Author:

Marcello Vecchi

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Presentation and future strategy concerning the project of the intense neutron source based on the principle of muon catalyzation suitable for the study of the material behaviour of the first wall of the fusion-reactors

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Introduction

The financing approval regarding the project Iter, enacted in spring 2005 by the "Fusion Scientific

Community" (subsequently called FSC), and the selection of the site Cadarache, give back priority also to the project of the intense neutron source for the characterization and the study of the behaviour of the structural materials which are exposed to neutron irradiation and set around the first wall of every fusion reactor.

In fact, also in the Iter-reactor, the first wall is irradiated by neutron flux with energy of 14 MeV and loads of 1 Mw/m2, unusual for the high values compared to the current consolidate nuclear technology.

These neutrons with their effects on steels, especially with the creation of vacancies, helium (from neutrons with a formation peak corresponding to an energy of neutrons of 14 MeV) and of hydrogen (from protons), weaken the carrying structures of the first wall with a real risk of a collapse in short time, in comparison to the estimated life of a fusion reactor.

No currently working irradiation machine or nuclear reactor approaches these performances, not even from far.

The necessity of the construction of the intense neutron source is therefore evident and the FSC has chosen since time to develop one based on the principle of the Li-stripping (first 90ies), called IFMIF.

In the period between 1992 and 2000 also ENEA has developed an autonomous project of an intense neutron source based on the principle of muon catalyzation phenomena (μ CF-INS), together with the Paul Scherrer Institute (PSI) CH, Los Alamos USA and Kurchatov Institute and Mucatex Russia. Since 1994, this project was financed also for two years with 500 Keuro by the ISTC program (International Science and Technological Centre) of Moscow and it has asked for an engagement of about 15 men/year for eight years.

ENEA has financed for the aforementioned 8 years 10/15 fellowships/year for Russian professionals, employees in the project in ENEA-Bologna in the Fusion-Department and some other activities in five research centres in Russia, for supporting of the project developed in Bologna, (about 250 Keuro/year for 8 years in total).

Altogether, ENEA's financial intervention can be estimated around 2000 Keuro in total, considering also the employment of ENEA professionals.

Therefore, the task of ENEA has been to play the work of a project leader and to carry out the coordination of the whole project.

The final document "Preliminary design of the intense neutron source based on μ -catalysed fusion for irradiation materials of fusion reactors", document ENEA B 301 N 00030, nowadays is still valid for its structure, contents and the results obtained.

The project had been suspended in 2001 further to uncertainties on the financing of the entire fusion programme from FSC.

Now this project returns to be topical with the reality of the financing of the Iter reactor. It's obvious that if the development of the IFMIF source completely satisfied the needs of the experts regarding the first wall's material characterization, there wouldn't be space and the discourse could be considered closed. On the contrary, IFMIF source is a compromise solution between the feasible

and the desirable and that which absolutely has to be investigated and established, with plenty of uncertainties and grey areas which are in need of a deeper study. It's already enough to think that the energy spectrum of the neutrons produced by the IFMIF source is a Gaussian with a medium value of 14 MeV, but with about 25% of neutrons with an energy over 20 MeV.

It's really difficult to value the impact and their damage of the material, also because of the openendedness of the cross sections of neutrons at these high energies, considering that in the real case there will never be an energy of neutrons higher than 14 MeV.

Strategy

It must be immediately clear that there is no intention to compete with the IFMIF-source, but to act according to two guidelines which seem logical:

1. Suggest to the FSC, together with the other Institutes which have developed with ENEA the μ CF-INS source, to assign a small financing for a project deepening.

The financing focusing on only one source project, considering the complexity and the cost, in fact seems to be a weak point in the fusion program.

Therefore it is considered a financing which doesn't concern the real and proper construction, because the construction of a source of that kind implies a financing on the scale of dozens of millions of euros, but an elaboration of the project, concretely feasible with a financing on the range of about 100-200 keuro/year.

The documents on which this request can be based are the three articles published in Fusion Technology 39, 2001, 2 which present a detailed calculation of the entire project μ CF-INS, in detail /7/, /8/, /9/, the general review of the project, appeared on the article of Hyperfine Interactions 00/1-10-2002, in detail /12/, and finally the document ENEA B 301 N 00030, which presents the whole technical project.

 considering that the two neutron sources are complementary regarding their calculation and their project development, it could be very useful for IFMIF project to refer to the scientific work on the eight years project characterization of the source µCF-INS, and thus benefit from the development of a parallel calculation.

Therefore, there would be offered the possibility that a group of professionals could develop a system of a specific calculations, and play the role of supervisor and support.

In fact, during the eight years of the μ CF-INS project's activity there have been tested more than 50 codes, and finally selected about twenty of them, which represent the develop-base of the μ CF-INS source project; this project is considered reliable because it is based on this qualified work of testing and verifying the results of the calculations, with a constant return and comparison with the experimental supporting data, which have been obtained by experimental programme held mainly in Russia and Italy.

In particular there have to be considered the following special subjects:

Neutron Part

It has been used a code, actually a whole series of Monte Carlo codes (GEANT3, MCNPX, INTERNUCLEAR CASCADE CODE, INR) which represent the best of calculation technology of the Russian and Western codes, and are able to study the phenomena of hadrons production owed to

interactions of low Z atoms (lithium) with deuterons and protons (valid case for both IFMIF and μ CF-INS). This code-chain can consider both low and high energies with appropriate and reliable (regarding engineering) interactions cross sections. In the beginning it has been started the simulation of bullet-deuterons with a proton and a neutron together (for example, in the case of the code HETC), with results showing low reliability, at least compared with the experimental ones achieved at Dubna by Cheplakov (for example, for the production of pions). Unfortunately, at the beginning of 1990 none of the neutron codes had a deuteron channel. Nowadays, as well GEANT3 as MCNPX are equipped with the mentioned channel, but the experience with the interaction phenomena and the nuclear data (interaction cross sections), developed within the project of the μ CF-INS source, remains, indeed, remarkable.

The development of the target

The IFMIF source, as well as the μ CF-INS, have a lay-out with a flowing in a pipe lithium target with an elevate velocity of lithium (order of 10m/s) and an elevate flow (order of litres/sec), due to the heat removal of the beam power (order of 20 MW).

The elevated thermal load on the tube wall (about 60 KW/cm3) and in the lithium (8 KW/cm3) causes a critic dimensioning of the target wall, considering also the critical flow values which should not be over 10 MW/m3 for a fluid like lithium. The component's life is consequently reduced ,with compromises between the component's life, its maintenance and functionality. For example, the target of the only source of neutrons working until today (RTNSII of Los Alamos), had a life of about 200 hours and a robotic system for its replacement and its functionality.

Thus it is needed a lot of experience for the project developing of this component. The codes used for the μ CF-INS source, the old but still valid HEATING9 and ANSYS5.3, in which has been inserted a model of turbulence (coefficient variation of eddy viscosity) more opportune for the functioning conditions of the project, assure a reliable dimensioning, accomplished to specific lithium experimental data based Russian codes (for the determination of the coefficient of heat-exchange with the wall), like the codes VARDIR and LITM of IPPE Obninsk.

Moreover, the participation at a benchmark regarding thermo-fluid dynamics, in which were compared the responses of the several standard problems of several specific thermo-fluid-dynamic codes like FLUENT, STARCD etc. to the ones of ANSYS5.3 modified like above, (the responses of the different codes were in a quite good engineer agreement), allowed to chose the latter code also for the thermo-fluid-dynamic calculation.

Being ANSYS5.3 a code above all structural, the possibility of developing the structural dimensioning starting from the thermal loads with a unique code, is a great advantage.

In the end, a target without window has been projected with the help of the FLOW3D code, which gives excellent results treating properly the thermal calculation of a fluid (the lithium) in presence of a void.

Shielding Part

The shielding from neutrons with an energy of 14 MeV and higher, is not trivial, especially for the reason of the narrow of the spaces around the target and the necessity to operate with a robotic system.

Solenoidic Part

No one in the world has the experimental experience like the one accumulate by ENEA and by PSI regarding solenoid coils with a meter of diameter, with fields of the order of 10 Tesla and nominal flow of 12 KA. One of the supporting codes of this project (MAG3D-WF1) has been inserted into the codes of neutron calculation and of interaction of particles.

Production of Tritium and dosage calculation

The code RAD, developed by the Institute for Nuclear Research, Russian Academy of Sciences, Moscow, assures a rapid calculation, but quite sophisticated and even relatively simple to execute for repetitive (iterative) calculation. The inventory of Tritium can therefore be determined with some credibility, also in the light of experiments made a Moscow.

Technology of Tritium

The calculation confidence with elevated quantity (order of Kg) of Tritium gained in the μ CF-INS source project, is based on the direct experience and the collaboration of ENEA with experts of one of the major range centres in the world: the centre of Arzamas, Sarov.

The concept of the project of intense muon catalyzation source

A beam of deuterons (12mA, 2GeV/d, 24 MW tot) has been focalized on a target of Lithium (flowing Lithium with velocity around 8m/s, in a pipe 1,5 m long and with a diameter of 16 mm) for the optimisation of the production of negative pions. These pions, confined in a converter (length 14 meters, radius 40 cm) by a mirror magnetic field (7 Tesla average and 12 Tesla on the boundaries), decay to muons which are focalized in a synthesizer containing a mixture of D+T of high density (0.08 gr/cm3). The geometry of the synthesizer is that of a double wall sphere and a radius of 10 cm, the mixture velocity of D+T is about 10 m/s, the power deposited by the absorption of the particles (positive and negative pions-muons) of the order of 150 KW. Taking into consideration that the theoretical energetic threshold for producing a pion from a Lithium-d interaction has a value of 0,6 GeV, but that this value for technological applications, like the µCF-INS source, rises to about 12 GeV, considering the muons and pions which escape from the converter or which are absorbed, the production of neutrons of 10 14 n/cm2s around the synthesizer is reached with a good approximation, starting from the beam characteristics of the above mentioned deuterons and from the optimisation of the source's geometry. It is conservatively esteemed that every muon catalyses about 100 fusions before its decay (150 those found experimentally). A volume of about 3 litres is available around the synthesizer for the material tests specimen. In practice around the synthesizer is created a small fusion reactor with the energy of the neutrons exactly of 14 MeV and a neutron flux of about 10 times the value of the first wall of the Iter fusion reactor (4,5 1013 n/cm2s).

This source reaches all the needs of the materials experts for the "ideal" source:

regarding the intensity of the neutron flux;

the gradients;

the material damage value of 10 dpa/year in Fe.

Not even for the materials test specimen volume, 10 litres of request against 3 litres of proposal.

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