CLADDING-STRENGTH ANALYSIS
UNDER THE COMBINED EFFECT OF CREEP
AND PLASTICITY IN FAST-REACTOR ENVIRONMENTS

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Since several years, BELGONUCLEAIRE is developing computer programmes in or-
der to investigate the thermal and mechanical behaviour of the oxide fuel
elements during their irradiation. This paper is relative to an analysis of
the clad behaviour of these fuel elements, performed by means of the CRASH III
computer programme, which constitutes an improved version of the early
CRASH II B programme described in [1].
The CRASH III programme, allowing the calculation of tri-axial stress and
strain in an axisymmetrical sheath, takes into account the combined effects
of the creep and the plasticity of the material. The creep and plastic
strains can be any functions of the temperature, the generalised stress and the
time.
The programme calculates the clad stresses and strains associated with:
- coolant outer pressure
- gas inner pressure
- non-linear temperature distribution through the cladding taking into
  account heat generation in the cladding material itself
- radial distribution of the clad swelling strains due to the fast flux
  irradiation. The swelling strains, which are assumed to be functions
  of the local temperature and local neutron fast fluence, are calculated
  according to different formulae issued from a literature analysis.
  Stresses induced by differential swelling are thus automatically
  accounted for.
- contact pressure and axial force due respectively to the fuel radial
  and axial expansion.
This last effect can only be adequately assessed by a fuel expansion model
linked with the clad model. However, the cladding behaviour programme may be
used separately from the fuel behaviour programme. In this case, for the aim
of simplification, it is assumed that the dimensional variations of the
fuel are linear functions of the contact pressure and of the axial force,
for each time step considered in the calculations. This allows thus a sepa-
rate calculation of the clad if the fuel dimensional variations are known.
The various loads applied to the sheath may be any functions of the time.
In particular cyclic loading effects can be easily investigated. The pro-
gramme can also account for outer and inner sheath corrosion.
To show the usefulness of the programme, some typical calculation examples
are presented together with a short description of proposed strength criteria
under creep and plasticity. The axial and radial thermal ratchetting of fuel
rods under cyclic loading conditions involving contact with the fuel, with
creep and plasticity occurring simultaneously, is investigated. Effects of
the differential steel swelling on the stress level are also discussed.

REFERENCE
   and Plastic Behaviour of Fuel Pin Sheaths.", Nuclear Applications and
   Technology, Vol. 9, July 1970, p. 60

* Published in Nuclear Engineering and Design 18 (1972) 53-68.
DISCUSSION

Q  R. W. WEEKS, U.S.A.
When you use a creep law with a nonlinear time dependence, do you still include

time-independent plasticity - and if so, how do you separate the plasticity from primary
creep?

A  M. GUYETTE, Belgium
Yes we do. The plasticity phenomenon is presently considered as independent of
the creep one, mainly due to a lack of material behaviour knowledge.

Q  J.H. GITTUS, U.K.
Do you have any instability problems that cannot be corrected by reducing the
time-step?

A  M. GUYETTE, Belgium
At the beginning of the development of the program we had some. However, with
the method we use now we have no problems any more.

Q  K.R. MERCKX, U.S.A.
Have you tried to put in a mean stress dependence in yield criteria to account for
the stress dependence of swelling?

A  M. GUYETTE, Belgium
Due to the lack of knowledge of material properties in this field we have not
made this correction up to now.

Q  V.S. BECKETT, U.K.
The achievable burn-up of an interacting fuel pin is dependent upon the cladding
strain. This in turn relies on the swelling laws assumed for the fuel. Do these swelling laws
include closing of the as-fabricated porosity within the fuel?

A  M. GUYETTE, Belgium
Yes they do.
R. W. WEEKS, U. S. A.

Q

The cladding stress calculations depend on what is assumed for the fuel behavior. Will the fuel model in Comethe III be stress-dependent?

M. GUYETTE, Belgium

A

The fuel behavior used in Comethe III is similar to that of Comethe II. It is temperature dependent and partially stress dependent.