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JANNUS: A multi-irradiation platform for experimental validation at the scale of the atomistic modelling

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ABSTRACT

The Joint Accelerators for Nanosciences and NUclear Simulation project was started in 2002 in the frame of collaboration between CEA and CNRS. Due to the scientific skills developed for a long time, two experimental sites have been considered: (1) at Saclay, three electrostatic accelerators are being coupled, a new 3 MV Pelletron machine equipped with a multi-charged ion source, a 2.5 MV single ended Van de Graaff and a 2.25 MV tandem and (2) at Orsay, a 2 MV tandem and a 190 kV ion implanter are being coupled together with a 200 kV transmission electron microscope to allow simultaneous co-irradiation and observation. A brief review is first presented on multi-irradiation facilities available in the world. Then, a technical description of the new experimental facilities being installed is given. The main experiments we intend to carry out using mono, dual or triple irradiation configurations in different nuclear application fields and especially in the fusion domain will be further presented.

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1. Introduction

The first paper on dual beam irradiation was given in 1977 by Brimhall and Simonen [1]. They evidenced that high temperature He pre-implantation of Ni irradiated by self ions enhances the formation of voids and reduces their average diameters in comparison with simultaneous He/Ni irradiation. Then, Farrell, Lewis and Packan showed that during the dual or triple irradiation of steel, hydrogen synergistic effects are rather limited on the evolution of microstructure [2]. In France, Lévy, Gilbon and Rivera clearly demonstrated that sequential and dual beam irradiation of 316 steel (Ni and He ions) could lead to substantially different results in terms of swelling amplitude [3].

The ability of ion beams to simulate the whole neutron-induced damage effects and its main consequences on both microstructure and mechanical properties changes in nuclear materials was first analyzed by Averback [4] and Ullmaier [5]. The main advantages of this simulation process is linked to the versatility of the available experimental irradiation conditions (temperature, dose rate, fluence, damaged thickness) and the possibility to carry on in situ or ex situ physico-chemical and structural characterization.

After a very brief review on the multiple ion beam facilities running worldwide now, we will present the progress of the implementation of the Joint Accelerators for Nanosciences and NUclear Simulation (JANNUS) project at CEA Saclay and Orsay (CNRS–CSNSM and Paris-Sud University). Before to conclude, we will discuss the main research topics that will be developed using JANNUS facility.

2. Multiple ion beam facilities worldwide

In a recent paper, we have given a review on the multiple ion beam facilities available worldwide [6]. They are summarized in Table 1 including MeV dual or triple ion beams, low energy multi ion beams and ion beam(s) coupled with a TEM [7–15]. Both Salford University (UK) and Indhira Gandhi Center for Atomic Research (IGCAR India) multiple ion beam facilities are actually under completion [12,15].

3. Main technical aspects of the JANNUS facility

The JANNUS project gathers two independent ion beam facilities: a triple irradiation facility at Saclay [6,16,17] and a TEM-coupled dual beam facility at Orsay [18]. The triple beam is constituted by a 3 MV Pelletron™ from NEC (Épiméthée) equipped with an ECR multi-charged ion source able to supply any ion beam except

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Table 1
Multi ion beam facilities under construction.

Laboratory	Facility	Reference
JAERI Takasaki (Japan)[b]	400 kV Implantor, 3 MV Van de Graaff, 3 MV Tandem	[7]
IAE Kyoto (Japan)[b]	1 MV Van de Graaff, 1.7 MV Tandetron, 1 MV singletron	[8]
HIT Tokyo (Japan)[b]	3.75 MV Van de Graaff, 1 MV Tandetron	[9]
CIRSE Nagoya University (Japan)[b]	200 kV Implantor, 2 MV Van de Graaff	[10]
CARECM Hokkaido University (Japan)[b]	300 kV Implantor, 1.25 MV TEM	[11]
MSD, IGCAR Kalpakkam (India)[a]	400 kV Implantor, 1.7 MV Tandetron	[12]
FZ Rossendorf (Germany)[b]	500 kV Implantor, 3 MV Tandetron	[13]
FSU Iena (Germany)[b]	400 kV Implantor, 3 MV Tandem	[14]
Salford University (UK)[a]	100 kV Implantor, 200 kV TEM	[15]

[a] Or under operation.
[b] Worldwide.

electronegative elements, a 2.5 MV Van de Graaff (Yvette) and a 2.25 MV tandem (Tandetron). The Orsay's facility couples a 200 kV TEM TECNAI™ from FEI, a 2 MV Van de Graaff/tandem (Aramis) and a 190 kV ion implantor (Irma).

The Saclay's triple beam facility is displayed in Fig. 1. The layout is divided in six linked rooms, separated by suitable concrete walls devoted to answer radioprotection requirements. The Orsay dual beam facility coupled to a 200 kV TEM is displayed in Fig. 2.

The beam line optics of the three machines have been designed and validated using the TraceWin code developed at CEA-DAPNIA/SACM Saclay [19]. An example is given in Fig. 3, it concerns the triple beam line from the 3 MV Pelletron™ (Épiméthée). It gives an idea of the beam envelope of a 3 MeV proton beam (Fig. 3(a)). Fig. 3(b) displays the image of the beam onto the target surface and permits to visualize the excellent beam transmission >95%. The same procedure has been applied for the optics of the beam lines coming from Irma and Aramis as described in [18] using the code Simion [20].

On the triple beam chamber mounted at Saclay (Fig. 4), the three beam ports are respectively located in the medium horizontal plane at 15° from both sides of the vertical plane and at 15° beneath. Each beam line is equipped with an energy degrader able to homogenize the irradiation damage along the whole ion range. On the top of the chamber, a pneumatic system holds three groups of seven Faraday's cups designed to control the beam fluence. The sample holder mounted on the rear part of the chamber covers the temperature range liquid nitrogen to 800 °C.

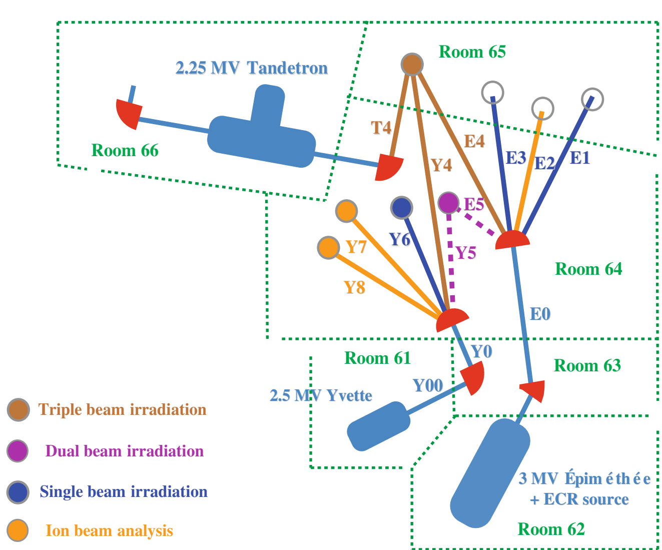

Fig. 1. General layout of the Saclay triple beam facility.

The TEM/dual beam facility at Orsay will start its exploitation during the third quarter of 2008. The Saclay dual beam facility should be ready to operate at the beginning of the fourth quarter of 2008. The starting of the triple beam at Saclay is scheduled at the end of 2009.

4. Main objectives of the JANNUS projects

The first goal pursued with the implementation of the JANNUS multi ion beam facility is to offer to the scientific community experimental tools to investigate ion irradiation damage mechanisms, synergistic effects of dual/triple beam irradiation and ion beam modification of materials. The second goal is to make working closer irradiation physicists and physico-chemists with modelling physicists in order to improve the atomic-scale modelling description of the irradiation behaviour of inorganic compounds. The third goal is to facilitate the access of higher education students to a multipurpose ion beam facility for teaching and training activities in the fields of ion irradiation, ion implantation and ion beam analysis.

5. Research topics planned to be explored

A wide range of materials will be investigated especially in the field of nuclear and nanosciences applications. It includes waste matrices, transmutation targets, fission reactor structure materials, claddings and fuels, generation IV materials and fusion reactor materials.

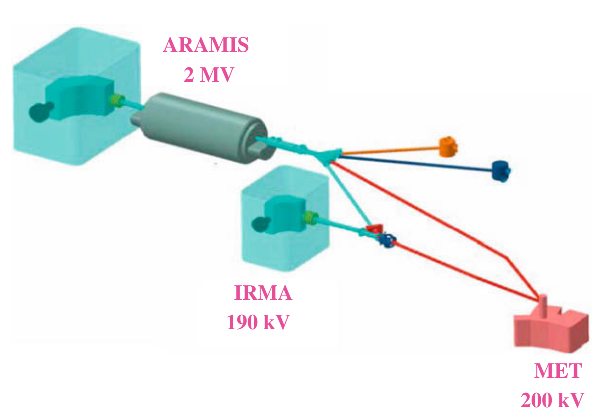

Fig. 2. General layout of the Orsay dual beam facility coupled with a 200 kV TEM.

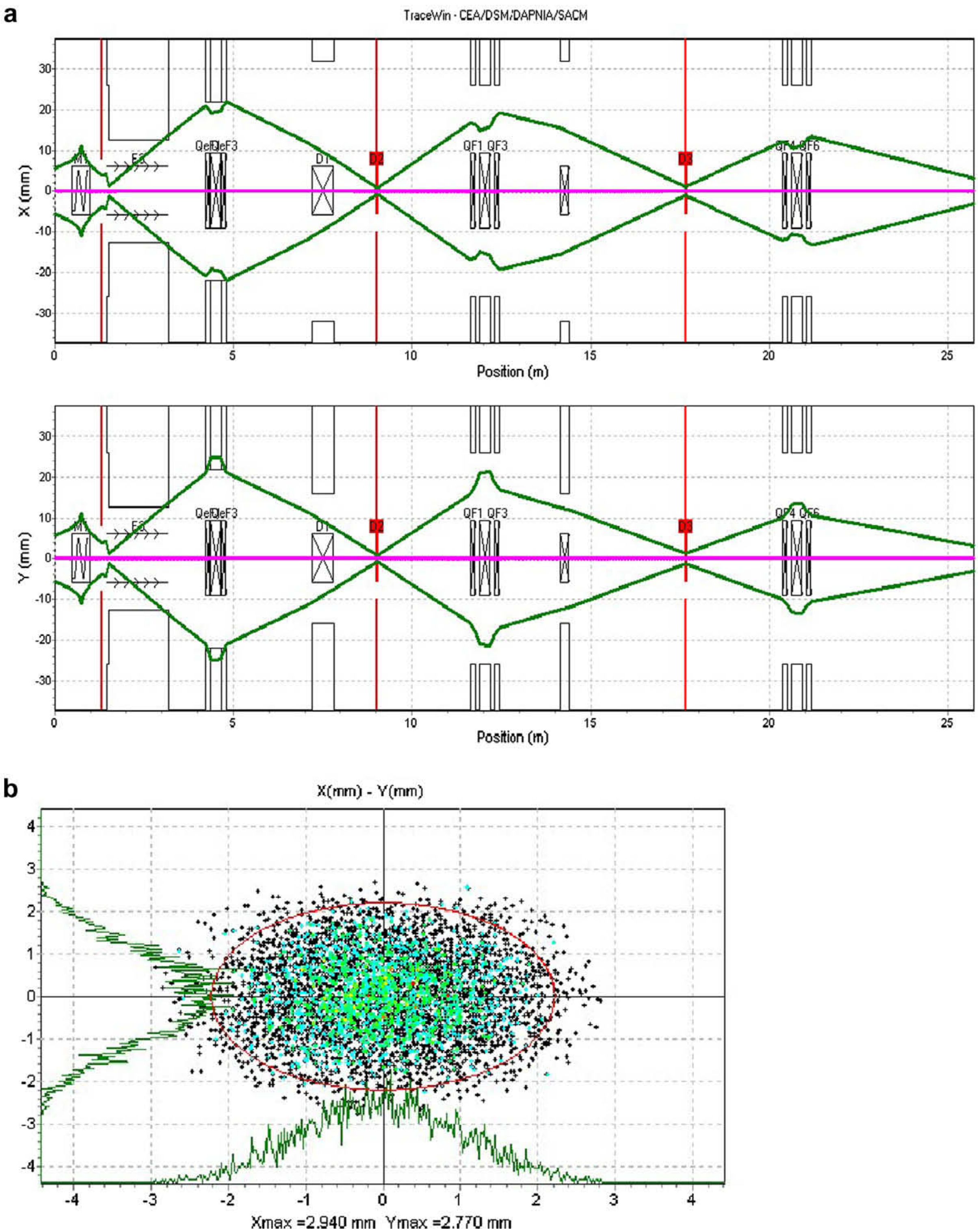

Fig. 3. (a) Beam line envelope for a 3 MeV proton beam simulated with Trace Win code and (b) image of the beam onto the target surface.

One of the major item which will be investigated deals with the evolution of the microstructure of the material during irradiation and its physical and mechanical consequences. The second item concerns the cumulative effects of simultaneous multi-irradiation.

For fusion applications, few research axes have been yet selected:

– The study of the evolution of the microstructure of model materials (ultra pure Fe, Fe–C and Fe–Cr alloys, silicon carbide).
– The experimental validation of kinetic Monte Carlo and chemical kinetics modelling approaches based on dual irradiation of diluted ferritic alloys.

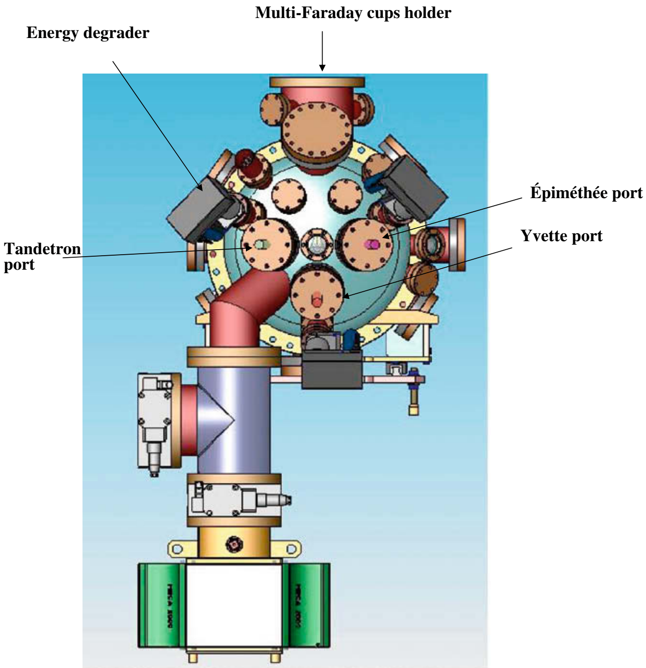

Fig. 4. Schematic front-view of the triple beam vacuum chamber installed at CEA Saclay.

– The combined effects of damage accumulation/helium incorporation/hydrogen incorporation on ferritic alloys and silicon carbide.

6. Conclusion

The multi-irradiation facility JANNUS includes first a triple beam facility at CEA Saclay and second a dual beam system coupled to a new 200 kV TEM at CNRS–CSNSM Orsay. A scientific committee and a program committee will be in charge of the planning management. The TEM/dual beam facility at Orsay will start its exploitation during the third quarter of 2008. The Saclay dual beam facility should be ready to operate at the beginning of the fourth quarter of 2008. The starting of the triple beam at Saclay is scheduled at the end of 2009.

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