From: "Gauntt, Randall O" <rogaunt@sandia.gov>
To: "'Jason Schaperow'" <JHS1@nrc.gov>, "Gauntt, Randa...
Date: Mon, Jan 31, 2000 6:23 PM
Subject: RE: Cladding behavior under steam and air conditions

reply to R Gauntt: "Thanks"

NUREG/CR-6042

Hi Jason,
Getting back to you on this question.

700-1000 C

MELCOR assumes that the gap inventory is released when the cladding temperature reaches 1173K, or 900C. It doesn't care if the pressure is low or high. This subject has been studied in detail by specialists, e.g.. clad ballooning modeling ,in the quest to model this process mechanistically, however I believe the simple MELCOR treatment and it's default failure temperature is a good guess. Some reasons why. First, my own experience has led me to believe that the failure is mainly due to a eutectic reaction between inconel grid contact points with the zircaloy cladding. The minimum liquidus temperature in the Ni-Zr binary system is 960C. So, out of 30,000 fuel rods, statistically, some are going to start failing with pinhole failures at the contact points, especially if there is any internal pressurization stressing the contact point. This perspective comes from the FzK CORA tests and the insights provided by Hofmann and Hagen. More detailed stress strain calculations are probably not warranted, again because of the statistical aspects of the problem combined with core-wide (or in this case pool-wide) incoherence. So, I think "simple" is as successful as "complicated" in predicting this behavior. The 900C failure temperature in MELCOR is probably a little conservative, one might argue for 1000C. Reality is probably more along the lines of... "at 900C the first failures begin to occur, by 1000C the rate of cladding perforations is increasing rapidly, and by 1100C, the number of unfailed clad rods in definitely in the minority." Realize that a single rod without a grid spacer to constrain the diameter might actually balloon pretty big and might not burst until higher temperatures had been attained. — discuss w/ CT

1000 - 1400C

Concerning rapid oxidation onset, MELCOR doesn't consider oxidation at all until 1100K. Between 1100K and 1853K, the lower rate kinetics of Urbanic Hedrick is used, above 1853K a higher rate expression is used when the oxidation rate increases suddenly as the phase of the ZrO_2 oxide changes from tetragonal to cubic. Practically speaking however, the oxidation runaway comes in before this phase change due to the heat of the oxidation reaction increasing generally faster than heat losses from other mechanisms. The range cited, 1000C to 1400C is fairly inclusive. This is to say if peak temperatures remain below 1000C, you will probably escape the runaway, but if you get to 1200C, you will probably see the oxidation "light up" like a 4th of July sparkler (literally that's what it looks like) as it goes into the "rapid oxidation" regime. 1400C rather conservatively defines the upper boundary to this regime. I don't think there is much likelihood that cladding can get that hot (1400C) and fail to "runaway". As you can tell, it's a continuum. The precise boundary limits depend on the specifics of the heat balance of which the decay heat is one contributor. I would expect fuel in a storage pool to be "cooler" overall than fuel in the reactor core following a transient. Lower decay heat level would imply that the fuel could afford a bit more oxidation heat generation before the net heat balance of sources and losses dictates the entry trajectory heading into runaway oxidation. In other words, cooler fuel might encounter slightly higher temperature thresholds before passing "the point of no return."

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I don't think that air oxidation would affect cladding perforation and first release of gap inventories. The QUENCH program itself didn't address air - this was done in an EC-members-only project looking at air ingression issues. I'll try to find any info I have, but I don't recall anything profound concerning the thresholds to rapid oxidation. The main differences are that the air oxidation doesn't produce hydrogen, and the heat of reaction is greater. The larger heat of reaction could hasten things a bit in terms of the feedback on the reaction kinetics. I think MELCOR air oxidation models are good. However, we don't seem to have direct access to the air ingression tests of Haste and Shepherd (ISPRA/FzK/Hungary research), but we could get to the data through Phebus - maybe.

Hope this helps.
Call me if you need more.
Randy
505-284-3989

-----Original Message-----
From: Jason Schaperow [mailto:JHS1@nrc.gov]
Sent: January 28, 2000 8:17 AM
To: rogaunt@sandia.gov
Cc: AXB@nrc.gov; CGT@nrc.gov
Subject: Cladding behavior under steam and air conditions

Randy,

We are assisting NRR in the analysis of spent fuel pool accidents. One of the issues concerns temperatures for clad rupture (for a low pressure sequence) and for rapid oxidation under steam and air conditions. Charles Tinkler suggested I get your input on this issue.

For steam conditions, Figure 3.1-1 of Perspectives on Reactor Safety, NUREG/CR-6042, Rev. 1, November 1997, shows a temperature range of 700 C to 1000 C for rupture and a temperature range of 1000 C to 1400 C for rapid oxidation. What temperature do we use in MELCOR for clad rupture (for a low pressure sequence) under steam conditions? In MELCOR calculations, at what temperature does rapid oxidation begin under steam conditions?

From speaking with Lawrence Dickson, I understand that the QUENCH tests address both steam and air conditions. Are the temperatures for clad rupture and for rapid oxidation significantly different for air conditions than for steam conditions?

Thanks for your help.
Sincerely,
Jason

!
!

CC: TWFN_DO.twf5_po(AXB,CGT)

From: Jason Schaperow
To: "rogaunt@sandia.gov"@GATED.nrcsmtp
Date: Fri, Feb 4, 2000 4:45 PM
Subject: Re: RE: Cladding behavior under steam and air conditions

An excellent explanation! Thank you very much for your effort.

Jason

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CC: Ali Behbahani, Charles Tinkler