[a]

aCentre for Occupational and Environmental Health, The University of Manchester, Manchester, UK

Richard.Wakeford@manchester.ac.uk

The health effects of tritium are of interest because it is a radioisotope of hydrogen, a pure beta-particle emitter, and the electron ejected from the triton is of low energy so has a short range and is densely ionizing relative to most other beta-particles. Consequently, a number of epidemiological studies have been conducted of those exposed to tritium occupationally and in the environment [1]. Although workers exposed to tritium offer an opportunity to examine potential risks to health, quantification of tritium-specific doses has been carried out for only a few studies, so that the conclusions that may be drawn from epidemiological studies in terms of tritium exposure risks are limited. Studies of environmental exposures are even more difficult to interpret reliably because tritium-specific doses are hardly ever available. However, an international collaborative effort to study workers exposed to tritium, which uses tritium-specific dose estimates, may be capable of meaningfully assessing the risk to health from exposure to tritium [2]. Nonetheless, the presently available epidemiological evidence does not indicate that the risk to health of tritium exposure has been seriously underestimated [2].

[1] M.P. Little and R. Wakeford, J. Radiol. Prot. 6-32 (2008) 28

[2] United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2016 Report, Annex C (2017)

Lecture 24

THE ECOTOXICOLOGY OF TRITIUM: EFFECTS ON FISH USING SEVERAL ENDPOINTS, FROM MOLECULE TO INDIVIDUAL RESPONSES – COMPARISON TO GAMMA RADIATION

B.Gagnaire[a], C. Arcanjo[a], I. Cavalié[a], V. Camilleri[a], M. Floriani[a], A. Festarini[b], S.B. Kim[b], D. Beaton[b], C. Della Vedova[a], C. Adam-Guillermin[a] and M. Stuart[b]

[a]IRSN – Institut de Radioprotection et Sûreté Nucléaire, Centre de Cadarache, 13115 St Paul lez Durance
[b]CNL – Canadian Nuclear Laboratories, 286 Plant Road, Chalk River, Ontario, Canada

beatrice.gagnaire@irsn.fr

Ecosystems are naturally exposed to ionizing radiations. To this natural exposure are added releases in the environment from anthropic activities related to the controlled or accidental releases from the nuclear energy cycle industries. Tritium, a low-energy beta emitter, is one of the radionuclides released during the normal operation of nuclear power plants and nuclear reprocessing plants. It is mainly released in the form of tritiated water (HTO) and integrates into the water cycle, which makes it particularly mobile within ecosystems. Studies conducted using high dose rates have highlighted the developmental and reprotoxic effects of tritium and ionizing radiations on aquatic vertebrates. However, few focused on molecular/cellular effects. It has been recently proposed that dose rates lower than 10 µGy/h can be acceptable for the protection of ecosystems towards radioactive substances. The application of such benchmark values to tritium is still under debate due to its potential difference in biological effectiveness relative to gamma irradiation.

In this context, this work aimed to characterize the impacts of tritiated water and gamma irradiation on fish health, as well as their modes of action. Studies focused on the embryo-larval stages of the zebrafish, Danio rerio, and on adults of the fathead minnow, Pimephales promelas. Those species were chosen in order to determine if effects on a model species like zebrafish could be extrapolated to an autochthonous species like fathead minnow. A battery of biological markers indicators of immunotoxicity (ROS production, lysosomal membrane integrity, phagocytosis activity), genotoxicity (DNA damages, gamma-H2AX activity, micronucleus frequency), neurotoxicity (acetylcholinesterase) and oxidative stress (catalase, SOD) was used, as well as measurement of expression of genes involved in these mechanisms, histology of tissues and measurements at the individual level (growth, development, behaviour) were used as part of those studies.

Zebrafish were exposed, in the laboratory, to tritium (HTO) or gamma irradiation at dose rates of 30, 130 and 1300 µGy/h. For HTO, at the molecular level, a transcriptomic analysis showed the modulation of genes involved in muscle contraction for 24hpf eggs. Analyses from tissular to individual levels showed muscle fiber alterations in 96hpf larvae for all dose rates, and this led to a decrease in swimming velocity after exposure to 130 µGy/h. For gamma irradiation, results highlighted effects on neurotransmission at different biological levels at 30 µGy/h (molecular, cellular and tissular levels). Fathead minnows were exposed to tritium during 60 days in field and laboratory studies at similar dose rates (up to 0,15 and up to 0,65 µGy/h, respectively). These dose rates were established based on the highest concentration of HTO measured at an upwelling on one water body in CNL site in Canada (180 kBq/L). Tritium effects were discriminated from field confounding factors using multivariate analyses. No effects were observed on survival and fish condition for both experiments. However, field and laboratory tritium exposure increased DNA damage and stimulated the responses of the immune and neural systems, revealing that mode of action of tritium was similar under the conditions of both the

field and the laboratory studies. These markers can therefore be considered as relevant for studying tritium effects in fish.

On the basis of these results, zebrafish seemed less sensitive to tritium than fathead minnows, as higher dose rates of tritium were necessary to observe similar effects on zebrafish larvae. For zebrafish, effects were more deleterious after gamma radiation than after HTO exposure.

Keywords: Tritium radiotoxicity/ecotoxicity; Tritium dosimetry; Ecotoxicology; tritium; gamma irradiation; zebrafish Danio rerio; fathead minnow Pimephales promelas; biomarkers

DOSIMETRY OF TRITIUM IN HUMANS AND NON-HUMAN BIOTA

F. Paquet

[a]*IRSN, PSE ENV-SRTE BP 3, 13115 Saint Paul Lez Durance Cedex, France*

francois.paquet@irsn.fr

During this last decade, there has been much debate about the dosimetry of tritium. Most of the debate centered on the radiation weighting factor to be applied, due to the very short-range of the beta particles emitted after disintegration of tritium, and also because of its heterogeneous distribution in tissues when incorporated as chemical forms that have a high affinity for DNA. The origins of the debate were partly a misunderstanding of the tools developed to calculate doses, and of their ranges of applicability.

The International Commission on Radiological Protection (ICRP) has proposed a methodology to calculate doses resulting from incorporated radionuclides based on the type (alpha, beta, gamma, neutrons) and energy of radiation, but not on specific elements. As a consequence, the doses resulting from the incorporation of tritium are calculated as for every other element of the periodic table. In the range of low doses, which may induce stochastic (cancer/heritable) effects in humans, the quantity effective dose E(50) serves for optimization procedures and for the demonstration of compliance with doses limits. Effective dose is calculated through a series of steps: the absorbed dose is defined as the mean energy imparted to matter of mass dm divided by the mass dm; then, the equivalent doses to individual target organs or tissues are calculated as a sum of absorbed doses, weighted by the radiation weighting factor w_R. For tritium and all beta radiation, w_R is set equal to 1; and finally, the effective dose is defined by a sum of tissues equivalent doses, weighted by their respective tissue weighting factor w_T. It is important to note that tissue and radiation weighting factors used for the calculation of the effective dose are defined for stochastic effects only. A revision of the effective dose coefficients for tritium for workers has been published in 2016 [1]; those for the members of the public are to be published in 2022.

In the range of doses that may induce deterministic effects (tissues reactions), the quantity to be used is the mean absorbed dose to the organ or tissue, weighted by an appropriate value of the Relative Biological Effectiveness (RBE) for the radiation and for the biological endpoints of concern. A large variation of RBE is observed according to the endpoint considered and is described in relevant ICRP Publications [2].

For the dosimetry of tritium in non-human biota, work has just been completed by ICRP. Whereas protection of humans has focused on avoiding deterministic and stochastic effects, protection of biota has largely focused on tissue reaction endpoints relevant to population viability. A review of RBE data relevant to biota for tritium has reported values centered around 1.5–2 compared with X-rays, and 2–2.5 compared with gamma rays. Lower values are observed for deterministic effects compared to stochastic effects. It is therefore proposed that for protection purposes, radiation weighting factors w_B for biota regarding tritium and all low LET radiations should be set to 1, and used to modify the absorbed dose rates to relevant Reference Animals and Plants (RAPs). Use of a single value of 1 for all low LET radiations is consistent with the approach taken to protection of humans. A caveat is made that if exposures to tritium beta particles, or to other low energy, low LET radiations, are within or close to the derived consideration reference level (DCRL) band, additional review, and possible modification of w_B, might be warranted.

[1]. ICRP 2016, Occupational Intakes of Radionuclides, Part 2. Ann ICRP 45 (3/4)
[2]. ICRP 2003. Relative Biological Effectiveness, Quality Factor and radiation weighting factor. Ann ICRP 33(4)

Scientific programme, Day 5 – Friday, 18th of June

12:30 - 13:00	***Connecting***	
Session 13	Topic: Radiotoxicity and dosimetry of tritium	Chair : Ion Cristescu
13:00-13:50 (50 min)	L26 - Impact of T on aquatic environment	Awadhesh Jha (Univ. Plymouth, UK)
13:50-14:40 (50 min)	L27 - Tritium dosimetry: Modeling approaches at the sub-cellular scale	Giorgio Baiocco (UNIPV, Italy)
14:40-15:00	***Coffee Break***	
Session 14	Topic: Tritium waste, management	Chair : Robert Vale
15:00-15:50 (50 min)	L28 - French National Agency for Radioactive Waste Management	Robert Mandoki (ANDRA, France)
15:50-16:20 (30 min)	***Discussion***	***Chair:*** Christian Grisolia / Sabina Markelj
16:20-16:30	***Goodbye***	***Thierry Orsiere / Christian Grisolia***

Duration of presentations: talk + discussion
40 + 10 min
30 + 5 min

ASSESSING IMPACT OF TRITIUM IN THE AQUATIC ENVIRONMENT

Awadesh N. Jha

School of Biological and Marine Sciences
University of Plymouth, Plymouth, PL4 8AA, UK

a.jha@plymouth.ac.uk

Tritium (3H), a radioisotope of hydrogen (half-life ~ 12 years) is ubiquitously distributed in the environment, both as a result of natural phenomenon (e.g. interaction of cosmic rays with nitrogen in the atmosphere) or as a result of anthropogenic activities. Compared to other radionuclides, tritium is discharged in huge quantity by nuclear establishments, mainly as tritiated water (HTO). Ultimately these discharges end-up in the aquatic environment to which organisms are exposed. Environmental monitoring and assessment of potential impact of HTO on human and natural biota is therefore important from both scientific and regulatory perspectives.

Adopting an integrated approach, we have been evaluating the potential biological impact of HTO on different life stages of aquatic invertebrates. Our initial studies had suggested that HTO is capable of inducing genetic damage in adult and early life stages of polychaete worms and marine mussels at much lower dose rates recommended by international organisations [1-2]. We also demonstrated that organic (i.e. tritiated glycine) and inorganic tritium (i.e. HTO) differentially accumulate in the tissues and induce different levels of genetic damage in the haemocytes of mussels [3]. In order to estimate the radiation dose following exposures to HTO, we adopted different methods of dose estimation in adult mussels [4]. Our study suggested that dose estimation software, ERICA tool is useful for estimating radiation dose [4]. To maximise the accuracy for dose estimation, it was realised that it is essential to quantify the activity within the organism as this would remove any assumptions about concentration ratio (CR). The use of the ERICA tool with water activity concentrations only, tends to over-estimate dose (due to conservative assumptions for CR). This has some implications as overestimation of dose could lead to artificially inflated parameters (e.g. ED50) which in turn could lead to underestimation of radiotoxicity.

Potential impact of radionuclides should be assessed along with other abiotic and chemical factors. Temperature is an abiotic factor of particular concern for assessing the potential impacts of radionuclides on marine species. We assessed the tissue-specific accumulation, transcriptional expression of key stress related genes and genotoxicity of HTO to marine mussels at either 15 or 20°C over a 7 day time course with varying sampling time [5]. Our study suggested a significant induction of DNA strand breaks showing temperature- dependent time shift. At 15°C, DNA damage only significantly elevated after 7d in contrast to 25°C where a similar response was observed after only 3d. Transcription profiles of stress related genes (e.g. hsp 70, hsp 90, mt 20, p53 and rad 51) indicated potential mechanisms behind this temperature-induced acceleration of genotoxicity. We further studied the interaction of HTO with two different concentrations of zinc (Zn), as environmentally relevant metal, in the presence of dissolved organic ligands (humic acid as dissolved organic carbon-DOC) and elevated temperature [6]. Mussels exposed for 14 d to these mixtures suggested a clear antagonistic effects of Zn on HTO-induced DNA damage at all Zn concentrations used. Overall, the study highlighted the importance of potential mixture effects in the environmental risk assessments of radionuclides. To assess the potential environmental impact of tritium, a multidisciplinary approach is required. Our work is progressing to achieve this goal.

Selected References: [1]. Hagger JA et al. (2005) Aquatic Tox 74, 205-217. [2]. Jha AN et al. (2005) Mutation Res 586, 47-57. [3]. Jaeschke BC et al. (2011) Environ Pollut 159, 274-280. [4]. Dallas LJ et al. (2016) J Environ Radioactivity 155-156, 1-6. [5]. Dallas LJ et al. (2016) J Environ Radioactivity 164, 325-336. [6]. Pearson HBC et al. (2018) J Environ Radioactivity 187, 133-143.

TRITIUM DOSIMETRY: MODELING APPROACHES AT THE SUB-CELLULAR SCALE

G. Baiocco[a,*], V. Malard[b]

[a]Radiation Biophysics and Radiobiology Lab, Physics Department, University of Pavia, Pavia, Italy
[b]Aix Marseille University, CEA, CNRS, BIAM, Saint Paul-Lez-Durance, France

giorgio.baiocco@unipv.it

The radiotoxicological and radiobiological consequences of tritium contamination strongly depend on the speciation of tritiated products. Tritium commonly occurs as tritiated water (HTO) or organically-bound tritium (OBT), but can also exist in many other forms, depending on nuclear-related construction materials, including tritiated particles of different nature and sizes. Furthermore, different exposure pathways are possible under accidental exposure scenarios (i.e., inhalation, skin absorption and/or ingestion). Overall, the chemical speciation determines, for a given exposure pathway, both the kinetics associated with the distribution of tritiated products at the organ/tissue level (including clearance) and the associated distribution at the cellular and subcellular levels.

Considering the average range of beta (β) electrons emitted by tritium decays in biological tissue (0.5 μm, corresponding to an average decay energy of 5.7 keV), it is clear that both the distribution of energy deposition events at the subcellular level and the cumulative energy ("dose") deposited in target cells will vary substantially when different tritiated products are considered. Both these two pieces of information are necessary to correctly assess tritium dosimetry and correlate dose to tritium biological effects.

In this lecture we will review the main concepts at the basis of sub-cellular dosimetry for tritiated products, and more generally, for short-range emitters and their related biological effects. We will then focus on the possible modeling approaches and simulation tools that are available to achieve a thorough assessment of energy deposition following internal contamination with radioactive particles. In particular, we will review a.o. track structure calculations [1, 2], micro/nanodosimetry [3] and analytical approaches [1, 4]. We will also discuss how to choose which model is more suited to provide information that can be integrated with experimental results, depending on the characteristics of the experimental setup in use (e.g. in vitro standard "2D" vs. "3D" cell cultures).

Keywords:Tritium radiotoxicity / ecotoxicity; Tritium dosimetry

[1] M. Siragusa *et al.*, Rad. Res., 188(2), 204-220 (2017)

[2] D. Alloni *et al.*, Rad. Res., 182, 322–330 (2014)

[3] J. Chen, Radiat. Prot. Dos. 156(3), 372-5 (2013)

[4] G. Baiocco *et al.,* Rad. Res. DOI: 10.1667/RADE-20-00208.1 (2021)

FRENCH NATIONAL AGENCY FOR RADIOACTIVE WASTE MANAGEMENT

R. MANDOKI, V. WASSELIN (Andra)

Andra is the French National Agency for Radioactive Waste Management. A regulatory framework defines the status, mission and activities of the Agency. After a short reminder of Andra' scope of activities, the lecture will focus on the radioactive waste management solutions already set up and in operation in France and on the on-going project development in Andra.

Tritium issues and limitations related to tritiated waste conditioning and disposal in CIRES and CSA facilities will be described. The case of possible tritium limitations for CIGEO tritiated waste acceptance will also be presented.

The French strategy for solid tritiated waste management will be reminded as foreseen and planned in France, in particular for future ITER (International Thermonuclear Experimental Reactor) tritiated waste. Challenged by the large inventory of tritiated waste arising from the ITER project in the coming decades, an analysis of the different waste categories to be produced by ITER and a comprehensive scheme of the overall waste management routes (characterization, sorting, processing, conditioning, disposal) has been performed in 2017 and 2018.

Based and justified by a waste hierarchy approach, opportunities for development and possible optimization paths were identified and discussed during the 2018 ITER waste review. These optimization paths to reduce interim storage duration[1], to minimize out-gassing rates[2], to facilitate tritiated waste acceptance to repositories, and possibly or globally to improve the general strategy of tritiated waste management will be presented.

Finally, the need to study and develop the proposed optimizations is highlighted and then put in perspective of the (possible) future fusion reactors development.

[1] VALOFUSION project, 2016-2020 – Led by CEA (Nuclear Energy Division) with the collaboration of CNRS (Institut Néel) and Cyberstar (ECM group)

[2] MACH3 project, 2016-2020 – Led by CEA (Nuclear Energy Division) with the collaboration of Ecole Centrale de Lille and ENSC Lille