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Office of Nuclear Reactor Regulation

FROM: G. N. Lauben, Section Leader
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SUBJECT: COMMENTS ON A DPV CONCERNING EARLY BLOWDOWN CLADDING RUPTURE DURING A LARGE BREAK LOCA

Per your request, I have reviewed certain aspects of the DPV on Containment Isolation Valves at Zion. In particular, I addressed the issues raised with respect to cladding rupture of high burnup high pressure fuel early in blowdown prior to containment isolation (about 7 seconds). The comments are enclosed. If you have any questions, please contact me on x23573.

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Enclosures:
As stated

cc: R.B.A Licciardo
A. Thadani

8909010165-XA

Comments on a DPV Concerning Early Blowdown Cladding Rupture During a Large Break LOCA

In a DPV (Reference 1) Bob Licciardo has postulated that PWR fuel rods with high burnup and high internal pressure could sustain cladding rupture within a few seconds of a large break LOCA prior to containment isolation. This is further postulated to lead to large off-site releases. Following is some information which may be helpful in addressing some of the issues in the DPV. Seven issues in the DPV are first addressed, then some preliminary observations are made. The DPV issues are referenced by page number and a quote or summary of the issue.

Issue 1 (p. 3-1) - "Appendix K evaluation is not designed to report the earliest rupture that can occur." (Also, see pp. 3-4 and 3-5.)

While Appendix K does not specifically require searching for the earliest rupture, early ruptures would always be the worst with respect to 50.46 limits if they were calculated to occur. Vendor analyses in the past have shown that because of the extensive cladding swelling prior to rupture, the resultant low transient gap conductance severely limits blowdown heat removal. As a consequence, vendor evaluation model calculations showed that the 2200°F PCT was always exceeded. Therefore, the vendors would always need to reduce the peak power to avoid early blowdown cladding ruptures. Vendor steady state fuel thermal performance and subsequent LOCA analyses showed that the peak linear heat generation rate (PLHGR) was always low enough to avoid early blowdown swelling and rupture for high burnup pins. These studies were done about 13 to 15 years ago with Appendix K evaluation models which are no longer used. I do not know if analyses with high burnup pins have been done with recently approved fuel performance and LOCA models. The older analyses always showed that low burnup post densification pins were always most limiting, in fact, because the PLHGR was highest and gap conductance was very low. High burnup pins are lowest in PLHGR although the pin pressure is highest. The combination of high cladding temperature and higher internal pressure are needed to cause cladding rupture.

Issue 2 (p. 3-2) - "This shows that on infringement of DNBR at 1/10 second, average clad temperature increase very rapidly from a normal operating value of 720°F to at least 1350°F, and then to 1750°F, over a total period of seven seconds."

1750°F is indeed a very high early blowdown peak cladding temperature (PCT), but virtually impossible for a high burnup pin with a much lower PLHGR. If a high burnup pin reached 1750°F, at 7 seconds it would most likely rupture. More realistic LOCA analyses have been performed as part of the Code Scaling, Applicability, and Uncertainty program in RES. A best estimate analysis was performed and code uncertainties evaluated for a large break LOCA (Reference 2). In order to accomplish this, sensitivity studies were performed which varied gap conductance, peaking factors, and several other variables. The plant used was a Westinghouse 4-loop 3411 MWt plant with 17x17 fuel and a low burnup of only 16000 MWD/MTU which resulted in a PLHGR of 9.35 kw/ft. The blowdown peak for the nominal CSAU case was 1103°F (see Figure 1). Based on over 250 clad temperature calculations and using Monte Carlo sampling techniques, it was determined that the 95th percentile blowdown PCT was 1447°F. It has been determined that 15x15 pins (as used at Zion) with burnups greater than 40,000 MWD/MTU have PLHGRs no greater than 6.4 kw/ft. Using the CSAU calculated sensitivity of blowdown PCT to LHGR, the value of 1447°F can be extrapolated to approximately 1320°F for the 6.4 kw/ft PLHGR high burnup 15x15 pin. This illustrates that the 1750°F blowdown PCT calculated by Westinghouse is quite conservative, especially for a high burnup pin. I believe that this Westinghouse calculation is probably at least 10 years old.

Issue 3 (p. 3-2) - "Exhibit 10 also shows that W fuels require a design limit of 1% on cladding strain as a design limit, and 1.7% as a damage limit. The work of this Section 3 will show how both of these limits can be exceeded inside the seven seconds on infringement of DNBR during the course of a LOCA, ..."

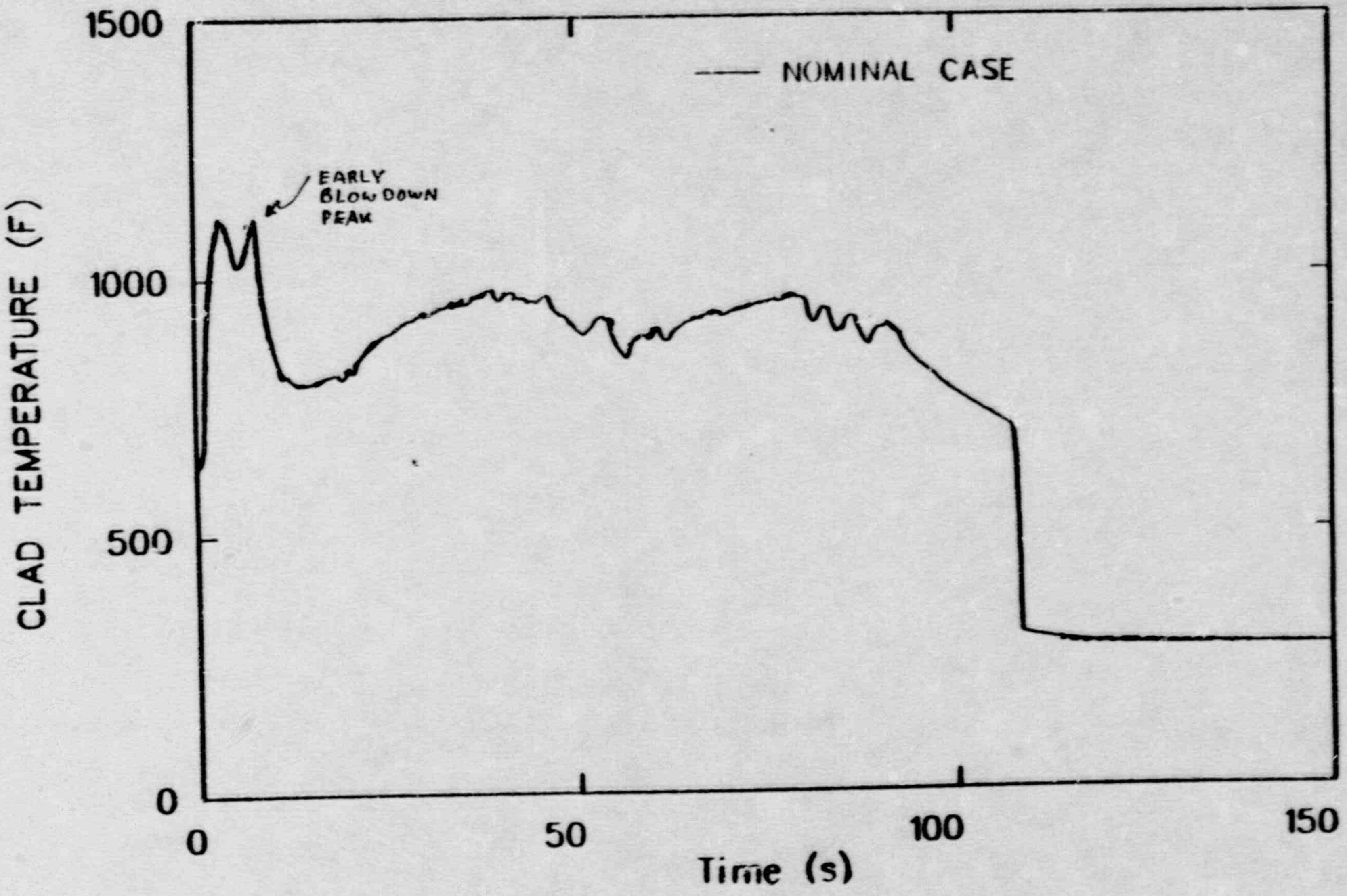

FIGURE 1. Nominal CSAU Case

As exhibit 10 states, these design values are for nominal operation or overpower conditions, not LOCA. Also, DNBR infringement has never been considered the operant criterion for fuel failure during a LOCA. Although, I am told that this is not as clear as it should be in the standard review plan or any applicable regulatory guides. Incidentally, PBF LOCA test do not show DNB occurring until 3-4 seconds for a very severe LBLOCA (Reference 3).

Issue 4 (p. 3-3) - "...there is a need for empirical tests to determine swelling and burst (rupture) characteristics under these same dynamic conditions."

The results of the PBF LOCA tests satisfy this condition and will be discussed as part of Issue 7.

Issue 5 (p. 3-3) - "Reference information shows that internal clad pressure under normally operating conditions is of the order of 1400 psig for new fuel and expected to increase to 2250 psig at the end of the 3rd cycle (for the fuel)."

It is not known what reference information is being invoked here. GAPCON calculations show the following results.

TABLE 1 GAPCON Pin Pressure Calculations

Code	Fuel	PLHGR kw/ft	Burnup MWD/MTU	Pressure (psig)
GAPCON	15x15	15	0	1700
GAPCON	15x15	10	50,000	2700
GAPCON	15x15	5	50,000	2500
GAPCON	17x17	15	0	1900
GAPCON	17x17	10	50,000	3300
GAPCON	17x17	6.5	50,000	3000

The Reference 4, GAPCON calculations were performed 9 to 10 years ago. The PAD 3.4 model (Reference 5) was approved by the NRC for design and safety analysis in May 1988. Proprietary calculations done with PAD 3.4 showed substantially lower pressures at comparable burnups and PLHGRs. It is well known that the GAPCON fission gas release model is very conservative. The PAD calculations were done at an arbitrarily high PLHGR and would show an even lower pressure at the reduced kw/ft.

Issue 6 (p. 3-3) - "It is proposed that, immediately, on a LOCA as clad temperature increases to 1350°F, gap pressure will increase by 20%, to 1800 psig .... At 7 seconds into the event, clad temperature has increased further to 1750°F, ... From this, it can be proposed that gap pressure for the complete rod can increase by 36% over its normal operating value to 2100 psig."

The basis for concluding that pin pressure increases during an LBLOCA blowdown is not known and contrary to the evidence. A series of 3 large break LOCA simulations (Reference 3) (LOC-3, LOC-5, and LOC-6) were performed in PBF with well instrumented Zircaloy clad UO_2 fuel elements pre-pressurized to simulate low and high burnup PWR fuel. PBF blowdowns are quite severe compared to postulated PWR LBLOCA blowdowns. In PBF, the pressure decrease and rate of mass loss is very rapid. No good reverse flow blowdown heat transfer is evident as is the case in LOFT results or PWR analysis. Figure 2 (Reference 6) shows the fuel rod pressure for rod 3 in test LOC-3. Also, shown are FRAP-T6 calculations using two different plastic deformation models. Clearly, pressure <u>decreases</u> throughout the transient. Figure 3 is a plot showing measured pressure decrease for Rod 11 in Test LOC-6. A FRAP-T5 characterization calculation was done for a postulated LBLOCA in Zion (reference 7) which also showed a pressure decrease throughout the transient.

Issue 7 (p. 3-5) - Concern is expressed about the relevance of electrically heated rods used in defining the swelling and rupture curves in NUREG-0630. It is suggested that the TREAT data shown in NUREG-0630 (Reference 6) would be more realistic. Also, on pp. 4-3 and 4-4, this concern is restated.

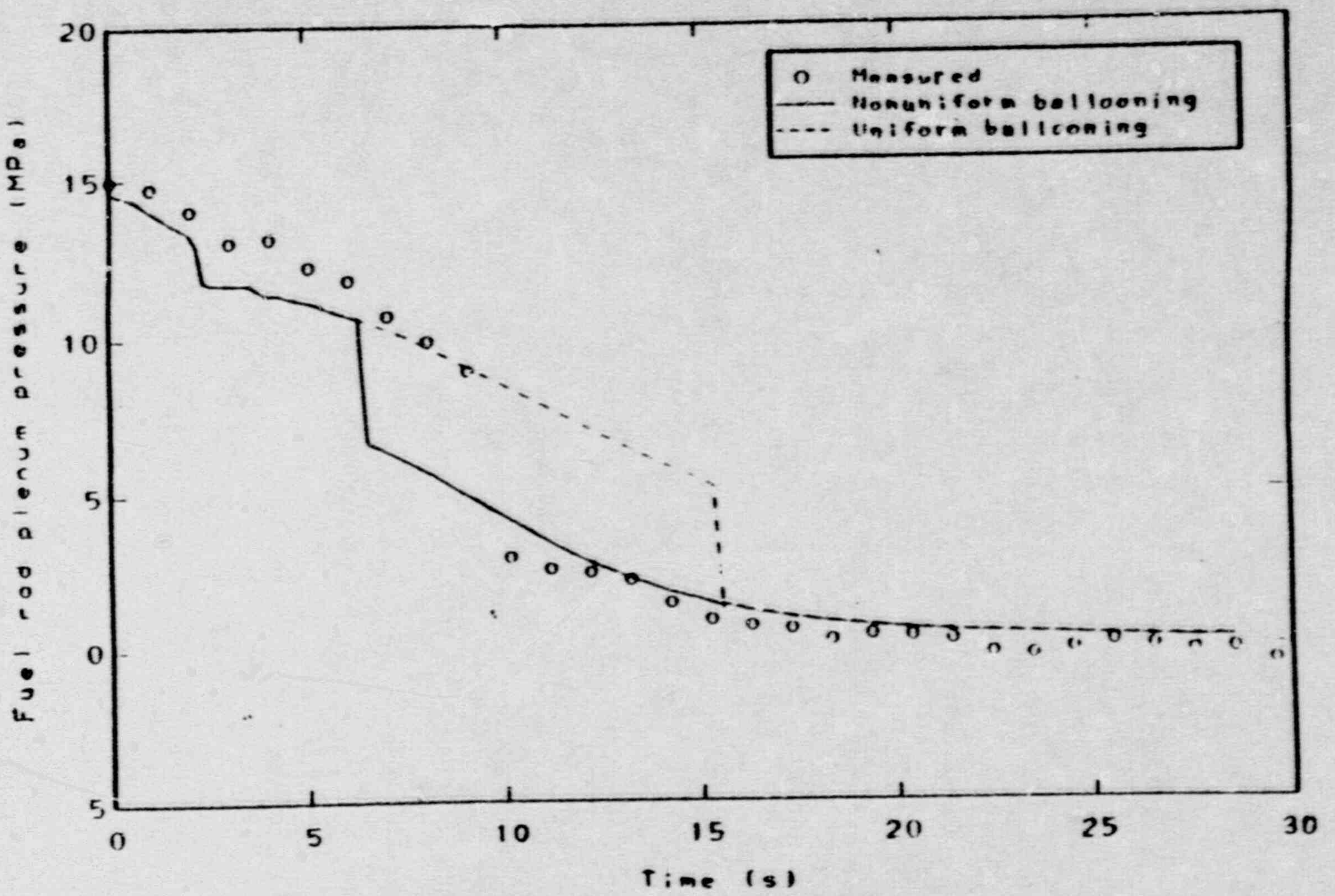

Figure 2. Comparison of measured and calculated fuel rod plenum pressure versus time for Rod 3 of PBF test LOC-3.

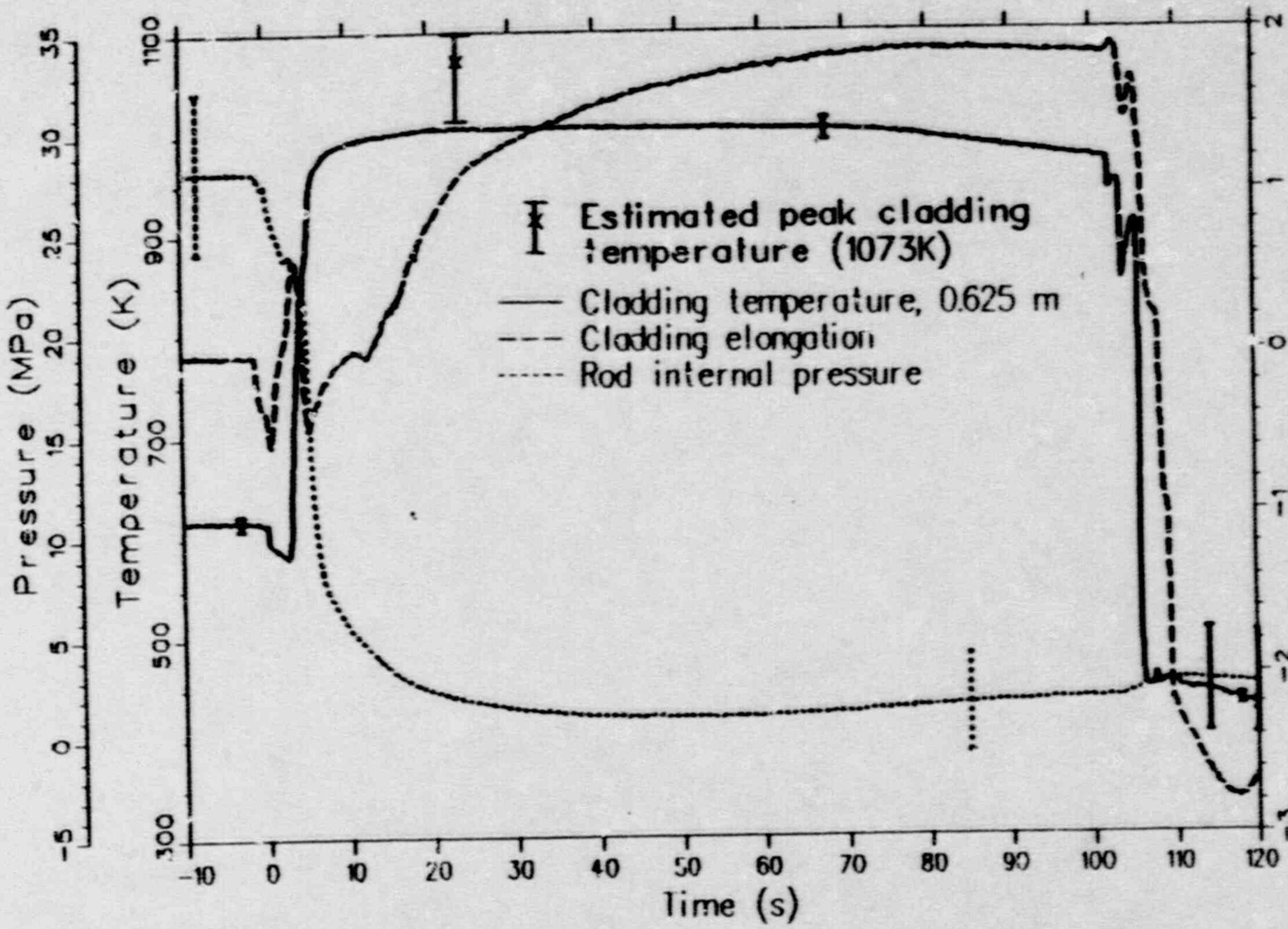

Figure 3. Thermal and mechanical response of Rod 11 during Test LOC-6.

It is clear that TREAT data is anomalous compared to the electrically heated rods and is attributed to difficulties in obtaining accurate temperature data in the burst region. A better source of in-reactor data is the PBF series discussed previously. Figure 4 is a plot from NUREG-0630 (Reference 8, Exhibit 16). Included are data points with temperature uncertainty for the 9 ruptured rods in the PBF LOC series of tests, and the FRF data from TREAT. It is clear that the more recent PBF data is very consistent with the NUREG-0630 curves.

Observations Regarding LBLOCA Blowdown Rupture of High Burnup Fuel Rods.

The main contributors to fuel cladding rupture are high pressure drop across the cladding and high cladding temperature. Early post-DNB cladding temperatures are determined to a very large degree by pre-accident stored energy which is a function of local peak power (PLHGR), pre-accident gap conductance, effective UO_2 thermal conductivity, blowdown heat transfer, and critical flow model. The CSAU study (Reference 2) confirmed this assessment. Of these variables, only PLHCR is controllable by plant operators, and then only to a limited degree. High burnup, third cycle fuel is always placed in low power regions. Pin pressure is determined by pre-pressurization and fission gas release. As shown in References 3 and 6, pin pressure does not exhibit a direct functional relationship to blowdown cladding temperature.

As noted earlier, the CSAU 17x17 95th percentile PCT of 1447°F (Reference 2) could be approximately extrapolated to 1320°F for a high burnup 15x15 pin. The 15x15 PCT calculated at 13.26 kw/ft (Reference 7) was 1543°F. The Zion hot pin did not rupture in Reference 7. The Reference 7 calculation extrapolated to 6.4 kw/ft would result in a PCT of about 1245°F. Therefore, 1320°F determined previously appears to be a good high side estimate of blowdown PCT for a high burnup 15x15 pin. In both Reference 7 and Reference 2, this blowdown peak occurred between 5 and 9 seconds.

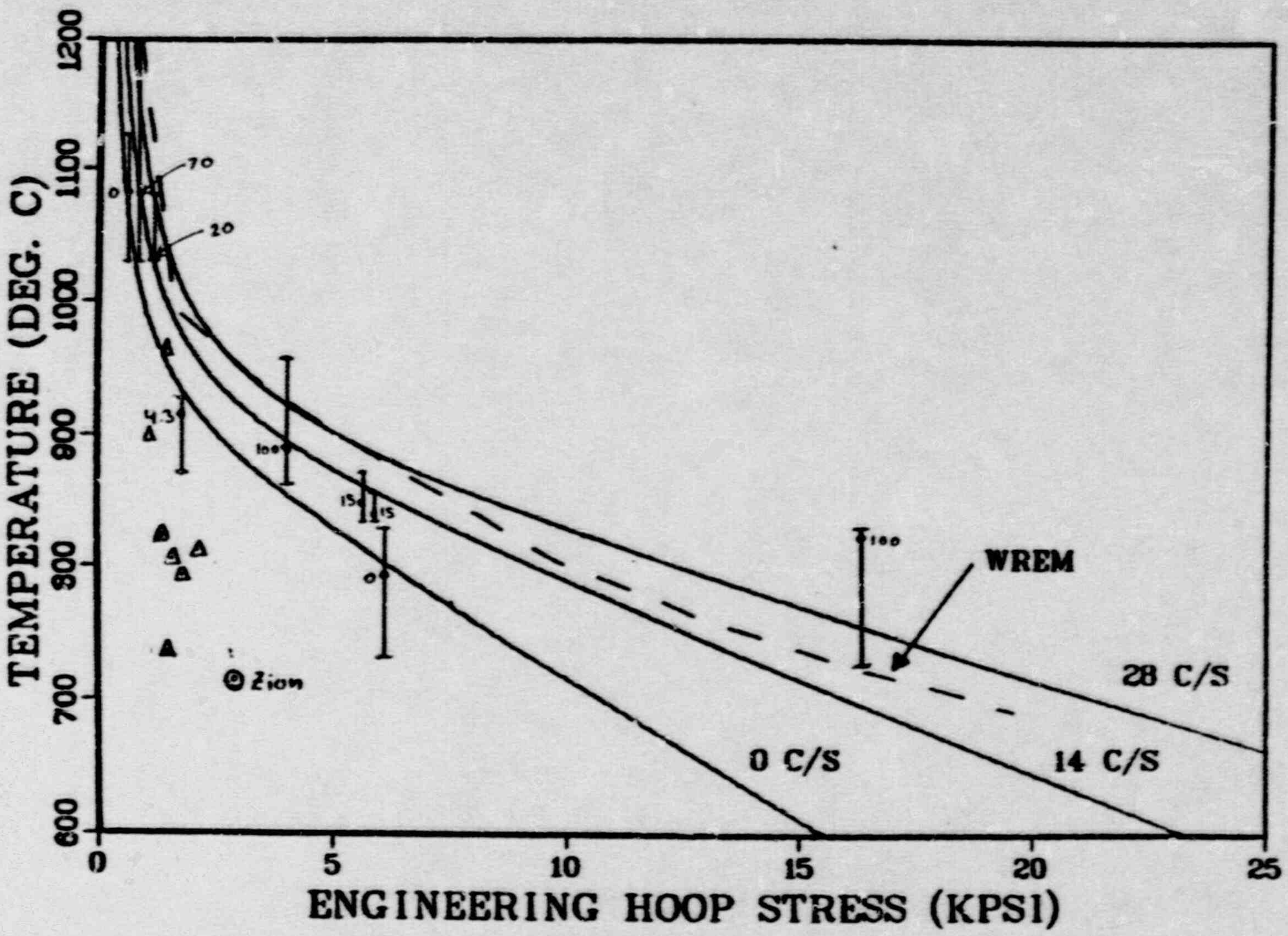

Fig. 4. WREM model and ORNL correlation of rupture temperature as a function of engineering hoop stress and ramp rate, with PBF LBLOCA test results. Numbers adjacent to test data points are ramp rates in °C/sec. TREAT data points are shown as triangles. The Zion high burnup pin estimate is given by a circle.

PAD 3.4 calculations for a 15x15 pin were not performed in Reference 5, but by extrapolating a 17x17 PAD analyses using incremental values from Table 1, it is estimated that the pre-accident 15x15 pin pressure at end of cycle 3 would be about 1500 psi. Based on the pressure decrease calculated for the 15x15 pin in the first 5 seconds in Reference 7, it is estimated that the pin pressure at 5 seconds for a high burnup 15x15 pin would be 1300 psi. The system pressure at that time was determined to be 920 psi. The pressure drop across the clad is therefore 380 psi and the engineering hoop stress is estimated to be 3.0 KPSI. As shown in Figure 4, this is well below the NUREG-0630 curves and even below the TREAT data. Therefore, it is not expected that any high burnup pins which have low LHGRs would experience any early blowdown ruptures.

It should be noted, however, that this is based on extrapolations, and surely direct calculations based on actual condition would be preferable. Also, if indeed high burnups are expected in the future with higher LHGR, this issue should be revisited. In fact, when significant changes in fuel design models and blowdown LOCA models are proposed, this issue should also be addressed.

REFERENCES

1. R.B.A. Licciardo, "An Evaluation of the Criterion for and the Calculation of Offsite Doses Deriving from Open Containment Purge Valves During a LOCA a Zion Units 1&2," July 20, 1989.

2. N. Zuber, et al., "Quantifying Reactor Safety Margins: Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large Break Loss of Coolant Accident," NUREG/CR-5249 (Draft) Draft Date: August 1, 1989.

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8. D.A. Powers, R.O. Meyer, "Cladding Swelling and Rupture Models for LOCA Analysis," NUREG-0630, April 1980.