THEORETICAL ANALYSIS OF THE STRAINS PRODUCED IN NUCLEAR FUEL CLADDING TUBES BY THE EXPANSION OF CRACKED CYLINDRICAL FUEL PELLETS

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Some of the stress, force and strain distributions produced in collapsed cladding by the expansion of cracked pellets during a power increase have been calculated analytically. As the radial and transverse cracks in the pellet open, the tendency for the cladding to stretch preferentially over them is reduced by frictional sliding at the pellet/clad interface. The frictional forces opposing sliding are intensified by a high coolant pressure (which holds the can onto the fuel) whilst the ability of the cladding to resist the friction forces without being locally deformed depends on its strength. The coefficient of friction, cladding dimensions, number of radial pellet cracks, strain hardenability and temperature gradients around the cladding influence the tendency for cladding strain to be concentrated over the opening pellet cracks.

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DISCUSSION

Q R. A. VALENTIN, U. S. A.

Since radial cracks will affect the Θ dependence of the temperature field one has a coupling between the cracking process and the temperature field needed to determine this cracking How is this effect considered in the computation and is it a major or second order effect ?

A J. H. GITTUS, U. K.

In a computer model we are calculating the angle between adjacent pellet-cracks from the rating and correcting tne cracked pellet-conductivity for the effects of normal-pressure.

Q H. BILGER, Germany

Did you apply your theory on BWR-fuels ? Are there conditions under which this effect becomes important (for example high burn-up) or is this effect negligible for BWR-fuels ?

A J. H. GITTUS, U. K.

The numerical examples given in the paper are, in fact, for a pressure-tube BWR

Q E. ROLSTAD, Norway

I am somewhat doubtful whether your constant moment pellet model applies for a heavily cracked pellet.Is not a constant stress, or rather constant force model better in this case ?

A J. H. GITTUS, U. K.

The constant force model is presented in the paper: it produces similar predictions to those of the constant moment model.

Q R. HAUSERMANN, Switzerland

1. Did you apply your theory to the BWR and PWR fuel ? In particular I am interested in the fact that if a BWR fuel cladding is free-standing and the PWR fuel cladding not it would show that a PWR rod fails earlier.
2. Are you able to show a complete collapse of the cladding which could be initiated by radial cracks in the pellet ?

A J. H. GITTUS, U. K.

1. Calculations have been done for PWR and BWR cases. They show that a free-standing clad sustains less damage than clad that exhibits creep-collapse.
2. I suggest that this phenomenon, if observed, may be due to the formation of discontinuities in the pellet-stack as a result of axial ratchetting.

Q K. OLSHAUSEN, Norway

From your model you can calculate ridge heights. How do they compare with the ones calculated by Veeder ?
Veeder's values agree quite well with experimental results. Are not your ridges due to different mechanisms than Veeder's ?

A J. H. GITTUS, U. K.

The ridge heights which I calculate are similar to those arrived at by Veeder.

Q W. P. CHERNOCK, U. S. A.

1. I would presume that these models do recognize the fact that healing of cracks occurs during operation. Therefore there are only peripheral cracks during operation. Has this, in fact, been considered in the models. If not, what will be the influence of this factor on the conclusions ?
2. I would like to call your attention to the heterogeneous nature of fuel-cladding interactions. For example, loading pellets into cladding requires substantial forces if the pellets are not perfectly perpendicular. Therefore there are high local heterogeneous fuel-clad interactions during operation resulting from differential pellet column-cladding expansion resembling the results of pellet loading experiments. How have these heterogeneous forces been accomodated in the model ? If they have not, what influence are they likely to exert ?

A J. H. GITTUS, U. K.

1. During excursions to new, high power-levels the peripheral cracks extend towards the pellet centre and the predicted strain-concentration due to cross-pin temperature-gradients can then occur.
2. Scoring of the clad-bore occurs during pellet-loading: the resultant strain-concentrations are smaller than those due to pellet-cracks and have been ignored in the analysis.

Q W. P. CHERNOCK, U. S. A.

1. Have you calculated the maximum rate of power increase in SGHWR with which you feel you would be comfortable ? What is this value ?

2. Your concept of introducing a cored pellet to minimize mechanical interaction problems in the case of your constant moment pellet could lead to utilization of this hole as a means for increasing heat ratings and this could negate the mechanical advantages by utilization of thermal advantages. Could you comment on this as well as on the prospect of fuel fragments falling into the hole and the resulting consequence on fuel performance ?

A J. H. GITTUS, U. K.

1. We have calculated this value but I cannot disclose it.
2. The tendency is for designers to raise the rating of cored pellets and this does erode the advantage which they offer in a power-cycling reactor.

Q J. VAN MIEGROET, Belgium

1. If you consider two identical pins except that the first one is surrounded by a uniform coolant temperature field while the second one encounters a fairly steep temperature gradient with the maximum temperature just equal to the uniform temperature of the first pin, do you expect with the model you just described that in some cases the failure probability of the second pin might exceed the failure probability of the first one ?
2. Does your model allow for a difference of treatment between a clad situation with a regularly changing coolant temperature around the pin periphery and a clad situation with a very local and steep temperature gradient leading to the same overall ΔT (spiral wire hot spot situation, for example) ?

A J. H. GITTUS, U. K.

1. Yes, there are such cases.
2. No, but we have a computer-code which does permit this case to be examined.