SIMULATION TECHNIQUES USING ACCELERATORS TO STUDY REACTOR MATERIALS.

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ABSTRACT

It is unavoidable the use of MTR- Reactors to study material property changes induced by neutron irradiation. But to carry out these studies, it is necessary to have a sofisticated infrastructure due to the complexity of the neutron irradiation parameters and also due to the fact that the irradiated specimens become highly activated. For basic and systematic studies to get a better understanding of the role that the different parameters play in a real neutron irradiation and its effects, some research laboratories have been developed simulation techniques, in which neutron irradiation is replaced by high energy charged particles from accelerators. In this work, we present some of the advantages and limitations of the use of accelerators for the evaluation of reactor materials and also a description of the technique to irradiate high purity Au samples using a Van de Graaff accelerator to study its anomalous thermal annealing behaviour.

INTRODUCTION

Structural components of advanced fission reactors and proposed fusion reactors will be exposed to an intense flux of fast particles that causes changes in their microscopic structure leading to macroscopic effects such as embrittlement , swelling , void formation , irradiation-induced creep , changes on phase stability , etc. which can impact on the safety and economy of these nuclear energy systems. Therefore it is necessary a comprehensive understanding of the basic process of the radiation damage effects for the development of adequated radiation resistant materials.

The observed radiation effects are due to the interactions of the energetic particles and the lattice atoms of the material which lead to Frenkel defects formation which interact among them and with crystal defects (dislocations , precipitations, grain boundaries, impurities, precipitates, etc). The other main effect is the formation of foreign elements (H, He, etc.) , produced by nuclear reactions ; from these , He causes embrittlement of metals and alloys. This effect will be more important in the first wall of the fusion reactors which will be working under the impact of fast neutrons and at high temperatures.

For the basic and systematic study of neutron radiation damage a variety of methods , such as computer simulation and simulation experiments using energetic heavy and light ions from accelerators , are being used. In what follows, the simulation technique using accelerators will be presented , together with its advantages and limitations in its use. Furthermore , a description of using a Van de graaff accelerator to irradiate Au samples will be presented.

IRRADIATION WITH MTR-REACTORS AND ACCELERATORS.

To evaluate reactor material properties changes induced by neutron irradiation , there are mainly two experimental ways to do it; using irradiation with neutrons in MTR-reactors or by simulation techniques with energetic charged particles from accelerators.

For basic and systematic studies irradiations in a test reactor such as the fast material reactor EBR II is not adequated because of its low displacement rate of de order of 10^{-6} dpa/sec. (displacement per atom per second) in comparison to Ni ions of 5 Mev from electrostatic accelerator with a high damage rate of 10^{-1} dpa/sec, or with Protons of 7 Mev from cyclotron that produce displacement rates of around 10^{-5} dpa/sec ,which leads irradiations in MTR-reactors for long periods of time to obtain effects in the range of the sensitivity of the measurement equipments. Fig. 1, shows the displacement rate of neutrons and charged particles in Ni.

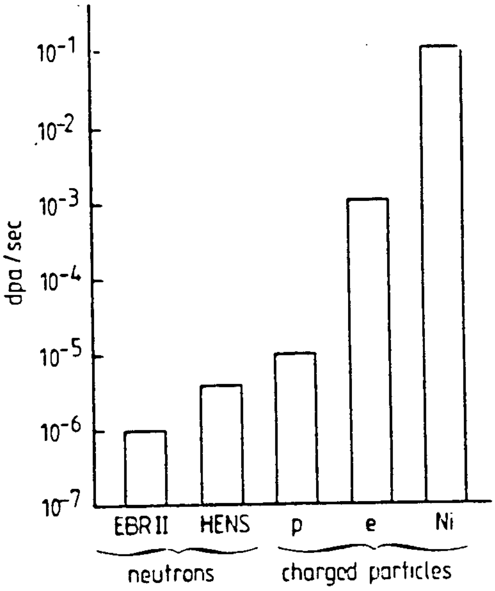

Fig. 1.- Atomic Displacement rates (dpa/sec) in a Niquel Matrix with neutrons and diferent particles. EBR II: Experimental Breeder Reactor II , HENS : High Energy Neutron Source [1]

Besides that , irradiation with neutrons is expensive and difficult to perform and produces specimens highly radioactive that can be handle only in sofisticated hot cells. Additionally, during neutron irradiations several induced-effects are simultanously produced , bringing in this way difficulties to the specific analysis of the experimental results. Another point to be considered in the irradiation with neutrons and charged particles is the penetration range of the particles.Neutrons of 1 Mev have in metals much greater range than charged particles. Penetration ranges of heavy and light ions , in metals , are shown in Fig.2 in which the range of Ni - ions, p,d, and alpha- particles in a Niquel matrix are given as a function of their energy .

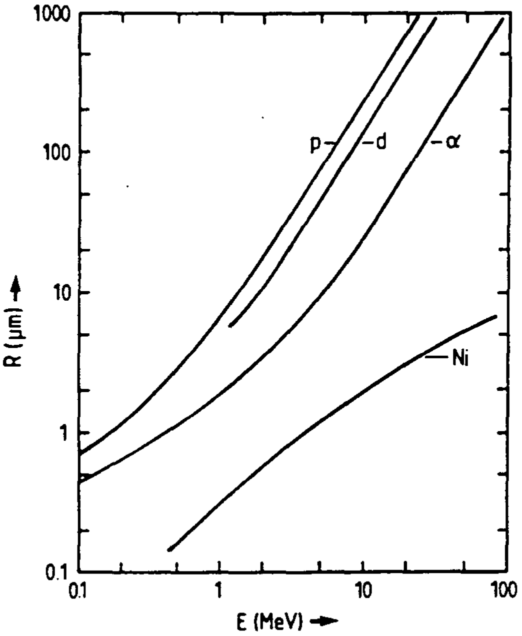

Fig.2 Penetration Range of charged particles in a Ni-matrix. [2]

With heavy ions , doses of the order of 100 dpa can be obtained in short periods of time , but their range is only of a few μm , suitable only for TEM observation of surface radiation-induce microstructure changes such as voids, precipitates , etc.

Light ions (p,d, α) from compact cyclotrons , (10 to 30 Mev), can reach an adequate penetration range and also a homogenous damage production in metals, suitable for mechanical test.But due to their low damage rates , they can only produce few dpa in a reasonable time. The gas He is produced by (n,α) - reactions in MTR- reactors at such low rates that to reach a concentration of 10 ppm it will take more than a year of irradiation ; but using α - particle implantation to reach such concentartion.it will take only 10 minutes.

Further advantages in using light ions are the easy access to the experimental system , low activations of the irradiated samples and the reliable control and monitoring of the experimental parameters such as : dose rate , temperature , sample environment,etc.

Since up to now there is not an operating fusion reactor facility , simulation techniques are the only useful experimental mean to test first wall and blanket materials for future fusion reactors.In other cases, reactor irradiations are unavoilable since reactor components have to be allways tested under real conditions.[3].

To illustrate the use of accelerators in materials reaserch , we describe the experimental set-up to irradiate with electrons and at low temperature , pure gold samples to study its anomalous anneling behaviour ,using a Van de Graaff accelerator.

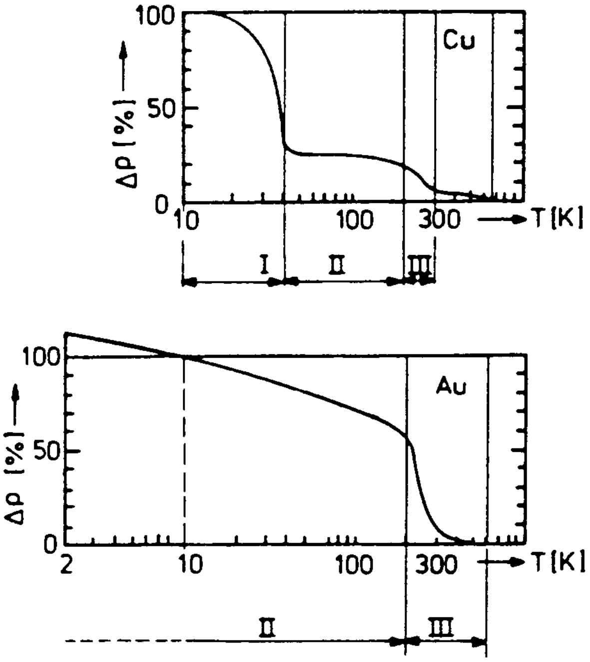

Fig.3.- Anneling behaviour of the electrical resistivity
of Cu and Au. [4]

It is well stablished that most of the fcc- metals have a similar thermal anneling behaviour. .Fig.3 shows the anneling of the electrical resistivity,which measure the defect concentration, of Cu and Au .In the case of Cu the mean feature is the stage I in which , after termal activation , the interstitials start to move and most of them recombine with close vacancies and , the rest of the interstitials some react among them to form small clusters and the other ones are traped by foreign atoms. All this process produce a well define drop of the electrical resistivity. In Stage II the small interstitials clusters grow up forming small interstitial loops at the end of the stage .Stage III which is characterize by vacancy migration , some of these vacancies annihilate at interstitial clusters and the others form vacancy agglomerations that, at the end of this stage , survive together with larger intersticial loops.[5].

In Au the main diference is the absence of stage I when compared with other fcc-metals.With the possibility that single instertitials could be moving and recombining with vacancies or forming agglomerates at helium temperature (4.2 K) as we can deduce from the anneling curve of Au in fig.3, it was proposed to irradiate pure Au samples under special irradiation conditions , to be analized with very sensible methods such as difuse x-ray scattering which is able to detect single interstitials , with the aim to clarify the thermal anneling abnormality of this metal. In what follows , only the irradiation system and quality of the samples are presented.

High purity gold single crystals samples (for x-ray measurements) and polycrystals (for electrical resistivity measurements)of the same purity were irradiated with electrons at 4.2 K , using a Van de Graaff accelerator at the KFA-Jülich low temperature irradiation facility [4].
In the irradiation system, both single and polyicrystal specimens were mounted in a holder set inside a cryostat which was assembled at the end of the beam line$_2$ of a Van de Graaff to be irradiated with electrons of 3 Mev 'and current density of 5 μA/cm^2 . In order to avoid the

mobility of the Frankel defects during irradiation, the samples were immersed in a flux of liquid Helium, inside the cryostat, keeping the sample environment at 5K. The temperature of the cooling system was monitored by means of a thermistor ; the defect concentration was determined by electrical resistivity measurements in the polycrystal specimens and, the irradiation doses were measured by a Faraday cup, set behind the samples. All these monitoring and control were possible due to the easy access around the irradiation system. and around the accelerator.

ADVANTAGES AND LIMITATIONS IN USING ACCELERATORS IN REACTOR MATERIAL RESEARCH

After presenting the main feature of the simulation techniques using charged particles from acceleretors in comparison with reactor irradiation, we can summarize the most important advantages and limitations of this technique in the following items :

-The use of accelerators for reactor materials reserch is less expensive and time saving when compared with reactor irradiations.

- Accelerator beam lines offer an easy access to the irradiation equipment so that experimental parameters such as temperature, dose rate, strain resolution, etc, can be reliably monitored and controlled.

- Light - ions accelerators (compact cyclotrons) can produce damage rates higher than in MTR- reactors but it is only possible to obtain few dpa with light ions in a reasonable time.

- With charged particles it is possible to obtain homogeneous radiaton damage in specimens with thickness of about 100 μm, which is greater than the thickness limit of 25 μm required for mechanical tests.

- After accelererator irradiations the samples finish with almost no radioactivity, so that they are safe to handle for their post-irradiation evaluation.

- Since up to now there is not available a reactor test facility for fusion materials reseach, accelerators remain as an usefull technological alternative to carry out these tasks.On the other hand, for advanced fission reactors materials development, the use of accelerators can be considered as an efficient and reliable experimental technique to complement reactor irradiations.At a long range, these reactor irradiations are an absolute necessity to evaluate reactor components in realistic environmental conditions.

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