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Irradiation Effects in Candidate Materials for the SNQ-Target Station

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Abstract

Based on calculations of the expected kind and amount of radiation damage for heavily loaded SNQ-target wheel components, an irradiation program for promising candidate materials is presented. It includes simulation experiments, neutron irradiations and various proton irradiation experiments. Typical examples are discussed in detail with the emphasis on medium energy - high current proton irradiation experiments to be performed at the LAMPF-accelerator.

1. Introduction and calculated radiation damage

In order to achieve a reliable operation of the SNQ-target wheel during its 12.000 h lifetime, a sufficient stability of the used materials against radiation damage effects is needed. Fig. 1 shows the most heavily loaded components from irradiations point of view.

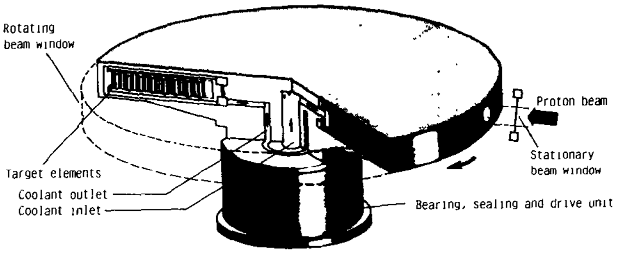

Fig. 1 SNQ-target wheel components exposed to intensive proton and neutron irradiation.

The amount of the expected radiation damage has been calculated by usual methods (Lohmann, 1981) in terms of displacement damage rates and He-/H-production rates for a variety of materials. The underlying assumptions are:

- proton beam energy 1100 MeV, time-averaged beam current 5 mA, characterizing the worst case,
- applicability of known 800 MeV-proton damage parameters to the 1100 MeV case,
- possibility of the evaluation of unknown proton damage parameters by linear extrapolation from the known data base,
- neglectability of neutron damage contributions for the stationary proton beam window (Coulter, 1977).

Results from these and other considerations are compiled in Tab. 1, indicating the supposed problem areas, too.

Component	Material	$\dot{S}$ (dpa/day)	P_{He} (appm/day	P_H (appm/day)	Main problem(s) under irradiation
Stationary beam window	SAP	0.2	60	260	He-embrittlement, high-cycle fatigue
	HM-based metallic glasses	1.9	170	1190	He/H-effects, thermal stability, high-cycle fatigue
Rotating beam window and target element cladding	AlMgSi, AlMg	0.01	0.6	1.6	fatigue, swelling, creep He-embrittlement
	Zry-2	0.02	0.7	4.5	H-effects, creep, fatigue, swelling, He-embrittlement
Target material	Pb	~ 0.02	~ 0.9	~ 7.8	gas production, swelling
	W	0.02	0.9	7.8	OBTT, He-embrittlement, fatigue
	U^{238}	0.3	0.7	6.1	dimensional stability, fatigue, anisotropic growth, He-effects
Slide ring sealing	SiC,WC,C	n- fluences up to 10^{20} n/cm^2 (> 0.1 MeV)			dimensional stability, friction coefficient
Coolant	H_2O	P_{H_2} = 110 g / h			radiolysis effects, enhanced corrosion

Tab. 1 Calculated radiation damage for various SNQ-target wheel components and expected main materials problems.

Inspection of Tab. 1 reveals the highest damage rates - exceeding even those of fusion reactor devices by orders of magnitude - for the stationary proton beam window. This component is hence considered as a desirable, but not imperatively needed part for the SNQ-target station. Promising materials are SAP (sintered aluminium product, Al-matrix + 7 % Al_2O_3), offering sufficient strength up to 400°C and the ability of accomodating high amounts of both He and H without drastic degradation of its mechanical properties (Krautwasser, 1983), and metallic glasses with high thermal stability like $Nb_{40}Ni_{60}$ being insensitive at least to displacement damage intrinsically (Lohmann, 1982).

Much lower damage rates can be seen for all rotating components, demonstrating thus the advantages of the rotating target wheel concept. Useful materials for the rotating proton beam window, the target wheel structure and the target element cladding are Al-alloys and - if needed from temperature conditions - Zircaloy-2. The choice of the target material itself is mainly determined by neutron yield considerations leading therefore to either Pb or W for non-fissile materials or to depleted U (Krautwasser, 1983) including fast fission contributions to the total neutron yield.

The concern in the case of the slide ring materials is the applicability of conventional (WC, C) and improved (SiC, C) combinations under SNQ-conditions (temperature, n-fluence).

As the proton beam penetrates the cooling water, the effects of water radiolysis possibly leading to enhanced corrosion of structural components have to be investigated, too, together with the development of suitable water conditioning techniques.

In general, a strong necessity for extensive irradiation tests is felt for all materials and components discussed above.

2. SNQ materials irradiation program

The basic idea of the SNQ materials irradiation program is to match both with the expected irradiation effects (cf. Tab. 1) and with the availability of existing irradiation facilities. A staged proceeding has therefore been chosen, summarized in Tab. 2.

This program includes a variety of experiments of different kinds ranging from small-scale simulation tests using KFA-facilities over more complex fast neutron and spallation neutron irradiations to experimental conditions under 800 MeV-p-irradiation being close to the real SNQ operating conditions; the latter investigations are hence basically considered as a proof test of certain SNQ-components up to a complete target wheel. A special advantage of this procedure should be mentioned: each program stage introduces more complicated irradiation and thermomechanical loading conditions, offering thus the possibility to proceed from simple irradiation effects (e.g. He- or p-effects only) to the complex SNQ-environment ultimetely.

In order to illustrate the SNQ materials irradiation program, some typical examples and experiments will be discussed below.

Irradiation type	Location	Purpose	Experiment type	Status
28 MeV - α	KFA-IFF (cyclotron)	Simulation of He-effects by α-implantation	- Post-irradiation test - in situ-thermal fatigue (designed)	- Current experiments for Al, SAP, metallic glasses - Planned for 1984
24 MeV - p	KFA-IFF (cyclotron)	Simulation of water radiolysis	in situ-tests on a closed water system	Planned for 1984
Fast n	Reactors: KFA-ZFR, HFR Petten	- Basic data for n-irradiated materials and components - compatibility of p- and n-damage data	Post-irradiation test	Planned after fall, 1983 for SiC, WC, C and W, U
Spallation n, mixed n/p-spectrum	LAMPF beam stop area	Proof test under realistic conditions	Post-irradiation test (SNQ-0, SNQ-SM-1/2)	Current experiments for Al and SiC/C
800 MeV - p	LAMPF beam stop area	- p-irradiation effects in SNQ candidate materials	- Post-irradiation test (SNQ-Ia/b) - in situ-thermal fatigue (SNQ-II)	Approved experiments for 1984 (Al, SAP, metallic glasses
		- Water radiolysis effects	in situ-measurement and conditioning	To be attached at SNQ-Ia
		- Proof test of a complete small target wheel under realistic conditions	in situ- and post-irradiation test (TRLA)	Proposed for 1985

Tab. 2 Survey over the SNQ materials irradiations program.

3. Examples of experiments from the SNQ materials irradiations program

3.1 Neutron irradiation experiments on W

W is one of the non-fissile target material candidates for SNQ. Whereas no major problems are seen concerning thermomechanical load and irradiation effects like swelling or change of mechanical properties (Bauer, 1981), at least one special irradiation effect remains to be investigated: the irradiation-induced shift of the ductile-to-brittle-transition-temperature (DBTT) as depicted in Fig. 2.

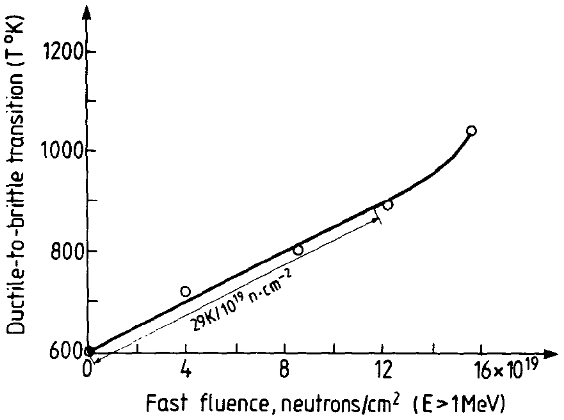

Fig. 2 Ductile-to-brittle transition of polycrystalline, recrystallized W as a function of the fast neutron fluence (Younger, 1970). The results are based on postexposure tests on samples preirradiated at about 395 K.

A distinct materials deterioration must be expected, if the DBTT is higher than or similar to the SNQ operating temperature, leading thus to either operation within the brittle range or - even worse - to a periodical thermal cycling over the DBTT during each wheel revolution.

The ongoing experiments are intended to generate data on the DBTT-increase rate and on mechanical properties of irradiated material. They include fast neutron preirradiations at SNQ-typical temperatures and fluences (350-400°C, $< 1 \times 10^{21}$ n/cm^2, E > 1 MeV) and corresponding post-irradiation tests. The materials to be investigated are pure W, W-10Re and W-26Re (both with an intrinsically low DBTT) and the sintered alloy Densimet 18. Promising materials from this screening experiments will be selected for more specific irradiation tests like TRLA (cf. Tab. 2).

3.2 Proton irradiation experiments

All proton irradiation experiments will be performed at the LAMPF-beam stop area, where a 800 MeV/$\leq$ 1 mA proton beam is available.

3.2.1 Static irradiation experiments

A set of suitable irradiation capsules (SNQ-Ia, -Ib) has been developped and is schematically shown in Fig. 3.

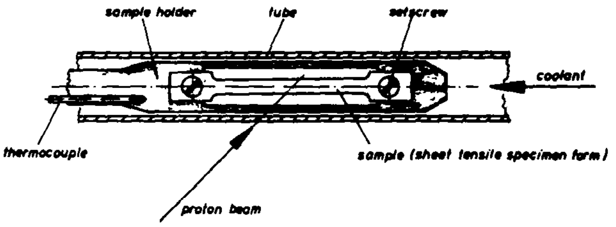

Fig. 3 Schematic sketch of the SNQ-Ia-, -Ib-experiments for static proton irradiations.

Capsule SNQ-Ia has an Al-structure and is dedicated to the irradiation of Al-alloys (cf. Tab. 1) at about 100°C to SNQ-relevant fluences. As can be seen in Fig. 4, it consists of 9 sample tubes at 4 different beam positions, providing thus also information on the dose dependence. Each sample tube contains a stack of 8 sheet tensile specimens, which are surface cooled by water.

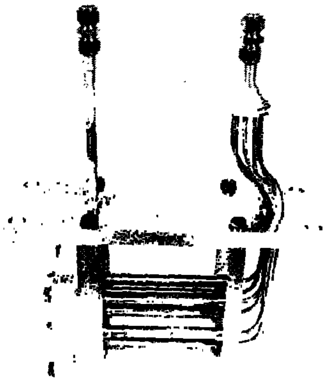

Fig. 4 Capsule SNQ-Ia for static proton irradiation experiments at temperatures up to 150°C.

Capsule SNQ-Ib has a stainless steel structure and will hence be used for irradiations at elevated temperatures (up to 500°C) on beam window candidate materials (cf. Tab. 1) like SAP or metallic glasses ($Nb_{40}Ni_{60}$) and also on promising W-alloys (cf. 3.1). The general design (Fig. 5) is similar to SNQ-Ia with the exceptions of only 3 sample tubes and a He-gas surface cooling of the samples.

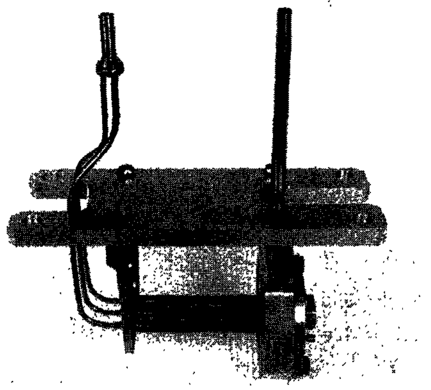

Fig. 5 Capsule SNQ-Ib for static proton irradiation experiments at elevated temperatures (≤ 500°C).

The envisaged data analysis for these experiments will be described under 3.2.3.

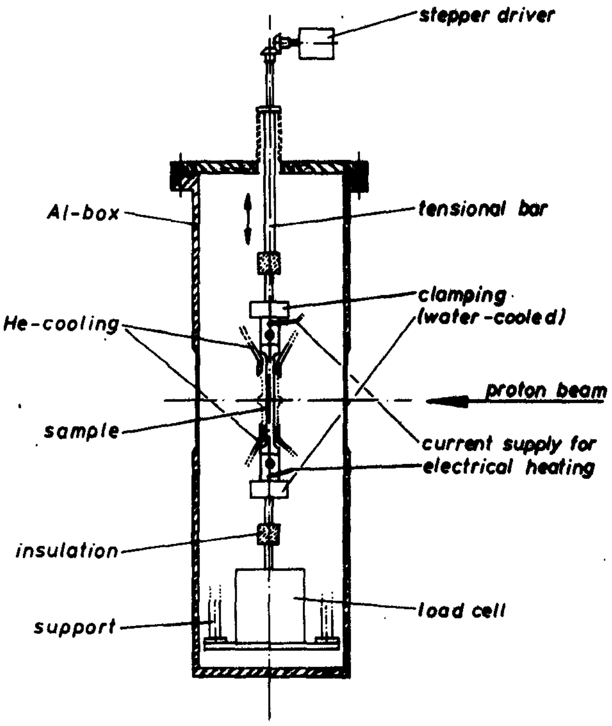

Fig. 6 Schematic sketch of the in situ-thermal fatigue experiment SNQ-II.

3.2.2 In situ-thermal fatigue experiment

In situ-thermal fatigue tests are of special importance because of observed synergistic effects of mechanical stress and irradiation (Sommer, 1983). This holds for all rotating parts of the target wheel, which are periodically hit by the proton beam (cf. Fig. 1). An apparatus for corresponding investigations without irradiation is operating at KFA, from which the design for the capsule SNQ-II has been derived. Fig. 6 shows the basic layout of SNQ-II.

The sample - again with sheet tensile geometry - is mechanically prestressed in tension and periodically heated up by a pulsed dc-current through its gauge length. Variation of both the mechanical prestress via the movable upper clamp and the electrical heating power input allows the determination of the materials thermal fatigue characteristic under mean stress-control. In order to get a rapid cooling-down after each heating pulse, the specimen is intensively cooled by He-gas on its surface and by edge-cooling in the water-cooled clamps. Sample temperature measurement is achieved mainly be resistance measurement of the gauge length. Materials to be investigated are primarily Al-alloys (cf. Tab. 1) close to SNQ-conditions, i.e. at a mean temperature of about 100°C and a ΔT of 24°C per heating pulse. Capsule SNQ-II allows the simultaneous operation of two specimens with independently variable parameters.

3.2.3 Data analysis for the foil specimen experiments

There will be a joint data analysis for the specimens of SNQ-I and SNQ-II. A preliminary compilation of the planned post-irradiation investigations is given in Tab. 3.

Analysis	Al-alloys	SAP W-alloys	Metallic glasses
Yield Stress	x	x	x
Flow Stress	x	x	x
Uniform and fracture strain	x	x	x
Ultimate tensile stress	x	x	x
Fracture characterization by scanning electron microscopy	x	x	x
Metallography	x	x	x
Microhardness	x	x	x
Microstructure characterization by transmission electron microscopy	x	x	x
Thermal fatigue (in-situ at SNQ-II)	x	-	-
Chemical analysis	x	x	x
Thermal conductivity	x	x	x
Crystallization temperature by differential thermal analysis	-	-	x

Tab. 3 Data analysis for the experiments SNQ-I and SNQ-II.

3.2.4 Test wheel experiment TRLA

In order to match the SNQ operating conditions as best as possible, a proof test of a complete small SNQ-target wheel TRLA (Testrad Los Alamos) is indicated as the ultimate goal of the irradiation experiments. The possible TRLA-design is shown in Fig. 7.

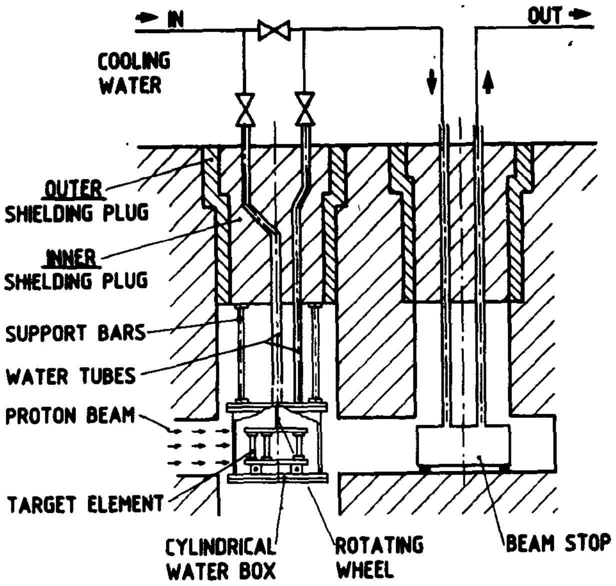

Fig. 7 Schematic sketch of the proposed test wheel experiment TRLA.

TRLA consists basically of a rotating target element structure within a cylindrical water-cooled box suspending from a shielding plug. Being mainly a materials test experiment, a total of 180 test pins will be inserted, subdived into Pb-, W- and U-sectors. Each sector contains different combinations of the target material alloy, the cladding material alloy and - if needed - an intermediate bonding layer. Provisions will be made to withdraw single target elements for inspection purposes. Essential engineering aspects like the test of the slide ring sealing and the driving water turbine as well as temperature measurements within certain target elements will also be covered by TRLA.

To guarantee a safe operation without major impact on the LAMPF operation in general, the TRLA experiment is located in front of the usual beam stop, offering thus the possibility to pull the whole experiment out of the proton beam area in case of a failure without a need for a shut-down of the accelerator, because there is a series connection of the cooling systems for both TRLA and the beam stop.

4. References

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