Elastoplastic behaviour under irradiation of metals: application to the interns of tank

Summary:

This document presents the writing of a law of behaviour under irradiation of the stainless steels 304 and 316, materials of which are made up the internal structures of tank of the nuclear reactors. The formalism of the model is identical for two materials, only the parameters are different from one material to another. The model takes into account, in addition to thermoelasticity, plasticity, creep under irradiation, as well as a possible swelling under neutron flux.
One details here the implementation of the model like his limits.

This law of behavior, if it were developed for specific needs at EDF, can be used to give an account of the behavior of any material presenting of the characteristics of plasticity, creep under irradiation and swelling.

Contents

1 Introduction

The purpose of this document is to describe the development and numeric work the implementation of a law of behaviour under irradiation materials constituting the structure interns nuclear reactor reactor vessels: the steels 316 and 316L cold worked for screws and bolts, as well as hyper-hardened steels 304 and 304L for the partitions, the reinforcements and the envelope of heart. This law of behavior is formally the same one for the two types of steel, only the parameters varying from one material to another.

The developed model must be able to give an account (in addition to thermoelasticity) of the plasticity induced by the tightening of the screws, well-known creep under irradiation for metallic materials, and of a possible swelling induced by the irradiation. The effects of creep under irradiation and swelling are differentiated by the fact that the deformation occurs with constant volume for creep, which is not the case for swelling. The various phenomena quoted above are listed in an exhaustive way in the document [ref. 1] and will thus not be the object of an additional description in what follows.

This document is articulated in the following way: the law of behavior chosen to describe the answer of hyper-hardened steels 304/304L and 316/316L hammer-hardened is first of all exposed, as well as the equations allowing its establishment in the form of implicit integration. Each mechanism is detailed in a general way. The dependence of the parameters material to the variables of order which are the irradiation and the temperature is clarified. The digital values of these parameters are exposed in the note EDF R & D HT 5/26/045 /A. One presents then the limits of the model and his application in Code_Aster.

It should be noted that the formalism presented here, if it were implemented within the framework of a quite specific application, can be used to describe the behavior of any type of material presenting of the characteristics of plasticity, creep under irradiation and swelling. In this case, it will be important with the user of Code_Aster to get the coefficients material necessary to the use of the model.

2 Formulation of the law of behavior

One proposes to employ an additive decomposition of the deformations. The mechanical deformation is then expressed like:

$$\underline{\varepsilon}_m=\underline{\varepsilon}_e+\underline{\varepsilon}_p+\underline{\varepsilon}_i+\underline{\varepsilon}_g \quad \textbf{éq 2-1}$$

Mechanical deformation, $\underline{\varepsilon}_m$ is defined like the total deflection minus the thermal deformation: $\underline{\varepsilon}_m=\underline{\varepsilon}-\varepsilon_{th}$. The other components are: elastic strain $\underline{\varepsilon}_e$, plastic deformation $\underline{\varepsilon}_p$, deformation of creep of irradiation $\underline{\varepsilon}_i$ and deformation of swelling $\underline{\varepsilon}_g$.

- The elastic strain is connected to the constraint by the law of Hooke: $\underline{\sigma}=\underline{\underline{E}}:\underline{\varepsilon}_e$. The tensor of elasticity $\underline{\underline{E}}$ depends on the temperature T .
- The plastic deformation is given by a law of the Von-Settings type. The surface of flow is expressed like:

$$f=\sigma_{eq}-\sigma^f \quad \textbf{éq 2-2}$$

where σ_{eq} is the constraint of Von-Settings and σ^f limit of flow. This one depends on the cumulated plastic deformation, p , temperature T , and of the fluence Φ . The plastic flow is given by the rule of normality so that:

$$\dot{\underline{\varepsilon}}_p=\dot{p}\,\underline{n} \;\text{ with }\; \underline{n}=\frac{3}{2}\frac{\underline{s}}{\sigma_{eq}} \quad \textbf{éq 2-3}$$

where $\underline{s}$ is the diverter of the constraints. $\dot{p}$ is given by the condition of coherence $f=0$ and $\dot{f}=0$. The laws of creep of irradiation are expressed (for a test with constraint and constant flows) [ref. 1] :

$$\varepsilon=\max\left(A_i\cdot\sigma\cdot\Phi-A_0\right) \quad \textbf{éq 2-4}$$

The coefficient A_0 translated an effect of threshold. In differential form, the preceding law can be rewritten like:

$$\dot{\varepsilon}=A_i\,\sigma\cdot\varphi \;\text{ if }\; \eta_i>A_0/A_i \;\text{ with }\; \dot{\eta}_i=\sigma\cdot\varphi \quad \textbf{éq 2-5}$$

where φ is flow ($\varphi=\dot{\Phi}$). One thus introduces an additional variable of state, η_i , to describe the effect of threshold. This uniaxial law must be wide with the multiaxial case. The creep of irradiation being done without variation of volume, one will describe this mechanism by a viscoplastic model founded under equipotential data by the constraint of Von-Settings. It will be also supposed that the evolution of the variable η_i is managed by this same constraint. The following laws then are obtained:

$$\dot{\eta}_i=\zeta_f\cdot\sigma\cdot\varphi \quad \textbf{éq 2-6}$$

$$\dot{p}_i=A_i\cdot\sigma\cdot\varphi \;\text{ if }\; \eta_i>\eta_i^s \;\text{ if not }\; \dot{p}_i=0 \quad \textbf{éq 2-7}$$

$$\dot{\underline{\varepsilon}}_i=\dot{p}_i\,\underline{n} \quad \textbf{éq 2-8}$$

where p_i is the deformation of creep of equivalent irradiation. A_i and η_i^s are coefficients of the model which can depend on the temperature (one can consider a dependence with respect to the fluence but the model will be more complex to identify). The function ζ_f allows to introduce a dependence with respect to the temperature into the law of evolution of the variable η_i (see equation 4.3-1). It will be noted that the model thus formulated will be able to function for variable temperatures and flows.

Notice n°1:

It will be noticed that the "creep" of irradiation is entirely controlled by the fluence and not by time. If a thermal mechanism of creep would be added, time would play an explicit part of manner of course.

Notice n°2:

To make sure of the good crossing of the threshold η_i^s, (from a digital point of view) it is necessary to define a criterion of error. This criterion "TOLER_ET" corresponds to % of going beyond the threshold which one authorizes during digital integration. The deformation of creep of irradiation begins as soon as the threshold η_i^s is crossed, but one forces Code_Aster to respect a reasonable evolution of variable η_i in the vicinity of the threshold η_i^s. So during calculation the criterion is not respected Code_Aster subdivides the steps of time, provided that the subdivision of the steps of time is authorized.

Swelling can be described by laws of the type:

$$\frac{\Delta V}{V_0}=F_g(\Phi) \quad \textbf{éq 2-9}$$

where ΔV is the variation of volume and V_0 initial volume. By differentiating this equation and by supposing that the variation of volume remains weak ($\Delta V \ll V_0$) one obtains:

$$\frac{\dot{V}}{V}=\frac{dF_g}{d\Phi}\varphi \quad \textbf{éq 2-10}$$

This speed of variation is identified with the trace of the tensor speeds of swelling: $\dot{V}/V=trace(\underline{\dot{\varepsilon}}_g)$.
It is supposed here that swelling is made in an isotropic way and thus that $\underline{\dot{\varepsilon}}_g$ can express itself like:

$$\underline{\dot{\varepsilon}}_g=\dot{g}\,\underline{1} \quad \textbf{éq 2-11}$$

where $\underline{1}$ is the tensor unit. One thus has $\dot{V}/V=3\dot{g}$

That is to say: $\dot{g}=A_g\varphi$ **éq 2-12**

with $A_g=\frac{1}{3}dF_g/d\Phi$. A_g is a new parameter material. This one depends on the temperature and the fluence. In a problem at variable temperature, it is thus important to employ the equation 2-12 and not the equation 2-9 (this one being implicitly written for a constant temperature). A possible coupling between state of stress and swelling is neglected.

The definition of the model rests on five internal variables: p , η_i , p_i , g and $\underline{\varepsilon}_e$. The temperature and the fluence are regarded as parameters imposed for a given calculation. These values come from calculations of neutronics and thermics. The equations of the model are recalled in the table 2.1.

Internal variables	Equations of evolution
p	coherence $\dot{p}$
η_i	$\dot{\eta}_i=\zeta_f\cdot\sigma_{eq}\cdot\varphi$
p_i	$\dot{p}_i=A_i\cdot\sigma\cdot\varphi$ if $\eta_i>\eta_i^s$ if not $\dot{p}_i=A_i\cdot\sigma\cdot\varphi\ \dot{p}_i=0$
G	$\dot{g}=A_g\varphi$
$\underline{\varepsilon}_e$	$\underline{\dot{\varepsilon}}_e=\underline{\dot{\varepsilon}}_m-\dot{p}\cdot\underline{n}-\dot{p}_i\cdot\underline{n}-\dot{g}\cdot\underline{1}$

Table 2.1 : Equations of the model.

3 Establishment: implicit integration

Implicit integration consists in finding the increments of the internal variables $\Delta V_i = (\Delta P, \Delta \eta_i, \Delta P_i, \Delta g, \Delta \underline{\varepsilon}_e)$ on a discrete increment of time Δt [ref. 2]. Discretization of the equations of the table 3.1 conduit with the system of nonlinear equations according to:

$$\underline{R}_e = \Delta \underline{\varepsilon}_e + \Delta p \underline{n} + \Delta p_i \underline{n} + \Delta g \underline{1} - \Delta \underline{\varepsilon}_m = 0$$
$$R_p = \sigma_{eq} - \sigma^f = 0$$
$$R_\eta = \Delta \eta_i - \zeta_f \sigma_{eq} \Delta \varphi = 0$$
$$R_i = \Delta P_i - H(\eta_i - \eta_i^s) A_i \sigma_{eq} \Delta \varphi = 0$$
$$R_g = \Delta g - A_g \Delta \Phi = 0$$

Table 3.1 : system of discretized equations

Where H is the function of Heavyside and $\Delta \Phi = \phi \Delta t$ is the increment of fluence. While posing $R = (\underline{R}_e, R_p, R_\eta, R_i, R_g)$, one thus seeks to solve the system: $R(\Delta V_i) = 0$. Internal variables appearing directly or indirectly (for example σ_{eq} can express itself according to $\underline{\varepsilon}_e$) are expressed like: $v_i = v_i^0 + \theta \Delta v_i$, where v_i^0 represent the values of the variables at the beginning of increment. θ is a variable parameter between 0 and 1. For $\theta = 0$, one obtains an explicit diagram of Euler (to be avoided); for $\theta = 1$ a completely implicit diagram is obtained.

The system of equations of the table 3.1 is solved by employing a method of Newton-Raphson which requires the calculation of Jacobien: $J = \partial R / \partial \Delta v_i$. This one can be calculated block per block (the worthless terms are omitted). One notes $\underline{\underline{N}} = \partial \underline{n} / \partial \underline{\sigma}$ and $\sigma^f_{,p} = \partial \sigma^f / \partial p$.

Derived from $\underline{R}_e$:

$$\frac{\partial \underline{R}_e}{\partial \Delta \underline{\varepsilon}_e} = \underline{\underline{1}} + \theta \cdot \Delta p \cdot \underline{\underline{N}} : \underline{\underline{E}} + \theta \cdot \Delta p_i \cdot \underline{\underline{N}} : \underline{\underline{E}} \qquad \frac{\partial \underline{R}_e}{\partial \Delta p} = \underline{n}$$
$$\frac{\partial \underline{R}_e}{\partial \Delta p_i} = \underline{n} \qquad \frac{\partial \underline{R}_e}{\partial \Delta g} = \underline{1}$$

Derived from R_p :

$$\frac{\partial R_p}{\partial \Delta \underline{\varepsilon}_e} = \theta \underline{n} : \underline{\underline{E}} \qquad \frac{\partial R_p}{\partial \Delta p} = -\theta \sigma^f_{,p}$$

Derived from R_η :

$$\frac{\partial R_\eta}{\partial \Delta \underline{\varepsilon}_e} = -\zeta_f \theta \cdot \Delta \varphi \cdot \underline{n} : \underline{\underline{E}} \qquad \frac{\partial R_\eta}{\partial \Delta \eta_i} = 1$$

Derived from R_i :

$$\frac{\partial R_i}{\partial \Delta \underline{\varepsilon}_e} = -A_i \cdot \theta \cdot \Delta \varphi \cdot \underline{n} : \underline{\underline{E}} \qquad \frac{\partial R_i}{\partial \Delta p_i} = 1$$

Derived from R_g :

$$\frac{\partial R_g}{\partial \Delta g} = 1$$

4 Coefficients materials

In the continuation, one presents the forms of evolution of the parameters of the equations according to the variables of order which are the temperature and the fluence. The values of these parameters for the materials 304 and 316 are consigned in report HT 5/26/045 /A.

4.1 Thermoelasticity

The Young modulus [ref. 3] is given by:

$$E=C_0^E+C_1^E\cdot T \quad \textbf{éq 4.1-1}$$

The Poisson's ratio is given by:

$$\nu=C_0^\nu+C_1^\nu\cdot T \quad \textbf{éq 4.1-2}$$

The thermal dilation coefficient tangent is given by:

$$\alpha=C_0^\alpha+C_1\alpha\cdot T+C_2^\alpha\cdot T^2 \quad \textbf{éq 4.1-3}$$

The secant dilation coefficient is then given, by taking a temperature of worthless reference, by:

$$\alpha^{sec}=C_0^\alpha+\frac{1}{2}C_1^\alpha\cdot T+\frac{1}{3}C_2^\alpha\cdot T^2 \quad \textbf{éq 4.1-4}$$

4.2 Plasticity

This part exploits report [ref. 3] to calculate the curves of work hardening of steels constitutive of the internal structures of tank after irradiation for various temperatures. One uses the expressions of the elastic limit to 0.2% of plastic deformation $R_{0,2}$, ultimate constraint R_m and of lengthening distributed e_u according to the temperature T, irradiation Φ (report [ref. 3] uses the term d to describe the irradiation) and of the rate of cold work hardening c. Report [ref. 3] also provides lengthening with rupture but this data is not exploitable in practice because it depends on the type of studied test-tube.
Lengthening distributed is expressed like:

$$e_u=e_u^0(T)\eta_3(c)\xi_3(d) \quad \textbf{éq 4.2-1}$$

The elastic limit to 0.2% is expressed like:

$$R_{0,2}=R_{0,2}^0(T)\eta_1(c)\xi_1(d) \quad \textbf{éq 4.2-2}$$

The ultimate constraint is not expressed directly. The difference $\Delta R=R_m-R_{0,2}$ is first of all represented by a function:

$$\Delta R=(R_m^0(T)-R_{0,2}^0(T))\eta_2(c)\xi_2(d) \quad \textbf{éq 4.2-3}$$

To adjust ΔR instead of R_m allows to ensure that: $R_m>R_{0,2}$. R_m is thus obtained like: $R_m(T,c,d)=R_{0,2}(T,c,d)+\Delta R(T,c,d)$
Let us note that the functions e_u^0, $R_{0,2}^0$ and R_m^0 are valid for the two materials (304 and 316) constitutive of the interns of tank. Functions $\eta_{1,2,3}$ and $\xi_{1,2,3}$ depend on material. One proposes to represent the curve of work hardening of materials for values of T, d and c data by a law power of the type:

$$\sigma_f(p)=K(p+p_0)^n \quad \textbf{éq 4.2-4}$$

where p is the equivalent plastic deformation of Von-Settings. K, p_0 and *N* are parameters to calculate in order to obtain the values of $R_{0,2}^0$, R_m and e_u.

The value of the deformation corresponding to lengthening distributed (noted $\varepsilon_u = \log(1+e_u)$) is obtained by the condition of Considers (by neglecting the elastic strain):

$$\frac{d\sigma^f}{dp} = \sigma^f \qquad \textbf{éq 4.2-5}$$

that is to say:

$$n K (p+p_0)^{n-1} = K (p+p_0)^n \Rightarrow p^0 = n - \varepsilon_u \qquad \textbf{éq 4.2-6}$$

The ultimate constraint is equal to:

$$R_m = \sigma^f(\varepsilon_u)\exp(-\varepsilon_u) = K\, n^n \exp(-\varepsilon_u) \qquad \textbf{éq 4.2-7}$$

That is to say:

$$K = \frac{R_m}{n^n}\exp(\varepsilon_u) \qquad \textbf{éq 4.2-8}$$

The elastic limit is given by (one neglects the variation of section here):

$$R_{0,2} = K (p_e + p_0)^n \text{ with } p_e = 0{,}002 \qquad \textbf{éq 4.2-9}$$

It thus remains to solve a single nonlinear equation compared to *N* :

$$S = R_{0,2} - \frac{R_m}{n^n}\exp(\varepsilon_u)(p_e + n - \varepsilon_u)^n = 0 \qquad \textbf{éq 4.2-10}$$

The search for the solution is made by dichotomy while taking ε_u for initial value of n . One calculates then n and K by using the equations 4.2-8 and 4.2-10.
If the material presents little work hardening (i.e strong irradiation or very important work hardening cold), it is not possible to find a solution with the equation 4.2-4. In this case one will use the law power of the form $\sigma^f(p) = K\, p^n$ with $n = \varepsilon_u$ and $\sigma^f(p) = K\, p^{nK} = R_m \exp(\varepsilon_u)/n^n$ that is to say $p_0 = 0$.
Use of the preceding laws for the low values of *p* can lead to not very realistic results. One will be able to consider that the yield stress cannot be lower than $\kappa R_{0,2}$ (with κ near to 1). The effect of the choice of κ on the answer in creep of a structure is negligible for values ranging between 0.8 and 1. One recommends, for a calculation in Code_Aster, to retain the value $\kappa = 0{,}8$. One will use moreover a linear extrapolation enters $p = 0$ and $p = p_e$ obtained starting from the values in p_e constraint and work hardening. The figure 4.2-1 indicate in a schematic way the pace of the law of work hardening proposed.

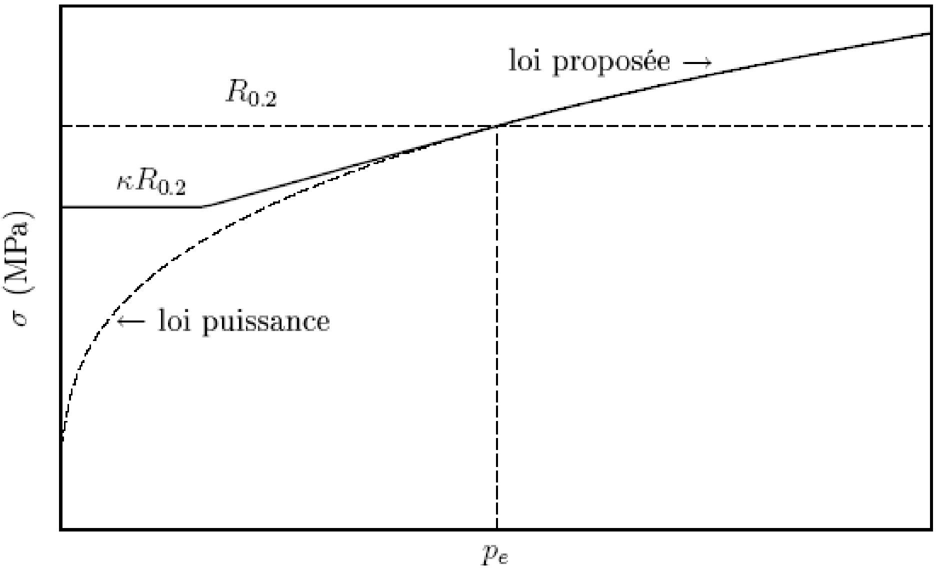

Figure 4.2-1 : Law of work hardening proposed.

4.3 Creep of irradiation

Data of creep of irradiation collected in [ref. 1] allow to determine the values of A_i and η_i^s. These values are a priori constant with the temperature. It is however probable that at low temperature, there is no creep of irradiation. To model this evolution, it is possible to make depend the coefficient A_i temperature:

$$A_i = A_i^0 \zeta_f(T) \qquad \textbf{éq 4.3-1}$$

where A_0^i is the value of the parameter for the high temperatures. In this equation ζ_f is a function which can make it possible to stop the phenomenon of creep below a threshold of temperature. It can be written in the form $\zeta_f(T) = \frac{1}{2}\left(1+\tanh\left(\mu_T\left(T-T_c\right)\right)\right)$, where T_c allows to regulate the temperature for which the creep of irradiation begins and where μ_T allows to regulate the width of the transition between temperature ranges with and without creep from irradiation.

4.4 Swelling

One will use a bilinear law of Foster which makes it possible to represent a time of incubation then a linear swelling [ref. 1, ref. 4]. One has then:

$$\frac{\Delta V}{V_0} = F_g(\Phi) = R \cdot \left(\Phi + \frac{1}{\alpha} Log\left(\frac{1+\exp\left(\alpha\left(\Phi_0-\Phi\right)\right)}{1+\exp\left(\alpha\Phi_0\right)}\right)\right) \qquad \textbf{éq 4.4-1}$$

For $\Phi \to \infty$ one obtains:

$$\frac{\Delta V}{V_0} = R \cdot \Phi - \frac{R}{\alpha} Log\left(1+\exp\left(\alpha\Phi_0\right)\right) \qquad \textbf{éq 4.4-2}$$

The fluence of incubation is thus worth: $Log\left(1+\exp\left(\alpha\Phi_0\right)\right)/\alpha$ (n.b.: if $\alpha\Phi_0 \gg 1$ this one is worth Φ_0). By deriving the equation 4.4-1 one obtains:

$$A_g = \frac{1}{3} R \left(1 - \frac{\exp\left(\alpha\left(\Phi_0-\Phi\right)\right)}{1+\exp\left(\alpha\left(\Phi_0-\Phi\right)\right)}\right) \qquad \textbf{éq 4.4-3}$$

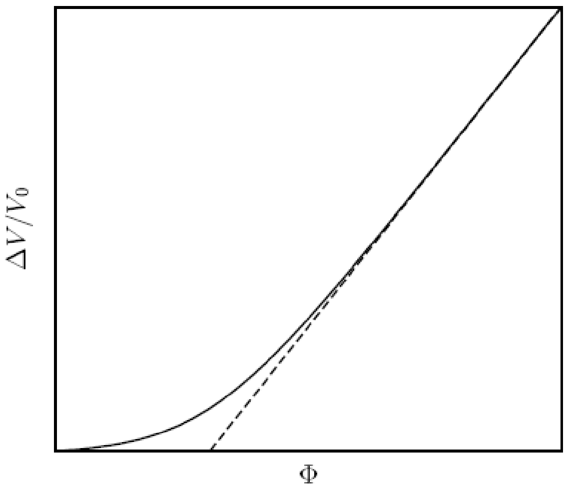

Figure 4.4-1 : Bilinear law of Foster [ref. 4].

The parameters material of the law of swelling are thus R, α , and Φ_0 .
As in the case of the creep of irradiation, it can be necessary to introduce a dependence with respect to the temperature not to impose a swelling at low temperature. One will be able to make depend R temperature by using a function ζ_g analogue with that employed for the creep of irradiation:

$$R=R^0\zeta_g(T) \text{ with } \zeta_g(T)=\frac{1}{2}\left(1+\tanh\left(\mu_g\left(T-T_c^g\right)\right)\right) \quad \textbf{éq 4.4-4}$$

5 Limits of the model

The model suggested was established starting from an experimental base in which the tests are carried out for monotonous requests: (I) tensile tests on materials preradiated in isothermal condition; creep tests of irradiation (and swelling) in isothermal condition for a constant flow. This law must however be employed to simulate the behavior of the interns of tank in real conditions; i.e. with variable flows and temperatures.
Thermal cycling induced a cyclic mechanical loading. The equations of the model, written in differential form, make it possible to manage the temperatures and variable flows but certain physical effects are not taken into account. It is for example the case of the kinematic work hardening which could intervene during a thermal cycling. There does not exist, to our knowledge, of compression/cyclic tensile tests on irradiated materials. Other questions can also arise: (I) which is behaviour in creep of irradiation of a preradiated material (at a different temperature and/or under constraint)? (II) exist does a coupling between creep of irradiation and plasticity?
Swelling is treated like an irreversible voluminal deformation. It is however the appearance of cavities which can grow under tensile stress (to even fill itself under that but compressive stress remains very hypothetical). This adverse effect, since the rate of vacuum increases more quickly, is however not taken into account.

The field of application of the model in temperature, fluence and stress creep is specified in note HT 5/26/045 /A for the materials 304 and 316. However, it is possible to use such a model within the framework of a calculation with Code_Aster for any other material that those. In this case, it is responsibility for the user of the code to make sure that the coefficients material which it uses are in agreement with the field of validity of its calculation.

6 Application of the model in Code_Aster

The definition of the model in a data file of Code_Aster is done in the following way:

```
ACIER=DEFI_MATERIAU (
  ELAS_FO=      _F (
    E                  =      function (T)
    NAKED              =      function (T),
    ALPHA              =      function (T),
    TEMP_DEF_ALPHA     =      reality,
  ),
  IRRAD3M=      _F (
    R02                =      function (T, dpa)           (cf eq 4.2-2)
    EPSI_U             =      function (T, dpa)           (cf eq 4.2-1)
    RM                 =      function (T, dpa)           (cf eq 4.2-3)
    AI0                =      reality                        (eq 4.3-1)
    ZETA_F             =      function (T)           (cf eq 2-6, 4.3-1)
    ETAI_S             =      reality                       (cf eq 2-7)
    RG0                =      function (T)                (cf eq 4.4-1)
    ALPHA              =      reality                     (cf eq 4.4-1)
    PHI0               =      reality                     (cf eq 4.4-1)
    KAPPA              =      reality                (cf appears 4.2-1)
    ZETA_G             =      function (T)                (cf eq 4.4-4)
    TOLER_ET           =      reality                  (cf notice 2 §2)
    ),
)
```

The internal variables are the following ones:

V1 : p
V2 : η_i
V3 : p_i
V4 : G
V5 : indicator of plasticization (0 if not from plasticization, 1 if plasticized)
V6 : Irradiation
V7 : Temperature

7 Bibliography

[1] J.P. Massoud, Lifetime of the irradiated interns of tank. File of synthesis: Irradiated materials (HT 4/27/045 /A), EDF R & D (2005).

[2] J. Besson, G. Cailletaud, J.L. Chaboche, S. Forest, non-linear Mechanics of materials, Hermes, 2001.

[3] Constitutive Materials Reliability Program Development of Material Model for Irradiated Austenitic Stainless Steels (MRP – 135), EPRI, Palo Alto, CA: 2004. 1011127.

[4] J.P. Foster, R.V. Strain, Empirical swelling equations for standard solution-annealed 304 stainless steel, Nuclear Technology (1974) 93-98.

[5] J. Besson, S.Leclercq, Law of behavior for A304 steels and A316 of the interns of tank under irradiation, Notes EDF/R & D - HT 5/26/045 /A, 2005.

8 History of the versions of the document

Version Aster	Author (S) or contributor (S) organization (S)	Description of the modifications
8.4	S.LECLERCQ, J.BESSON EDF/R & D /MMC, ENSMP-CDM	Initial text, formulation of law IRRAD3M
9.1	J.L. FLEJOU EDF/R & D /AMA	Improvement of the digital integration of the laws: analytical for swelling, and criterion of crossing of the threshold for creep.
10.0	J.L. FLEJOU EDF/R & D /AMA	Modification of the law for the calculation of the sensitivity to the IASCC.