Scientific Research in Priority Areas
Tritium for Fusion
2007 - 2011

Tutorial Lectures for Young Scientists and Students

Friday Afternoon, October 29, 2010

Meeting Room No.1 at the Hall

13:20-18:30	Chairman M. Nishikawa (Kyushu Univesity)
13:20	T1 Introduction, What is tritium T. Tanabe (Kyushu University)
13:50	T2 Tritium in ITER M. Glugla (ITER)
14:50	T3 Tritium in Fusion Reactor T. Yamanishi (JAEA)
15:50-16:10	Coffee Break
16:10	T4 Tritium Science and Technology in the Future S. Willms (LANL)
17:10	T5 Tritium and Environment S. Konishi (Kyoto University)
18:10-18:30	Discussion and Closing

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1. Introduction
- What is tritium or what problem does tritium give? –

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Tritium (T) is a radioactive hydrogen isotope decaying to ^{3}He emitting a β-electron and an antineutrino (ύ) with a half life of 12.323 year [5], T → ^{3}He + β + ύ. The decay rate of 1g of tritium is equivalent to 3.5574 x 10^{14} Bq. This means that during storage, about ~ 5.5 % is disappearing in a year. The energy of emitted β-electrons is widely distributed with the maximum of 18.6 keV and average of 5.7 keV. The integrated decay heat is 324 mW/1g T, which is not very large but could result in thermal release of tritium from heavily tritium loaded materials.

The properties of T as a mass is mostly the same as those of hydrogen (H) and deuterium (D), and any T handling system is just like chemical plant handling normal hydrogen. However its radioactivity adds various problems to handle T safely. The most important point is accountancy. The radioactivity of T does not allow any waste or loss, i.e. even a pico-gram (10^{-9} g) of T must be traced on handling of kg order of T. T is easily detected by β-electron counting with the detection limit and/or accuracy of several Bq/cm^2 on solid surfaces and around 0.1 Bq/cm^3 in water. However, the β-electron counting is limited to below 10^9 Bq or mg order of T. For much larger amount of T, mass and/or pressure measurements are principal, same as the measurements of other hydrogen isotopes. The measurement of decay heat allows calorimetry but its accuracy is only 10^{-2} to 10^{-3}. All present tritium measurements except the β-counting give accuracies of only 2 to 3 digit and any loss of T less than 0.1% is hardly possible to detect.

Since public exposure to T is regulated at a level as tiny as a few Bq/cm^2, T must be strictly confined in handling systems. Fortunately, T escaping from the handling system by desorption and permeation and surface contamination are easily detected, while T retained in bulk of solid materials cannot be detected, because the β-electron can penetrate through materials only a few μm in depth. (Its maximum range in air is 6 mm and less than 1μm in metals.) Therefore movable tritium in the solid, mostly in metals, is problematic for safety.

Comparing with easy detection of T, determination of its chemical form is quite hard. For T safety, its chemical form does matter. Tritiated water is several orders of magnitude more hazardous than HT and/or T2 gas. In addition, T can easily replace the ubiquitous H and D in water and hydrocarbons in air. And any materials surfaces absorb water molecules and enhance isotopic replacement producing hazardous tritiated water. In addition, the β-electrons could cause and/or enhance undesirable chemical reactions (radio-chemical reactions) in living things appearing as radiation hazard. In a fusion reactor system, we have to handle huge amounts of T, which would require a little different and additional knowledge than those obtained in handling a small amount of T or in tracer technique.

2. Tritium in ITER

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The helium concentration of deuterium / tritium (D-T) burning plasmas in fusion reactors is limited to a few percent because of basic physics reasons. Low helium contents can only be achieved through continuous D-T fuelling and pumping; the generally small burn-up fractions of D-T in fusion reactors require a closed D-T fuel cycle.

ITER is an experimental reactor aiming at fusion powers ten times higher than the auxiliary input power (Q=10). However, under these conditions the plasma is still “driven” and not “burning”. Due to uncertainties in the fuelling efficiencies under different operational modes (inductive, hybrid, steady state) the Tritium Plant of ITER has to cope with unprecedented tritium flow rates and tritium processing requirements.

For plasma density control ITER relies on pellet injection, supported by the possibility to modulate the divertor flow by throttling the cryo-pumps. Plasma diagnostics call for a widely distributed Vacuum System; its roughing pumps discharge to Tritium Plant gas processing for D-T recovery and detritiation prior to discharge into the environment.

Safe handling of tritium in ITER is achieved by multiple passive physical barriers and active Detritiation Systems. In contrast to other tritium facilities ITER features room atmosphere detritiation in case of incidental or accidental spills and will have the facility to recover tritium from tritiated water collected in the Detritiation Systems.

Processing D-T fuel covers a wide range in physical chemistry; when dealing with all three hydrogen isotopes a variety of overlapping effects have to be considered. Gaseous hydrogen interacts with solids and particularly with metals through physisorption and /or chemisorption on surfaces. Hydrogen isotopes can be dissolved in metals, can form hydrides, and can permeate through metal membranes. Heterogeneous catalysis, chemical reaction kinetics and chemical equilibria, separation techniques in fluid systems and analytical techniques such as chromatography, spectrometry and calorimetry are important for the design of fusion fuel cycle systems and the ITER Tritium Plant.

The lecture will provide a detailed inside into the fuel cycle of ITER. Tritium processing within the Tritium Plant and their physicochemical backgrounds will be explained, and issues, challenges and opportunities will be addressed.

3. Tritium in a Fusion Reactor

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From viewpoint of R&D for ITER, main components of the tritium systems have been developed in domestic R&D of each country and ITER-EDA. A series of integrated tests of the main components are essentially significant subject, and will be carried out as one of the most significant issues of ITER. The tritium handling technologies have also been developed in the world. The multiple confinement system is basically used for the tritium handling. The primacy confinement is the component itself which has strict leak tightness. The components are set in the secondary confinement system. The pressure of the secondary confinement is controlled at a negative pressure. A detritiation system is equipped to recover tritium from the components. The detritiation system is composed of catalyst and molecular sieve beds. This tritium confinement system has been demonstrated in the world. Although a new component of scrubber column is applied to ITER as the detritiation system, this new system will also be demonstrated at ITER.

In the lecture, in accordance with the above understandings, I present the followings: what has been demonstrated in the past on the tritium technology; what will be demonstrated at ITER; and what should be demonstrated toward a fusion reactor. There are still many R&D subjects on the following fields for a fusion reactor: blanket technology; tritium accountancy; tritium confinement for the power generation system; and water detritiation system for primary and secondary coolant. The effect of tritium water on various materials should carefully be studied: corrosion; contamination; decontamination; and permeation Recent results in these fields carried out by Japanese Universities and JAEA will be presented in the lecture. A part of the blanket technologies have been carried out in the BA activities, and are therefore introduced in the lecture.

A long schedule is required for the R&D of a DEMO reactor: even the DT operation of ITER will be started from 2027. Young generation researchers are quite required to carry out the above long time and many R&D subjects. The tritium facilities were made 20-30 years ago in Japan, for instance, TPL and Toyama University. We really need a new facility before these facilities will be shutdown.

4. Tritium Science and Technology in the Future

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Tritium science and technology development is important for a variety of applications. Great progress has been made since this area began in the middle of the last century. But, much additional development will be needed to meet emerging challenges. One of the primary drivers will be the development of magnetic and inertial confinement fusion. The challenges associated with this area are being assessed in a variety of venues. One such effort conducted in the United States was referred to as the Research Needs Workshop (ReNeW) exercise. Among other fusion needs, ReNeW identified future needs for tritium science and technology for magnetic fusion with a view to ultimately building the DEMO fusion reactor (will generate substantial electricity by fusion power). This analysis determined that tritium needs will fall in seven areas summarized as fuel processing, vacuum and fueling, tritium handling, nuclear facilities, tritium breeding, extraction of bred tritium and in-vessel tritium. In each area the state-of-the-art was summarized and gaps for realizing DEMO were listed. Results from this exercise will constitute the bulk of this session. But attention will also be given to other areas such as inertial confinement fusion and fission needs.

5. Tritium and Environment

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In the design and evaluation of fusion reactor, considerations from safety, environment and social aspects are extremely important. When fusion energy would be technically realized, if it would not be deployed in the future global energy market, efforts and resources devoted for the development will not be justified. Confinement and emission control of tritium in fusion and tritium facility would be technically possible, although there may be some constraint of cost and budget. The real impact of tritium appears, however, in the environment, public and society only after it is released from the stack, and is out of control. It is therefore necessary for the engineers to understand how tritium migrates in the environment, and eventually make any possible effects to people, so that effective tritium control could be designed and implemented. Deployment of fusion depends on such an impact, or understanding by the public, who accept it

Following the release from the stack or drain or possible leak from a building facility, tritium migrates in the environment. Its effect can be analyzed first by the identification of the impact pathway. A number of numerical models were developed to describe and simulate their behavior, mainly with compartment models, in which each status and location of the tritium are defined as compartment, and transfer of tritium between the compartments is expressed as a function of the environmental factors. Both hydrogen and water forms are observed, but water is more important and complicated. Along with the physical transport in the environment, biological and ecological behavior is important for tritium. At the end, tritium becomes a concern by the intake to a human body. Injection, inhallation and absorption are major paths. Adding to tritiated water that can easily be taken by bodies, OBT-organically bound tritium could be more important, because it is likely to stay longer in the body. Finally, if the concentration is low, tritium is considered to cause causers, by probabilistic effect starting from the damage on DNAs. Public is concerned this possible health risk. Also, contamination of food and agricultural product with tritium can also cause economic damage due to rumors. If we know these mechanisms of impacts, the ultimate purpose of the tritium control would be understood, that is not to decrease the release, but to minimize the impact.