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HW-56352 A

E. A. Evans
8/1/56

LONG CARTRIDGE FUEL ELEMENTS FOR "SAFE-FAILURE"

This document consists of
12 pages, No. 1 of
1 copies.

INTRODUCTION

"Safe-failure" is an important criterion for power reactor fuel elements designed to contain core materials which react rapidly with high-temperature coolant. Out-of-pile experiments⁽¹⁾ indicate that, without a "safe-failure" fuel element, expensive and possibly catastrophic reactor shutdowns may occur if the fuel element jacket fails during irradiation in high temperature water. That jacket failures occasionally will occur, regardless of the material or fabrication process involved, seems to be generally agreed.

Fuel elements involving cluster arrangements⁽²⁾, oxide cores⁽³⁾, and wafer assemblies with "bulkheads" for compartmentalization⁽⁴⁾ have been proposed as being relatively safe in event of jacket failure. A fourth possibility is a type of long cartridge fuel element.^(*)

DISCUSSION

A long cartridge fuel element designed for "safe-failure" would consist of an outer jacket containing:

- (1) An inner jacket, or jackets, covering the core material and providing high-integrity corrosion protection if a defect appears in the outer jacket during irradiation; and
- (2) Pressurized helium gas between the outer and inner jackets to provide a rapid, reliable pressure indication of any perforation of the outer jacket^(**), and also to improve heat transfer.

This double-jacketed fuel element, with a simple, built-in alarm system, should make

(*) Various types of long cartridge fuel elements have been investigated previously at Hanford⁽⁵⁾ and used successfully in other reactors.^(6,7)

(**) J. W. Riches has suggested that a small amount of a radioactive gas mixed with the helium would provide an additional alarm system by actuating radioactivity monitors in the coolant.

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possible the safe use of fuel element core materials such as metallic uranium (with reactivity gains), or magnesium matrix cores⁽²⁾ (for stability at high burn-ups, and for high thermal conductivity to permit large core diameters without melting near the center of the core).

Two general types of long cartridges having double jacketing and gas-pressure leak detection should be considered.

- (1) A long, outer jacket containing short, jacketed, uranium slugs or stacks of wafers. The outer jacket would be formed from zirconium, stainless steel, or other material, and the inner jackets from aluminum or aluminum alloy. A thin aluminum oxide layer on the inside and outside of the aluminum jackets covering the short slugs would be used to prevent diffusion reactions.
- (2) A long, outer jacket, containing a long inner jacket. The outer jacket would be the same as described above; the inner jacket would be of essentially the same length and would contain washers, slugs, or a single rod or tube of fissionable material.

Both types of elements probably should be suspended in a vertical position to obtain uniformity of heat transfer.

Although "safe failure," and positive warning of partial failure would be the principle objectives in using a double-jacketed, long cartridge fuel element, there are other characteristics which should be considered.

- (1) Simplified, relatively inexpensive, jacket fabrication - particularly of materials such as zirconium - should result from using tubes instead of cans as the primary coolant barrier. Ribs could be placed on the outside of the cartridge fuel element thereby avoiding fabrication problems involved in placing ribs on the inside of the reactor process tubing.
- (2) Welds normally exposed to the coolant would be eliminated, except at the ends of the long jackets; if aluminum or aluminum alloys were used for short,

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inner jackets they could be applied readily by processes such as point-closure⁽⁸⁾. Elimination of end effects by using the continuous jacket would prevent erosion, corrosion, reactivity losses, and misalignment associated with short slugs exposed to the reactor coolant.

- (4) Decreased uranium distortion might be achieved by the use of slugs or wafers in the inner jacket or jackets and, possibly, from the restraining effect of the jackets. Tendency of the core material to split also might be decreased by the higher temperatures which would exist near the surface of the core materials in a double-jacketed fuel element^(*).
- (5) Matrix slugs containing magnesium and uranium are more stable than massive, metallic uranium at extremely high exposures, but they have the disadvantage that the matrix material corrodes extremely rapidly in high-temperature water. A "safe-failure," long cartridge element therefore might be an excellent companion for the matrix slug. The temperature drop from the surface to the center of a matrix core would be relatively small because of the relatively high thermal conductivity of this material. This characteristic would make it possible to use a matrix core of relatively large diameter in a long cartridge, thereby achieving greater nuclear reactivity for certain applications.
- (6) Continuous charging and discharging might be feasible with a long cartridge. Ring seals near each end of the long cartridge between the cartridge outer jacket and the reactor process tubing might allow the ends of the long cartridge to be opened and the inner elements to be charged or discharged without shutting down the reactor and stopping the coolant flow. This concept would be very difficult with high-temperature, high-pressure, aqueous coolant,
-
- (*) Splitting of the core probably could be detected by monitoring the helium for radioactivity caused by release of fission products into the annulus between the inner and outer fuel element jackets. Also, expansion of the outer jacket due to core splitting could be detected by coolant pressure monitors.

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but with organic coolants equipment such as end seals would be relatively simple.

A long cartridge element probably would introduce new problems:

- (1) Fabrication difficulties might be encountered in making very thin^{W41} -- say, 0.005 to 0.020-inch thick-tubes for long jackets. There are reports⁽⁹⁾, however, that such tubing can be made from zirconium on a production basis -- probably, with less difficulty than with making short cans. Co-extrusion, swaging, sizing, hydrostatic pressure, and unskinning are some of the procedures which might be applicable.
- (2) Inadequate or non-uniform heat transfer might occur because of the lack of metallurgical bonding. The experience of Canadian, British and, to some extent, U. S. reactors, indicates that this may be no problem. In any event, unbonded elements may be necessary because, with a few possible exceptions such as the co-extruded U-Zr bond, bonding layers are not stable at the temperatures which probably will be encountered in future reactors. Experience with insulated slugs at the Materials Testing Reactor indicates that bonding may not be essential, and the following report from early Hanford work also offers some reassurance:

"Tests on thermal cycling were made to determine the effect on the thermal transfer from slug to jacket after cycling enough and operating under conditions such that the aluminum jacket would creep and no longer return to a snug fit on the slugs. After 4300 cycles, the heat transfer coefficient "h" was found to be around 1.5 cal/cm²/sec/°C while a value of around 0.4 was found even on a slug so loose in the jacket that it rattled when cold. This compares with the original measurements of around 1 to 2 cal/cm²/sec/°C which indicates that the slugs come up to practically their original tight fit in the jacket when heated again(1)".

Calculations indicate that approximately 500 C would be the maximum temperature in a long cartridge having the following characteristics: 1.3 inch O.D., 0.5 inch I.D., with a natural uranium core bonded to an inner zirconium jacket 0.005-inch thick and operating at 25 KW/ft. in a tightly-fitting, outer, 0.020-inch thick zirconium jacket exposed to 300 C coolant.

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CONCLUSIONS AND RECOMMENDATIONS

Operation of a power reactor at high temperatures without undue hazards due to using massive, chemically reactive, metallic fuel element cores may be possible with a long cartridge having an outer jacket which is "backed-up" by a high-integrity, inner jacket that will protect the fissionable core material if a defect appears in the outer jacket.

Prompt removal of a defective long cartridge element would be possible because high-pressure helium between the two jackets would give rapid, positive warning to a pressure-measuring gauge fitted to the end of the fuel element. Immediate discharge of the defective element would not be necessary, however, because of the corrosion protection afforded by the inner jacket, or jackets. The concept is applicable to a variety of fuel element jacket and core materials and geometries.

The latest American, British and Canadian experience with unbonded fuel elements should be investigated more extensively, and accurate heat transfer and reactivity calculations and measurements should be made with the long cartridge assemblies which appear to be most promising. (In-pile and out-of-pile experiments by the Metallurgy Sub-Section will provide helpful information concerning heat transfer.)

The most promising fuel element should be fabricated and tested in the MTR, ETR, H-Pile, or KER facilities. An MTR test could be most quickly and conveniently performed by using only a short section of the element. Accurate experimental temperature measurements could be obtained from such a test and the rupture behavior of an element of the proposed design could be determined safely and relatively quickly. The design and fabrication procedures for fuel elements which may be suitable for such a test are being investigated.

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Line 10
Hv-56350 RD

U 1.434 OD
0.75 ID

Al 1.465 OD WITH 0.4" Al_2O_3 ON EXTERIOR
1.435 ID

Zr 1.498 OD
1.468 ID

0.5 ID
1.2 OD, 2500/ft

AREA	AT °C (50 KW/IN)	AT 25 KW/IN	1.498
25 WATER FILM	21	10.5	AT
21 Zr (15 MILS)	28	14	1.468
21 NO BOND (Zr- Al_2O_3 INTERFALE, He FILLED)	45	21	1.435
Al $_2$ O $_3$ (0.4 MIL)	21	11	1.434
Al (15 MILS)	1	0	1.434
Al $_2$ O $_3$ (0.4 MIL)	21	11	1.434
Al $_2$ O $_3$ -U INTERFACE	21	11	1.434
U - OD TO ID. (0.342")	220	110	1.434
TOTAL	402	199	1.434
WATER	250	250	1.434
	650	450	1.434

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LONG CARTRIDGE FUEL ASSEMBLY

Handwritten: 44-56,352 RD

April 13, 1955

TABULATION OF SLUG RUPTURE TESTS IN ELMO-3 AND 4

No.	Type	Temperature, C	Velocity, fps	Time*, hours	Delay, minutes before flow stoppage	Remarks
1	AlSi bonded solid U	175	90	24	not known	ELMO-3 boiling loop (10% quality)
2	AlSi bonded Al canned solid U	250	2	4 hrs.	45 min.	Bulged schedule 80 S.S. pipe
3	AlSi bonded Al canned solid U	280	8	1-1/4	18 min.	Gunbarrel section surrounds slug
4	Zr. canned U-Mg Matrix (0.9" O.D.)	240	10	1/2	2 min.	failure started at 230 C as determined by flow decrease
5	Al canned U-Mg Matrix (1.44" O.D.)	220	11.5	1/10	3 min.	failure started at 210
6	S.S. canned U-Mg Matrix (1.5" O.D.)	240	12	1/4	3 min.	failure started at 230 C
7	Mech. bonded Al canned, solid uranium	250	8	1/2	15 min.	swelling is about twice original diameter
8	Unbonded, Al canned solid U	240	12	1/3	5 min.	

*NOTES:

1. The photographs of Nos. 1 and 2 show only the ruptured slug; whereas the remainder include the tubing surrounding the slug.
2. Time refers to hours above 200 C.
3. Delay time refers to minutes elapsed from first indication of flow decrease until complete flow stoppage.

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44-56350 RD

April 15, 1955

No.	Type	Temperature, C	Velocity, fps	Time, hours	Delay, minutes Before flow stoppage	Remarks
9	Al Canned, I&E, Nickel bond, Uranium	260	11	1/2	20 min.	Defect on outside; Inside hole completely plugged; less outside swelling than normal.
10	Same as 9	280	11	3	About 180 min.	Defect on inside; flow stoppage gradual and not complete.
11	Zirconium canned, Uranium Mg Matrix 1.1 in. O.D.	270	4.5	2/3	7 min.	Normal process tube used; extra large annulus; tube split in two locations.

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The test section of ELMO-4 is a 3-inch Schedule 80 stainless steel pipe. The defected slugs were contained in process tubing positioned in the center of the pipe, with the loop flow directed through the process tubing. Thus, room for expansion of ruptured slug and process tube was provided. A sketch of the pipe, tube, and slug is shown below:

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