Material: Ferritic Steel: F82H
Property: T (˚C) versus Irradiation Shift, Ke (MPa*sqrt(m))
Condition: irradiated
Data: Experimental

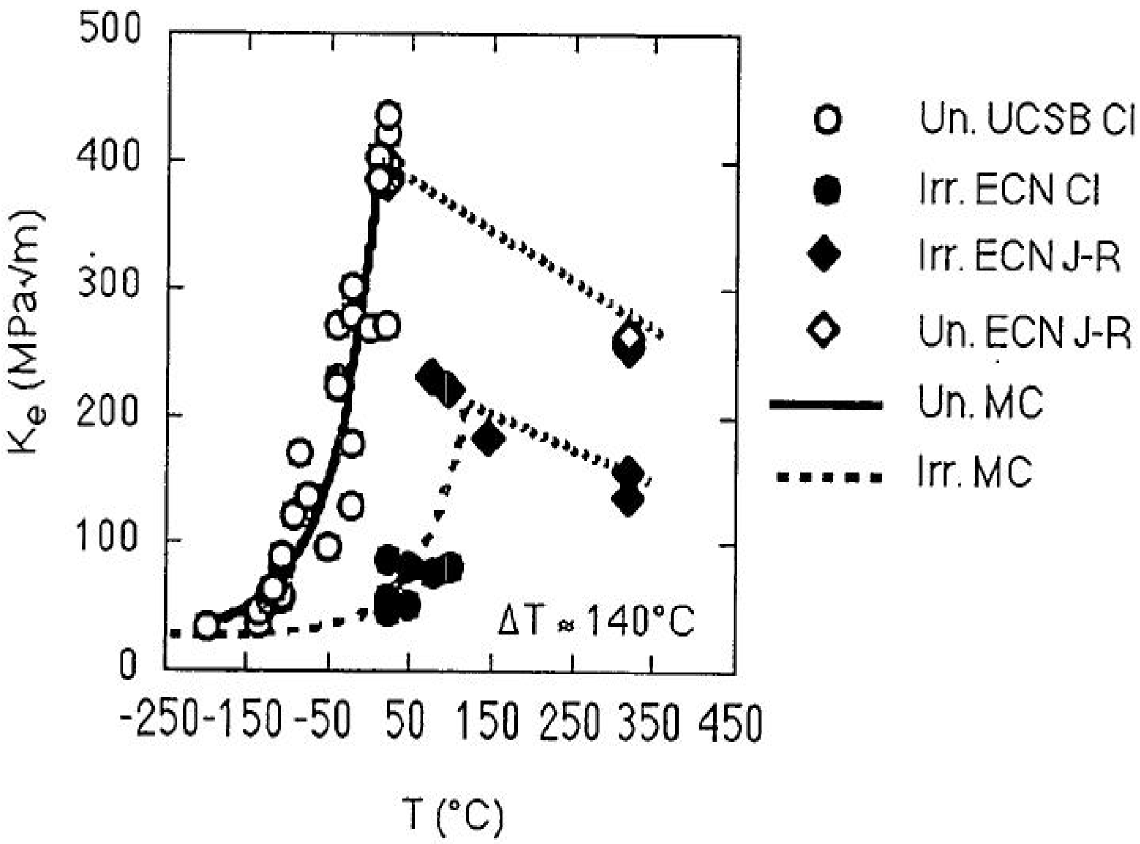


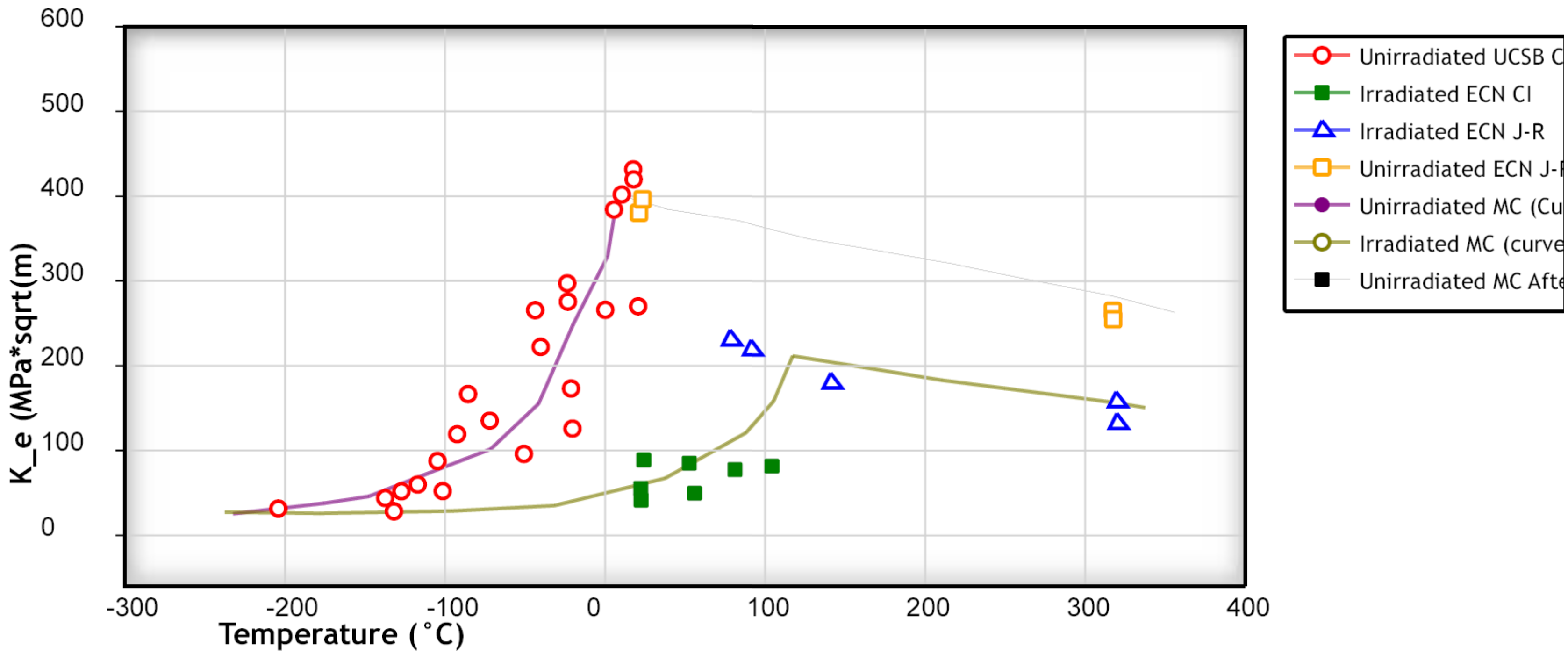
Fig. 6: Irradiation shift for F82H steel, 2.5 dpa and T_{irr} =573K

Source:
Fusion Materials Semiannual Progress Report, 25, 1998, 119-124

Title of paper (or report) this figure appeared in:
Mechanical Properties of Two 7-9Cr Ferritic/Martensitic Steels

Author of paper or graph:
G.R. Odette, G.E. Lucas, P. Spatig

Caption:
Irradiation shift for F82H steel, 2.5 dpa and T_irr = 573K (delta(T) = 140°C)



Irradiation shift for F82H steel, 2.5 dpa and T_irr = 573K (delta(T) = 140°C)

Reference:

Author: *G.R. Odette, G.E. Lucas, P. Spatig*

Title: *Mechanical Properties of Two 7-9Cr Ferritic/Martensitic Steels*

Source: *Fusion Materials Semiannual Progress Report, 1998, Volume 25, Page 119-124,* [PDF]

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Plot Format:

Y-Scale: ◉ linear ○ log ○ ln

X-Scale: ◉ linear ○ log ○ ln

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MECHANICAL PROPERTIES OF TWO 7-9CR FERRITIC/MARTENSITIC STEELS

G. R. Odette, G. E. Lucas and P. Spätig (University California, Santa Barbara)

OBJECTIVE

The objective of this work is to generate a data base in support of developing fracture assessment methods of fusion structures comprised of ferritic/martensitic steels.

SUMMARY

Tensile and fracture tests were performed on two ferritic/martensitic stainless steels. The temperature dependence of the yield stress and the thermal stress dependence of the activation volume were found to be in good agreement with a model based on the propagation of double kinks on screw dislocation segments. Effective fracture toughness-temperature curves were developed for two specimen sizes, and a constraint correction based on a critical stress ($\tilde{\sigma}$) - critical area ($\tilde{A}$) model was found to rationlaize the diffrences. The status of the Master Curve Experiment is discussed.

PROGRESS AND STATUS

Introduction

Design and operation of fusion reactor structures will require appropriate data compilations and advanced integrity assessment methods in order to safely and effectively manage irradiation embrittlement without undue conservatism. The data will largely come from a limited number of tests on small specimens, compatible with both available irradiation volumes and the practical constraints of time and resources. A method has been proposed based on the concept of a set of master toughness-temperature curves, $K_e(T)$, which are indexed by temperature shifts (ΔT) that efficiently account for the effects of strain rate, irradiation, specimen/component size and geometry [1]. The MC-ΔT method not only directly links to specifying engineering design and operation limits, but is also compatible with the more fundamental micromechanics-, and ultimately microstructure-, based understanding and predictive models. Indeed, such connections are required for the effective use of small specimens and tractable irradiation programs. This work is part of an ongoing study to develop constitutive relations and effective toughness-temperature data in support of developing an MC-ΔT approach for ferritic/martensitic steels.

Materials

Two normalized and tempered martensitic steels were investigated. The first one is a reduced activation, tungsten-stabilized steel (Fe-7.65Cr-2.0W-0.1C-0.18V-0.04Ta) being studied as part of an International Energy Agency (IEA) program. The second alloy is a modified vanadium and niobium-stabilized steel, close to the T91 designation (Fe-8.26Cr-0.1C-0.95Mo-0.2V-0.075N). The heat treatment of these two steels was:

i) 0.5h at 1313K for normalization and 2h at 1013K for tempering (IEA)
ii) 2.5h at 1343K for normalization and for 4.75h at 1038K for tempering (T91)

Tensile tests

Tensile properties have been studied over the temperature range 77K - 293K. For the IEA steel, the tensile tests were performed on round specimens (3mm diameter, 18 mm gauge length) and on small flat tensile specimens for the T91 steel (0.5 mm thick and 9 mm gauge length). This study focuses on the temperature and strain rate dependence of the yield stress, as part of an overall effort to develop rigorous constitutive models for ferritic-martensitic steels.

Like other bcc metals and alloys, these steels exhibit a strong temperature and strain rate dependence of the yield stress associated with thermally activated dislocation slip. Baseline tests were carried out over a wide range of temperatures at a strain rate of 2×10^{-4} s^{-1}. The constant strain rate tests were supplemented by strain rate jump tests described elsewhere [2]. Figure 1 shows the temperature dependence of the yield stress for both steels where previous data for IEA steel of Spätig *et al.* (1998) [3] at high temperature have been included. Figure 2 gives an example of a strain rate jump test. The analysis involves decomposition of the yield stress into thermal, σ^*, and athermal components. The thermal component is described by a Arrhenius–type equation with a temperature independent pre-exponential term and an exponential argument that contains a temperature dependent activation energy term minus a stress times activation volume term, V. The activation volumes were measured from the strain rate jump tests and the activation energy of the rate controlling dislocation slip process was deduced from the activation volumes. The temperature dependence of the yield stress and the thermal stress dependence of the activation volume were compared with the model of Dorn and Rajnak [4]. This model is based upon the nucleation and propagation of double kinks on screw dislocation segments. Figures 3 and 4 show the temperature dependence of σ^* and the thermal stress dependence of V in dimensionless units, respectively. Here, σ_p is the Peierls stress and $2U_k$ is the thermal activation energy for nucleating a pair of kinks at T_c. A good agreement between the experimental data and the model has been found up to about 200K for both steels. At temperatures above 200K, it is found that the plastic flow cannot be described in terms of a single rate controlling process, since other mechanisms become operative.

Fracture tests

The effective fracture toughness K_e was measured for the T91 steel as a function of temperature T with fatigue pre-cracked compact tension specimens. Figure 5a shows the experimental $K_e(T)$ curve for this alloy. Six 0.2T specimens at each temperature of 148K, 168K and 188K and six 0.5T specimens at 198K were tested to characterize the intrinsic scatter of toughness data in the transition region. An additional nine 0.2T tests were carried out over a range of temperatures from the lower shelf to lower knee region. All specimens failed by quasi-cleavage, in some cases after a large amount of plastic deformation. Indeed, the effective toughness measured with 0.2T specimens at 198K is higher than that obtained with the 0.5T specimens, illustrating the effect of constraint loss assoicated with large scale yielding, *i.e.* when the plastic zone at the crack tip is no longer small with respect to the specimen dimensions [5]. However, the K_e values obtained with small specimens can be adjusted to those which would be measured in small scale yielding by application of correction factors, $K_{ssy} = CFK_e$, where $CF = (J/J_{ssy})^{1/2}$ derived from finite element method simulations [6] of crack tips fields and by using a critical stress, $\tilde{\sigma}$, critically stressed area, $\tilde{A}$, local fracture criterion. The ratio is the J required to produce the same $\tilde{\sigma}/\tilde{A}$ as the corresponding small scale yielding J, J_{ssy}. The corrected data are presented on Figure 5b.

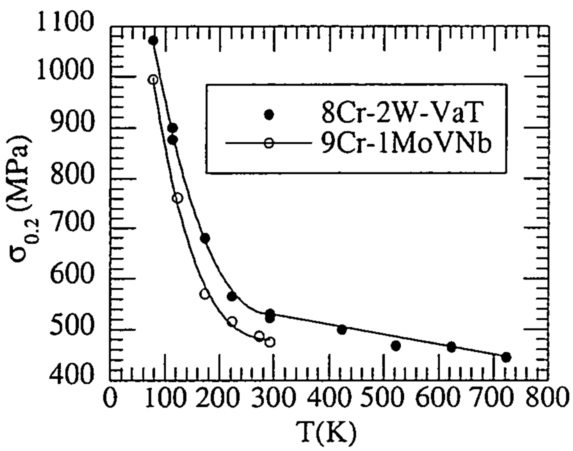

Fig. 1: Temperature dependence of the yield stress

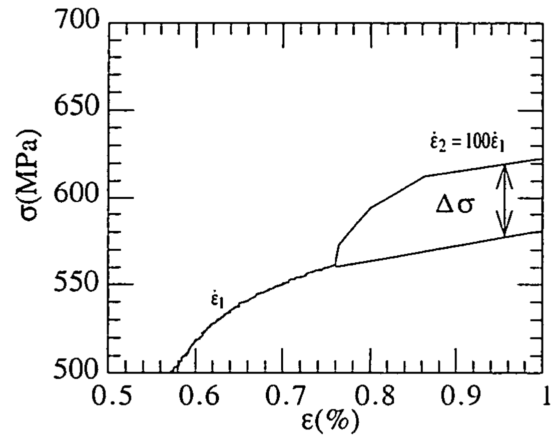

Fig.2: Example of strain rate jump at 223K at the yield stress, IEA steel

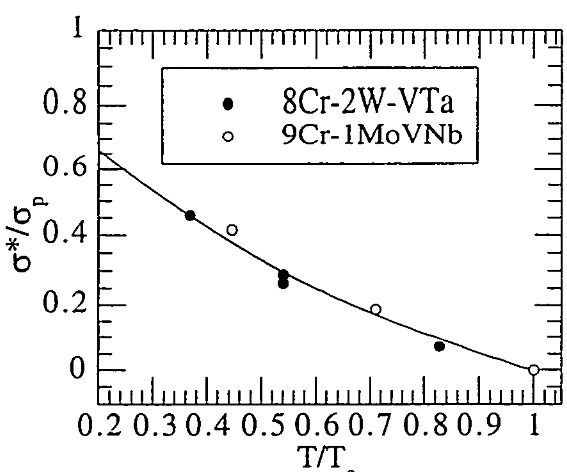

Fig. 3: Temperature dependence of the thermal stress

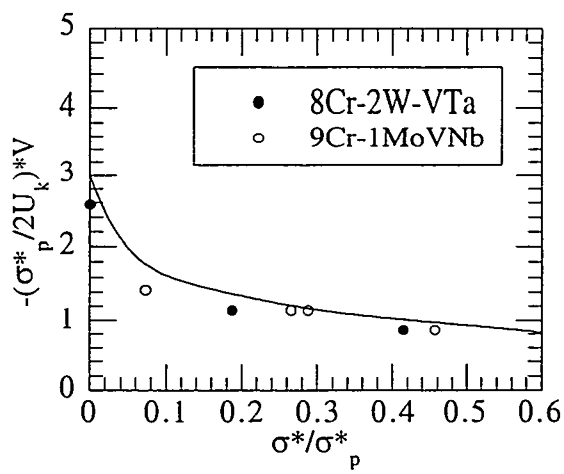

Fig. 4: Thermal stress dependence of the activation volume

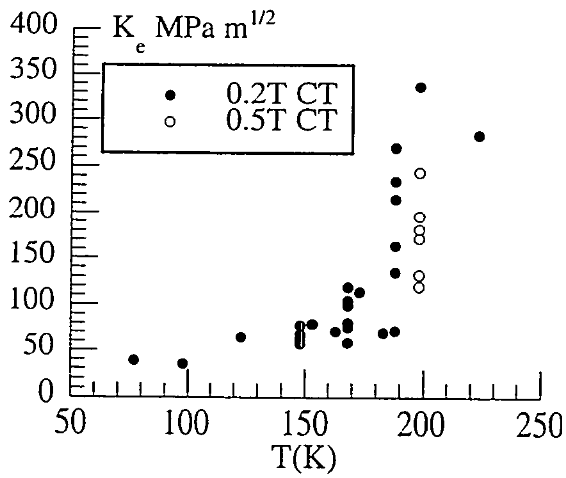

Fig. 5a: Temperature-dependent fracture toughness for T91 steel

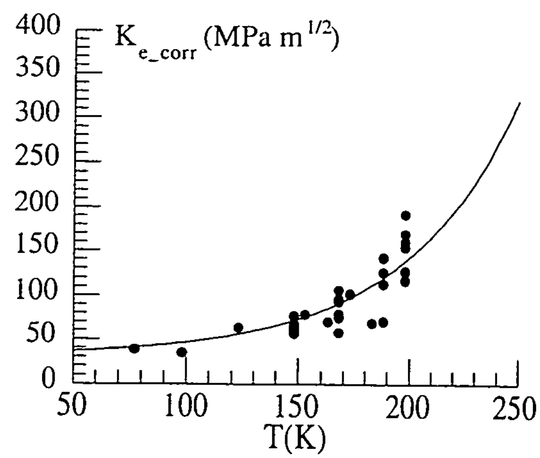

Fig. 5b: Constraint corrected fracture toughness data for T91 steel

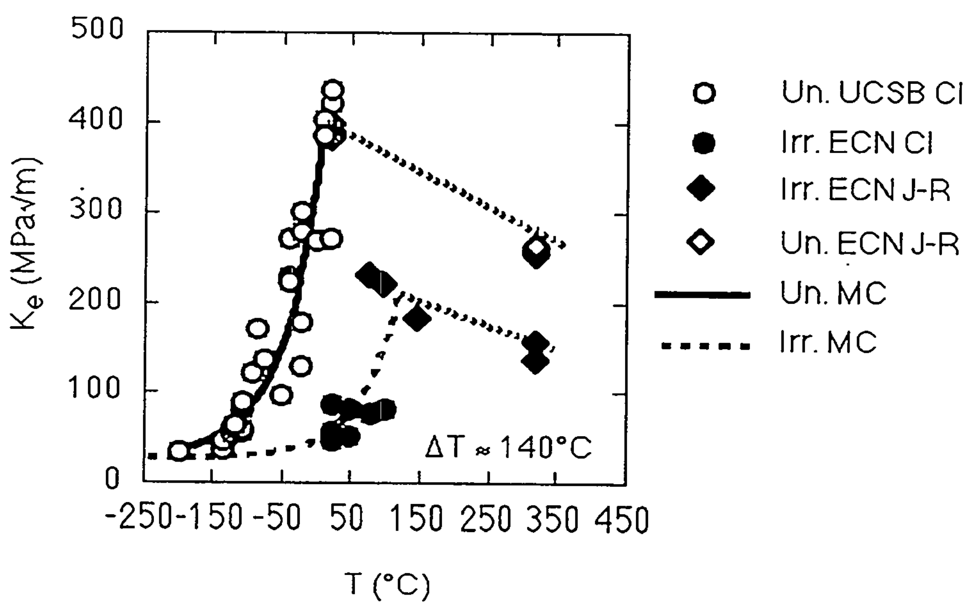

Fig. 6: Irradiation shift for F82H steel, 2.5 dpa and T_{irr} =573K

Clearly, constraint loss corrections are a promising approach to analyzing small specimen data [5]. Note, to complement previous work, a similar study will be carried out on the IEA alloy in the near future.

Recently, measurements of $K_e(T)$ of the IEA steel following neutron irradiation to 2.5 dpa at 573K were reported by van Osch *et al.* [7]. In combination with previous measurements of K_e (T) for the IEA steel in the unirradiated condition, these results can be used to evaluate both cleavage initiation temperature shift, ΔT, and J_R-da ductile toughness decrease, ΔK_{Jr}. for these irradiation conditions. The results, shown in Figure 6, indicate a $\Delta T \approx 140K$ and a $\Delta K_{Jr} \approx -120$ MPa$\sqrt{m}$.The $\Delta T \approx T_{oi} - T_{ou}$ is primarily due to irradiation hardening, $\Delta\sigma_I \approx 175$ MPa. The ΔT can be estimated using the equivalent yield stress model (EYSM): $\sigma_y(T_{oi}) = \sigma_y(T_{ou}) + \Delta\sigma_i$ [8,9], where $T_{ou} \approx 160K$ and T_{oi} are the temperatures of the unirradiated and irradiated steels, respectively, at a reference toughness of 60 MPa$\sqrt{m}$. The predicted ΔT based on the EYSM is 133K compared to a measured value of 140K.

MAÇE current status:

We have planned a related set of irradiation experiments called the Master Curve Experiments (MACE), in which tensile, fracture, and microstructural specimens of ferritic/martensitic steels will be irradiated over a range of temperatures and doses in a facility being installed at the Budapest Research Reactor KFKI AEKI. At the end of August 98, the authorization was given by the Hungarian safety authorities to run the new irradiation rig BAGIRA (Budapest Advanced Gas-cooled Irradiation Rig) at KFKI AEKI. Thermal tests with dummy material and dosimetry measurements started last September. The preliminary tests include a sequence of three loadings of 16%, 40% and 100% of the ultimate target. The fast neutron flux exceeded initial calculated estimates resulting in higher than expected heating rates. This problem was solved by increasing the cooling gas flow. Currently, the test with 40% of the target loading is running with a stable operating temperature of about 245±15°C, with a gradient of about 15°C between the middle and the end of the sample assembly. A final test is planned with a loading near the target level. Dosimetry measurements will be performed at this time. Initiation of actual specimen irradiations in MACE at 250°C with a target dose of 0.5 dpa are expected to begin within 6 weeks of the completion of this final test.

REFERENCES

[1] Odette, G. R., Edsinger, K., Lucas, G. E., E. Donahue, ASTM-STP-1328, American Society for Testing and Material, Philadelphia, PA (1998) 298-327.

[2] P. Spätig, G. R. Odette, G. E. Lucas, submitted to J. Nucl. Mater (1999).

[3] P. Spätig, R. Schäublin, S. Gyger, M. Victoria, J. Nucl. Mater. 258-263 (1998) 1345.

[4] J. E. Dorn and S. Rajnak, Trans. AIME 230 (1964) 1052.

[5] G. R. Odette, K. Edsinger, G. E. Lucas, E. Donahue, Small Specimen Test Techniques, ASTM STP 1329, American Society for Testing and Materials (1998) p. 298

[6] M. Nevalainen and R. H. Dodds, Inter. J. Fracture 74 (1995) 131.

[7] E. V. van Osch, M. G. Horsten, G. R. Odette, G. E. Lucas ASTM-STP 1325, American Society for Testing and Materials (in press).

[8] G. R. Odette, E. Donahue, G. E. Lucas, J. W. Sheckherd, DOE/ER-0313/20, Department of Energy (1996) p. 11.

[9] G. R. Odette, P. M. Lombrozo, R. A. Wullaert, Effects of Irradiation on Materials, ASTM-STP-970, American Society for Testing and Materials (1985) p.841.