Powers

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

#7

MAR 3 1 1978

MEMORANDUM FOR: File

FROM: M. L. Picklesimer
Fuel Behavior Research Branch

SUBJECT: MINUTES OF WORKSHOP ON SIMULATION OF NUCLEAR FUEL RODS IN LOCA, NATIONAL BUREAU OF STANDARDS, GAITHERSBURG, MD. NOVEMBER 11, 1977

As a result of discussions held by the UKNII, the USNRC, and the FRGBMI on June 29, 1977, in London, England, a workshop was planned and held in conjunction with the WRSR Annual Information Meeting, NBS, November 7-11, 1977. The objective was to examine the latest information on the behavior of Zircaloy fuel cladding during ballooning and bursting by transient and isothermal heating, the effects of different methods of heating, and the behavior predicted for nuclear heated fuel rods in a LOCA. The agenda of the workshop is attached as Enclosure A and was followed except for the addition of a presentation by T. Healey, Central Electricity Generating Board, England, on "Analysis of Axial Ballooning Behavior of Directly Heated Zircaloy Tubes." The attendence list is given in Enclosure B. Copies of the available handouts of the meeting are attached.

The meeting was convened at 9:20 by the Chairman (M. L. Picklesimer, NRC) with an introduction into the justification and objectives of the workshop. He then discussed his analytical examination of the extended axial ballooning (reported by Hindle) from the standpoint of a "negative feedback" control of local ballooning which is inherent in Joule-heated tubes having "cold" surroundings. The principal conclusion was that for specimens ballooning at temperatures in the alpha-phase range there was a temperature of the surroundings below which extended axial ballooning would be observed and above which it would not. If the specimen was at 800°C, then this temperature was approximately 570°C. Since a fuel rod in a nuclear heated fuel bundle would not "see" surroundings uniform in temperature and more than 200°C colder than the fuel rod, the extended axial ballooning observed by Hindle in a controlled laboratory test could not occur in a real reactor in a real LOCA.

D. O. Pickman then presented the work on extended axial ballooning conducted by E. D. Hindle at the Springfields Laboratory (UKAEA). The tests are conducted by Joule heating of single Zircaloy fuel tubes severely restrained by internal alumina pellets and exposed to low temperature steam in surroundings at a temperature of not greater than 70-80°C. Hindle has extended the temperature range

3

B-3
B-4

in which extended axial ballooning can be observed to 890 to 1150 K. He also concludes that greatly increased or decreased internal pressures are not an adequate solution to the problem of extended axial ballooning.

W. A. Fiveland, Babcock and Wilcox, discussed the work he and others at the B&W Alliance, Ohio installation had conducted on transient heated burst tests in argon of single and multirod tests of Zircaloy cladding heated by internal radiant heaters (tungsten filaments in quartz tubes), with shaped heated shrouds. They observed no extended axial ballooning, and found local balloons (with burst) only a few tube diameters in length.

T. Healey, Berkeley Nuclear Laboratories, UK Central Electricity Generating Board, England, presented the work and analysis he had done with Clay and Duffey in an analysis of the Hindle results. He concluded that the extended axial ballooning observed was an artifact of the test method as a result of a coupled heat transfer-creep deformation mechanism which allows a localized strain perturbation to cool preferentially and force neighboring regions to begin to strain. He emphasized that results from Joule heating experiments should not be used to infer the thermal and deformation response of tubes heated by internal elements, or by decay heat from nuclear fuel.

After a coffee break, D. L. Burman, Westinghouse Nuclear Fuels Division, presented an analysis of experimental results on circumferential temperature gradients produced in Zircaloy fuel cladding by off-center fuel pellets during transient heating. His measurements indicate that circumferential temperature gradients of 40°F and more can be expected at any axial position in pelleted fuel rods during transient heating at 25°F/second.

The very recently obtained creep-rupture tests on Zircaloy fuel cladding obtained at ORNL in the MRBT program were then reported by R. H. Chapman. Using an internal conduction heater (electrically heated) for simulation of the nuclear fuel, creep-rupture tests having nominally 50, 100, 160 and 250 seconds to rupture at 760°C had essentially the same burst strains and axial strain profiles as shown by specimens burst in transient heating at nominally 50°F/second using the same two heaters as in the creep-rupture tests. No extended axial ballooning was observed, and comparison of the creep-rupture results with the transient heating results indicates that there is no effect of heating rate at rates of 0 and 50°F/second when an internal conduction heater is used in his test.

F. Erbacher, GfK-Karlsruhe, Federal Republic of Germany, presented the results obtained in single rod tests in the PNS program using internal conduction heaters of a different design than the ORNL heaters and at a slower heating rate. Their experimental results confirm those obtained by Chapman at ORNL except that the circumferential strains were somewhat greater. In addition, Erbacher presented the results of several in-pile tests, using nuclear heated rods, which were in excellent agreement with those tests conducted out-of-pile, in both burst strains and axial strain profiles.

The effects of circumferential and axial temperature gradients produced by internal pellets during transient heating (Joule) burst tests were discussed by T. F. Kassner, ANL. He then presented an analysis of the data which included a strain-localization parameter based on axial restraint and circumferential temperature gradients which correlated data determined over a wide range of degrees of restraint, temperature gradients, and heating rates.

Data reported by A. A. Bauer, BCL, on the transient heating burst tests of irradiated cladding removed from the spent fuel of the H. B. Robinson plant were in excellent agreement with those reported by Chapman from the MRBT program, showing that the irradiation damage produced by a burnup of about 30,000 MWD/MTM was effectively annealed out by the time the burst temperature was reached (740°C was the lowest burst temperature yet observed in the program).

Conducting an analysis of the transient heating burst data reported by Kassner, at ANL, with the inclusion of a limited amount of other data, P. G. Smerd, Combustion Engineering Inc., concluded that burst strains and strain patterns are quite sensitive to many factors of the test, that the method of heating is the most important of the test parameters, and that internal conduction heaters are the most realistic for simulation of nuclear heated fuel rods.

Experimental gap conductance measurements made at Halden in NRC sponsored tests were analyzed by R. E. Williford and C. R. Hann to permit calculation of circumferential temperature gradients of 15-20°C typically on the ID of fuel rod cladding for the case of eccentric fuel pellets during normal operation of a reactor. Williford reported also that the asymmetric relocation of fuel fragments was found to severely localize the temperature differences of about 20°C to a circumferential sector of only a few degrees wide (a few tenths of a mm in a 15x15 PWR rod).

J. A. Dearien then showed that the computer code FRAP-T could be used to calculate typical circumferential temperature variations of

45°C at a peak clad temperature of about 1000°C in a BWR fuel rod at 160 seconds into a LOCA, that the ballooned section of one rod could cause the ballooning and burst of a neighboring rod to occur at another axial position, and that an axial temperature difference of only 5°C could cause localization and restriction of the balloon length. He also showed that FRAP-T could be used to accurately model the axial strain profiles observed in burst specimens heated by Joule heating (Hindle) and by an internal conduction heater (Chapman).

The distribution of peak cladding temperatures observed in a simulated fuel bundle in a FLECHT tests was reported by L. Hochreiter, Westinghouse. Typically, the peak clad temperatures measured at a given elevation varied around any chosen rod from 5°F to as much as 200°F (or greater) from one neighbor to another. In no case were the temperatures of the "surroundings" uniform to 50°F for any rod reported. The temperature differences changed with time and the approach of the quenching front. Generally, the data showed that the uniformity of temperatures, both axially and circumferentially required to produce extended axial ballooning would not occur, provided that the FLECHT tests produce a reasonable simulation of the behavior of a nuclear fuel bundle during a LOCA.

The LOCA tests planned for the PBF were discussed by W. J. Quapp, EG&G. Single rod tests with "cold" flow control shrouds will be conducted to examine the behavior of nuclear heated fuel rods during blowdown and heatup phases of LWR LOCA's. Test objectives include the determination of the effects of axial and circumferential temperature gradients, cladding deformation patterns and gap gas flow response, the extent of the metal-water reaction, and the degree of oxygen embrittlement, and the production of in-pile data for comparison to the MRBT out-of-pile data.

The last presentation was made by S. A. Naff, EG&G, who described the NRC IFA-511 program planned for conduct in the Halden reactor to compare the response of Zircaloy fuel cladding for both nuclear and electrically (internal conduction) heated tests in the same test space.

The floor was opened for general discussion. After questions were answered as to the experimental and analytical work presented, F. Erbacher stated that it was also necessary to conduct an accurate simulation of the heat transfer conditions expected in a LOCA. There seemed to be unanimous support of this sentiment from the researchers of the audience.

T. Healey presented his summary of the workshop, concluding that both axial and circumferential temperature gradients must occur in a nuclear rod during LOCA, and that they must be present in any realistic simulation.

While many of the participants were convinced that extended axial balloons would not occur in a LOCA, representatives from the UKAEA Springfields Laboratory and the UKNII thought it premature to rule it out. It was suggested that another workshop may be necessary.

After expressing his appreciation of the efforts by the several speakers and of the attention of the audience, the Chairman closed the workshop at 5:05 p.m.

M L Picklesimer

M. L. Picklesimer
Fuel Behavior Research Branch
Division of Reactor Safety Research

Enclosures: 2, as stated

Enclosure A

TENTATIVE WORKSHOP AGENDA
NOVEMBER 11, 1977

SIMULATION OF NUCLEAR FUEL RODS IN LOCA
Conference Room B
National Bureau of Standards
Gaithersburg, MD

Chairman: M. L. Picklesimer, NRC

9:15 - 9:40	Introduction and Statement of the Problem	M. L. Picklesimer, NRC
9:40 - 10:00	Extended Axial Ballooning in Zircaloy Cladding - Joule Heating	E. D. Hindle & D. O. Pickman, SNPDL/UKAEA
10:00 - 10:20	Single and Multirod Tests, Internal Radiant Heating	W. A. Fiveland & A. L. Lowe, B&W
	Analysis of Axial Ballooning Behavior of Directly Heated Zircaloy Tubes	T. Healey, B. D. Clay,(CEGB & R. B. Duffey (EPRI)
10:20 - 10:40	COFFEE BREAK	
10:40 - 11:00	Transient Burst Tests and Circumferential Temperature Gradients, External Radiant Heating	D. L. Burman, Westinghouse
11:00 - 11:20	Single and Multirod Tests, Transient and Steady State, Internal Conduction Heating	R. H. Chapman, ORNL
11:20 - 11:40	Single and Multirod Tests, Transient and Steady State, Internal Conduction Heating	F. Erbacher, PNS/GfK, Karlsruhe
11:40 - 12:10	Effects of Temperature Gradients in Transient Heating Burst Testing, Joule Heating	T. F. Kassner, ANL
12:10 - 12:30	Transient Heating Burst Tests on Irradiated Cladding, Internal Conduction Heating	A. A. Bauer, BCL
12:30 - 1:30	LUNCH	
1:30 - 1:50	Factors Influencing Strain Behavior in Simulated LOCA Transients	P. G. Smerd Combustion Engineering
1:50 - 2:10	Effects of Pellet Eccentricities in Halden Gap Conductance Tests	R. E. Williford & C. R. Hann, BNWL
2:10 - 2:30	Effects of Manufacturing Tolerances on Surface Temperature of Neighboring Pellets During LOCA	A. L. Lowe & B. Bingham Babcock & Wilcox

2:30 - 2:50	Distribution of Peak Cladding Temperatures in a Bundle During LOCA as Calculated by FRAP	J. A. Dearien, EG&G
2:50 - 3:10	Distribution of Peak Cladding Temperatures in FLECHT Tests	L. E. Hochreiter, Westinghouse
3:10 - 3:30	COFFEE BREAK	
3:30 - 3:50	Single and Multirod Nuclear Tests in PBF	W. J. Quapp, EG&G
3:50 - 4:10	A Halden Experiment to Compare Nuclear and Electrically Heated Rods During Reflood	S. Naff, EG&G

Enclosure B

Roster of Attendees

Name	Organization
M. L. Picklesimer	FBRB/NRC
J. D. Harvie	AECB Canada
J. G. Waddington	AECB Canada
Leo Sepold	GfK Karlsruhe/INEL Idaho
J. B. Sayers	UKAEA, Harwell
C. C. Baylis	BNFL Springfields Works, UK
R. H. Chapman	ORNL
R. A. Shaw	SNL Springfields UKAEA
D. O. Pickman	SNL Springfields UKAEA
K. Suzaki	Toshiba Electric Co., Ltd.
Tim Healey	CEGB Berkeley Nuc. Labs., UK
T. N. Rutherford	NII (H + S.E.), UK
D. R. M. Fryer	NII (H + S.E.), UK
R. N. H. McMillan	UKAEA, SRD.
G. M. Jordan	UKAEA (SRD)
J. Randles	JRC-Ispra
Paul Shewmon	NRC-ACRS
Adrian Roberts	EPRI
F. J. Fayers	UKAEA, Winfrith
R. I. Hawes	UKAEA, Winfrith, UK
John A. Dearien	EG&G Idaho
Carlo Mancini	CNEN, Rome, Italy
Dale E. Fitzsimmons	Battelle Northwest/PNL
A. A. Bauer	Battelle-Columbus
W. J. Quapp	EG&G Idaho
D. L. Burman	Westinghouse
T. F. Kassner	ANL
A. L. Lowe, Jr.	B&W-NPGD
W. A. Fiveland	B&W-A.R.C., Research
J. L. Crowley	ORNL
E. L. Courtright	PNL
P. J. Pankaskie	BNW/PNL
C. L. Mohr	BNW/PNL
J. A. Christensen	BNW/PNL
R. E. Williford	BNW/PNL
E. F. Jageler	Combustion Engineering
Richard Oehlberg	EPRI
Perlingi Fien	NUCLITAL
P. L. Hedrick	PNL
M. J. Arnold	CEGB/UK
R. S. Hoverd	GEC/UK
K. T. Routledge	NPC/UK
J. G. Collies	UKAEA/UK

Name	Organization
W. G. Lussie	EG&G Idaho, Inc.
A. W. L. Segel	AECL, Chalk River
R. Dimenza	c/o AECL, Chalk River
S. Finzi	J.R.C. EURATOM. ISPRA (Varese-Italy)
A. Pedretti	CNEN, Italy
J. L. Ricard	A.E.C.B., Ottawa
D. J. Merrett	NPC/UK
Michio Ishikawa	JAERI
Paul Boehnert	NRC/ACRS
J. O. Cermak	Westinghouse
L. E. Hochreiter	Westingbouse
Granville Sewell	ORNL
F. D. Coffman	USNRC/DOR
R. V. Belluz	AECL,Power Projects
T. Kobori	PNC, Japan
R. C. Hagar	ORNL (PWR-BDHT)
L. J. Ott	ORNL (PWR-BDHT)
R. E. Textor	Union Crabide Corp., Oak Ridge
R. A. Hedrick	ORNL (PWR-BDHT)
W. L. Riebold	C.E.C.-J.R.C. Ispra/Italy
E. Dluzniewski	GRS-F.R. Germany
A. J. Hedemann	GKSS-FRG
T. A. Doyle	EURATOM-JRC, Ispra, Italy
F. J. Erbacher	GfK-F.R. Germany
F. Wunderlich	KWU-F.R. Germany
P. G. Smerd	Combustion Engineering
D. S. Rowe	Engineering Consultant
L. H. Vons	E.C.N. - Petten - Holland
P. S. Check	NRC/NRR
D. A. Powers	NRC/NRR
R. O. Meyer	NRC/NRR
Russ Ball	BAW - Lynchburg
Manfred Fischer	GfK - Karlsruhe
Rom Duffey	EPRI
H. Koponen	IRP, Finland
B. Tolley	CEC Brussels
G. P. Marino	NRC/RSR
L. Thompson	NRC/NRR
M. Tokar	NRC/NRR
S. A. Naff	EG&G - LOFT
J. L. Butragueno	NRC/Standards