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DEVELOPMENTAL TESTING
SNAP 2
FUEL ELEMENTS
(Title Unclassified)

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M-3679 (36th Ed.)

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DEVELOPMENTAL TESTING

SNAP 2

FUEL ELEMENTS

(Title Unclassified)

By

J.L. ISAACS

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CONTENTS

	Page
Abstract	4
I. Introduction	5
II. Procedure	7
A. Thermal Soak	7
B. Vibration and Shock	7
C. Ramp Heating	9
D. Endurance Test	9
III. Results and Discussion	11
IV. Conclusions	23
References	24

TABLES

1. Reference Levels of Vibration and Shock	9
2. Permeation Data of Group 1 Elements (1100°F)	11
3. Permeation Data of Group 2 Elements (1100 and 1200°F)	12
4. Permeation Data of Group 3 Elements (1200 and 1300°F)	14
5. Permeation Data of Group 4 Elements (1200°F)	17
6. Vibration and Shock Data of Group 4 Elements	20
7. Effect of Core Position on Permeation Rate	22

FIGURES

1. SNAP 2 Fuel Element	5
2. Planned Test Sequence	8
3. Endurance Permeation Data of Group 1 Elements (1100, 1200, and 1300°F)	10
4. Postendurance Permeation Data of Group 1 Elements (1000 to 1300°F)	10
5. Endurance Permeation Data of Group 3 Elements (1300°F)	16
6. Typical Group 4 Elements After Vibration and Shock	18
7. Fuel Element Locations During Vibration and Shock	21
8. Effect of Core Position on Permeation Rate	21

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ABSTRACT

Forty-three developmental SNAP 2 fuel elements (normal uranium) were subjected to environmental inputs, in order to obtain a qualitative measure of their performance.

Seven fuel elements completed the program, and seven others failed during testing. The testing of the remaining 29 elements was discontinued when the SNAP 2 fuel element development program was redirected.

The SNAP 2 fuel elements were found to perform well at 1300°F and under vibration and shock at the component qualification level for SNAP 10A. Generally, the elements were damaged if vibration and shock levels exceeded the component qualification level for SNAP 10A by a factor of two or more. The damage appeared to a direct function of the level of the input.

NAA-SR-10188

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I. INTRODUCTION

The test program discussed in this report was designed to obtain a qualitative measure of the performance of SNAP 2 fuel elements.

These fuel elements, as shown in Figure 1, consist of a hydrided zirconium - 10 wt % uranium fuel rod enclosed in a Hastelloy-N cladding assembly. The inside

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Figure 1. SNAP 2 Fuel Element
(Figure Unclassified)

of the cladding assembly is coated with AI-8763-D, a ceramic hydrogen barrier developed by Atomics International. Normal uranium fuel elements were tested, simulating the fully enriched uranium which would be used in a SNAP 2 reactor.

Since the operating life of the SNAP 2 reactor is largely dependent on the presence of the hydrogen (neutron moderator) in the fuel rods, the AI-8763-D ceramic hydrogen barrier was developed to keep hydrogen loss at a minimum. The condition of this hydrogen barrier, which is structurally the weakest part of the fuel element, is determined by measuring the hydrogen loss (permeation) rate at a specific elevated temperature. Any increase in the hydrogen loss rate at this temperature indicates damaged ceramic and a less efficient fuel element.

NAA-SR-10188

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The fuel elements in this program were subjected to environmental inputs which simulate the four phases of SNAP 2 reactor operation. They are:

<u>Design Input</u>	<u>Simulated By</u>
Prelaunch Ckeckout	Thermal Soak
Launch	Vibration and Shock
Reactor Startup	Ramp Heating
Reactor Operation	Thermal Endurance

Similar tests have been performed on fuel elements of the same size with an earlier ceramic hydrogen barrier,^{1, 2} and on fuel elements of a different size with the same ceramic hydrogen barrier.³ The fuel elements tested in this program were the first fuel elements of this size with AI-8763-D ceramic hydrogen barrier to be tested.

The 43 fuel elements in this program were tested in four groups, with each group receiving somewhat different inputs:

<u>Group</u>	<u>Number of Elements</u>
1	2
2	7
3	5
4	29

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II. PROCEDURE

The basic criterion used to determine whether an element can withstand an input is its hydrogen permeation (loss) rate. The permeation rate (L) is determined, before and after each input, by isothermally heating the element in an evacuated chamber, and determining the hydrogen leak rate by use of a H₂ mass spectrometer.⁴ Significant increases in the permeation rate indicate damaged ceramic.

Figure 2 shows the planned sequence of inputs for each group of fuel elements. These inputs simulate all reactor environmental conditions except irradiation. Separate experiments are in progress to determine the effects of irradiation on the hydrogen barrier.⁵

Although the severity of inputs varied from group to group, each element was to be tested in the same sequence. The inputs are described briefly in the following sections. A detailed description of the test equipment and testing procedures can be found in Appendix I of Reference 2.

A. THERMAL SOAK

This input simulates prelaunch checkout of the reactor. It consists of heating the element from ambient temperature to the test temperature indicated on Figure 2, dwelling at the test temperature for 10 hr, and then cooling to at least 400°F. Each element received three of these cycles. The rate of change of temperature is 300°F/hr or less, and the elements are in vacuum (approximately 10⁻³ torr) during the test.

B. VIBRATION AND SHOCK

In order to simulate launch, elements are loaded into a core vessel, and are vibrated and shocked. The core vessel is filled with water during vibration and shock. The water has a damping effect, similar to that of the liquid NaK which will surround the fuel elements during launch. Table 1 shows the reference (100%) levels of the vibration and shock inputs. When higher level inputs (200 and 250%) are applied, only the magnitude of the input is varied. The frequency and sweep time of vibration, and the number and duration of shocks, remain the same.

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NAA-SR-10188

8

*L indicates a hydrogen permeation test, and the subscript shows the test temperature (°F)

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Figure 2. Planned Test Sequence
(Figure Unclassified)

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TABLE 1
REFERENCE LEVELS OF VIBRATION AND SHOCK
(These are the vibration and shock levels
required to qualify SNAP 10A fuel
elements for flight)

Vibration

The vibration input is applied along each of the three mutually perpendicular axes. Each axis receives a single sweep at a constant octave sweep rate, proceeding from low to high frequency in 25 min.

<u>Frequency</u> (cps)	<u>Magnitude</u>
5 - 20	1/4 in. double amplitude
20 - 400	5.0g
400 - 3000	7.5g

Shock

<u>Axis</u>	<u>Magnitude</u> (g)	<u>Number</u>	<u>Duration</u> (msec)
Longitudinal*	20	2 each direction	6 ± 1
Lateral	10	2 each direction	6 ± 1
Normal	10	2 each direction	6 ± 1

*The longitudinal axis is along the centerline of the fuel element

The reference levels shown in Table 1 are the levels which are used to qualify SNAP 10A fuel elements for operation in a flight reactor.⁶

C. RAMP HEATING

This input simulates reactor startup. The earlier elements (Groups 1 to 3) were ramp heated isothermally to the temperatures shown in Figure 2 at a rate of 150°F/min. The cooling rate was never greater than 50°F/min. Each element was ramp heated 5 times, and was in vacuum (approximately 10^{-4} torr) during the test. The elements in Group 4 were not ramp heated.

D. ENDURANCE TEST

In order to simulate reactor operations, the elements are maintained in vacuum at the temperatures shown in Figure 2. The hydrogen permeation rate is measured periodically during this time. Endurance tests were planned for 1-year duration, but testing was stopped before any of the elements had accumulated the 1 year at temperature. The elements in Group 4 received no endurance test.

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7635-5157

Figure 3. Endurance Permeation Data of Group 1 Elements (1100, 1200, and 1300°F)

7635-5158

Figure 4. Postendurance Permeation Data of Group 1 Elements (1000 to 1300°F)

NAA-SR-10188

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III. RESULTS AND DISCUSSION

In order to make a preliminary evaluation of the performance of the AI-8763-D hydrogen barrier in 1-1/4 in. OD fuel elements, two SNAP 2 elements (N-45 and N-46) were made in October 1962. These elements were tested with elements in the SNAP 10A Qualification Test Program,² and received the same pre-endurance inputs. The permeation data, given in Table 2, show that

TABLE 2
PERMEATION DATA OF GROUP 1 ELEMENTS
(1100°F)

Permeation Test	Hydrogen Permeation at 1100°F [cc(STP)hr]	
	Element N-45	Element N-46
Acceptance	0.49	0.39
Pre Thermal Soak	0.50	0.50
Post Thermal Soak	0.52	0.47
Post Vibration and Shock	0.43	0.44
Post Ramp Heat	0.52	0.41
Post Endurance	0.14	0.13

no pre-endurance input damaged the elements. During the endurance test, the two elements were loaded in a single vacuum retort. After 450 hr of endurance test at 1100°F, during which the permeation rate decreased by a factor of three, the elements were heated to 1200°F and maintained at that temperature for about 1670 hr. They were then transferred to another furnace and maintained at 1200°F for 700 additional hours. The temperature was then raised to 1300°F and maintained there until the elements completed more than 7000 hr of endurance test. The permeation rates during endurance test are given in Figure 3. Figure 4 shows the results of postendurance permeation measurements, made at temperatures between 1000 and 1300°F. The straight lines on Figure 4 are the results of least-squares curve fits. The resulting equations are:

$$\text{N-45: } \log_{10} (\text{permeation}) = 9.575 - \frac{16,300}{T (^{\circ}\text{R})}$$

TABLE 3
PERMEATION DATA OF GROUP 2 ELEMENTS
(1100 and 1200 °F)

Element Number	Permeation Temperature (°F)	Hydrogen Permeation Rate [cc(STP)/hr]							
		Acceptance	Before Thermal Soak	After Thermal Soak	After Vibration and Shock	After Ramp Heat	After Endurance	Hours in Endurance	V & S* (% of Reference)
N-120	1100	-	0.06	0.07	0.07	0.09	-	168	200
	1200	0.37	0.36	0.36	0.33	0.42	2.3		
N-122	1100	-	0.06	0.09	0.09	0.13	-	264	200
	1200	0.30	0.33	0.48	0.52	0.51	5.7		
N-123	1100	-	0.06	0.06	0.13	0.13	-	168	200
	1200	0.35	0.36	0.30	0.66	0.61	1.6		
N-124	1100	-	0.11	0.08	0.24	0.24	-	168	200
	1200	0.37	0.53	0.46	1.22	1.09	3.6		
N-125	1100	-	0.02	0.31	0.28	0.39	-	144	250
	1200	0.63	0.12	1.50	2.10	1.16	7.2		
N-126	1100	-	0.06	0.06	0.07	0.10	-	264	250
	1200	0.43	0.32	0.29	0.45	0.46	5.6		
N-127	1100	-	0.09	0.09	0.14	0.15	-	192	250
	1200	0.49	0.50	0.48	0.67	0.59	8.6		

*See Table 1 for Reference Levels of Vibration and Shock

NAA-SR-10188

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$$N-46: \log_{10} (\text{permeation}) = 8.521 - \frac{14,320}{T(^{\circ}R)}$$

In the equation, the first constant shows the location or height of the least-squares line, and the second constant represents the slope or temperature dependence. The last term of a similar equation for permeation of eight SNAP 10A fuel elements before endurance test averaged $16,720/T(^{\circ}R)$.⁶ The SNAP 10A fuel elements have different ceramic, but otherwise are identical to these SNAP 2 fuel elements.

In early 1963, seven SNAP 2 fuel elements were fabricated. These elements were to be the first of a large group of elements with AI-8763-D ceramic which were to be evaluated for operation in a SNAP 2 reactor at 1200°F. These elements (Group 2) were to be tested according to the plan given in Figure 2, which included endurance testing at 1300°F. Later, the average operating temperature of the fuel elements in a SNAP 2 reactor was raised to approximately 1300°F.⁷

The Group 2 elements appeared to be susceptible to damage from both the environmental inputs and/or from handling. Each input damaged one or more elements, but no pre-endurance input was damaging to all of the elements. The permeation rates of only two of the fuel elements (N-124 and N-125) exceeded the SNAP 10A acceptance limit [0.8 cc(STP)/hr at 1200°F] during pre-endurance testing. However, all of the elements exceeded the acceptance limit, and five of the elements "failed" [permeation > 3.0 cc(STP)/hr at 1200°F, which is equivalent to 11 cc(STP)/hr at 1300°F⁶] during the first several hundred hours of 1300°F endurance testing. The permeation test data are given in Table 3.

Permeation measurements during endurance test showed that all elements had reasonable permeation rates after 24 hr at 1300°F; but, during the following 100 hr at 1300°F, the hydrogen permeation rate of the elements increased by an average factor of eight. Thus, it appeared that the 1300°F temperature damaged the ceramic hydrogen barrier.

To determine whether damage was caused by testing at 1300°F, five additional fuel elements (Group 3) were obtained for test. The test plan is given in Figure 2. While the elements in Group 2 received high-level vibration and shock, and thermal tests at 1100 and 1200°F, the elements in Group 3 were

TABLE 4
PERMEATION DATA OF GROUP 3 ELEMENTS
(1200 and 1300°F)

Element Number	Permeation Temperature (°F)	Hydrogen Permeation Rate [cc(STP)/hr]							
		Acceptance	Before Thermal Soak	After Thermal Soak	After Vibration and Shock	After Ramp Heat	After Endurance	Hours in Endurance	V & S* (% of Reference)
N-193	1200	0.69	0.58	0.69	0.45	-	-	3072	100
	1300	-	1.75	2.47	1.63	-	-		
N-196	1200	0.28	0.12	0.10	0.05	-	-	3144	100
	1300	-	0.45	0.34	0.24	-	-		
N-197	1200	0.29	0.18	0.20	0.17	-	-	3072	100
	1300	-	0.67	0.83	0.55	-	-		
N-198	1200	0.57	0.46	0.60	0.39	-	-	3144	100
	1300	-	1.90	2.15	1.71	-	-		
N-199	1200	0.41	0.38	0.46	0.24	-	-	3144	100
	1300	-	1.34	1.46	1.03	-	-		

*See Table 1 for Reference Levels of Vibration and Shock

NAA-SR-10188

14

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vibrated and shocked at the reference level, and were thermally tested at 1200 and 1300°F. All five elements completed the pre-endurance tests without damage, even though the test temperatures were 1200 and 1300°F (the data are given in Table 4). The elements were then placed on endurance test at 1300°F. Initially, the permeation rates of the elements were slightly higher than the pre-endurance rates, but they were still well below the SNAP 10A acceptance limit [0.8 cc(STP)/hr at 1200°F, which is equivalent to 3.0 cc(STP)/hr at 1300°F]. During the following 3115 average hours of endurance test, the elements were not damaged. Graphs of endurance permeation rate vs time for the Group 3 elements are given in Figure 5.

Since these five elements in Group 3 completed pre-endurance tests and 3115 hr (average) of endurance test, all at nominally 1300°F, without damage, the "failure" of the Group 2 elements is attributed to either: (a) high-level vibration and shock, followed by 1300°F testing; or (b) production variation which made these Group 2 elements "nonrepresentative."

The final 29 fuel elements were received for test during January 1964. It was planned to test these elements at 1300°F, and to subject them to high levels of vibration and shock. The test sequence is given in Figure 2. The elements had completed thermal soak, vibration and shock, and the corresponding permeation tests, when the SNAP 2 fuel element development program was redirected. Testing was discontinued. The elements are now stored in the Special Source Materials vault at Santa Susana, California, in case the program is reactivated.

All of the 29 elements completed thermal soaking without damage, but high levels of vibration and shock damaged the ceramic hydrogen barrier. After vibration and shock, six elements exhibited permeation rates greater than the SNAP 10A acceptance limit [0.8 cc(STP)/hr at 1200°F], but no element had a permeation rate greater than 1.2 cc(STP)/hr. The average 1200°F permeation of the 29 elements increased from 0.21 to 0.54 cc(STP)/hr (Table 5). Examination of the test elements revealed that the outer surfaces had been abraded and scratched during vibration and shock. The elements which showed the greatest amount of external damage were found to have the largest increases in permeation. Thus, the damage seemed to correlate with the amount of contact or interference between the elements. A photograph of typical elements is shown in Figure 6.

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NAA-SR-10188

16

7635-5159

Figure 5. Endurance Permeation Data of Group 3 Elements (1300°F)

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TABLE 5
PERMEATION DATA OF GROUP 4 ELEMENTS (1200°F)

Element Number	Permeation Rate at 1200°F [cc(STP)/hr]					
	Acceptance	Before Thermal Soak	After Thermal Soak	After Vibration and Shock	Vibration and Shock Level	Proposed Endurance Temperatures (°F)
N-2000	0.53	0.42	0.39	0.47	250	1300
N-2001	0.14	0.03	0.10	0.21	250	1300
N-2002	0.45	0.22	0.32	0.63	250	1300
N-2003	0.35	0.22	0.27	1.13	250	1300
N-2004	0.39	0.20	0.22	0.92	250	1350
N-2005	0.26	0.13	0.15	0.36	250	1350
N-2006	0.33	0.39	0.20	0.46	200	1350
N-2007	0.53	0.36	0.23	0.66	200	1350
N-2008	0.34	0.29	0.21	0.38	200	1350
N-2009	0.19	0.24	0.24	0.25	250	1300
N-2010	0.31	0.19	0.19	0.29	250	1350
N-2011	0.30	0.27	0.32	0.85	250	1300
N-2012	0.28	0.10	0.18	0.18	200	1350
N-2013	0.12	0.05	0.05	0.46	250	1350
N-2014	0.23	0.05	0.27	0.33	200	1350
N-2015	0.12	0.08	0.18	0.29	200	1300
N-2016	0.15	0.13	0.12	0.30	250	1350
N-2017	0.33	0.31	0.17	0.39	200	1300
N-2018	0.26	0.23	0.26	0.61	250	1350
N-2019	0.25	0.12	0.24	0.76	200	1300
N-2021	0.24	0.21	0.19	1.16	200	1300
N-2022	0.24	0.14	0.17	0.58	200	1300
N-2023	0.54	0.48	0.63	0.87	250	1300
N-2024	0.16	0.33	0.37	0.96	250	1350
N-2025	0.14	0.08	0.07	0.44	200	1300
N-2026	0.16	0.12	0.15	0.54	200	1300
N-2027	0.18	0.12	0.07	0.30	200	1350
N-2028	0.18	0.17	0.08	0.42	200	1350
N-2029	<u>0.18</u>	<u>0.17</u>	<u>0.12</u>	<u>0.64</u>	250	1350
Average	0.27	0.20	0.21	0.54	-	-

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Figure 6. Typical Group 4 Elements After Vibration and Shock
(Figure Unclassified)

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18

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Examination of the core vessel and of dummy elements* after vibration and shock revealed that:

- a) The average diameter of the holes in the lower grid plate was within specification; the largest hole was 0.003 in. oversize.
- b) The average diameter of the holes in the upper grid plate was 0.002 in. oversize; the largest hole was 0.006 in. oversize.
- c) The average diameter of the upper ("blind") end pins of the dummy fuel elements was 0.003 in. undersize; the smallest diameter was 0.005 in. undersize.
- d) The average diameter of the lower ("glass-closure") end pins of the dummy fuel elements was 0.008 in. undersize; the smallest diameter was 0.014 in. undersize.

Examination of the 29 test fuel elements after vibration and shock showed that:

- a) The diameter of each upper ("blind") end pin was within specification.
- b) The diameter of 14 of the lower ("glass-closure") end pins was under-size (0.002 in. maximum), while the corresponding diameter of the other 15 elements was within specification.

Thus, we conclude that the extremely high input levels, imposed during these tests (and during previous tests with the grid plates and dummy fuel elements), provided sufficient rattling and hammering of the elements to both enlarge the grid plate holes and to reduce the diameters of the end pins.

From the data in Table 6, the average increases in permeation rate due to vibration and shock were obtained for each input level and for each position in the core vessel (Figure 7). These averages were then normalized, based on the average increase of the center elements. The results are given in Table 7. The permeation increases are larger for elements located further away from the centerline of the core vessel. Linear curve fits of the data (1.0, 0.0) give the following equation:

250% Level: Normalized increase = $1.000 + 1.875$ (normalized distance)

200% Level: Normalized increase = $1.000 + 0.771$ (normalized distance)

*Dummy elements are used to complete a core load of 37 fuel elements, since no more than 6 test elements were vibrated and shocked at one time. A more detailed description of vibration and shock testing is given in Reference 2.

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TABLE 6
VIBRATION AND SHOCK DATA OF GROUP 4 ELEMENTS

Element Number	Load Number	Core Vessel Position	V & S Level (% of Reference)	Increase in 1200°F Permeation Rate [cc(STP)/hr]
N-2000	1	1	250	0.08
N-2001	1	2	250	0.11
N-2002	1	3	250	0.31
N-2003	1	4	250	0.85
N-2004	1	5	250	0.69
N-2005	1	6	250	0.20
N-2006	2	1	200	0.26
N-2007	2	2	200	0.42
N-2008	2	3	200	0.17
N-2009	3	1	250	0.01
N-2010	3	2	250	0.10
N-2011	3	3	250	0.53
N-2012	2	4	200	0.00
N-2013	3	4	250	0.41
N-2014	4	1	200	0.06
N-2015	6	1	200	0.10
N-2016	5	1	250	0.18
N-2017	4	2	200	0.22
N-2018	5	2	250	0.35
N-2019	4	3	200	0.53
N-2021	4	4	200	0.97
N-2022	6	2	200	0.41
N-2023	5	3	250	0.24
N-2024	3	5	250	0.48
N-2025	6	3	200	0.36
N-2026	4	5	200	0.38
N-2027	6	4	200	0.23
N-2028	6	5	200	0.34
N-2-29	3	6	250	0.52
Average	-	-	-	0.34

NAA-SR-10188

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Figure 7. Fuel Element Locations During Vibration and Shock (Figure Unclassified)

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Figure 8. Effect of Core Position on Permeation Rate (Figure Unclassified)

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TABLE 7

EFFECT OF CORE POSITION ON PERMEATION RATE

Vibration and Shock Level* (%)	Core Vessel Position (X)	Normalized Distance From Core Centerline (Distance/Element Diameter)	Number of Elements	Average 1200°F Permeation Increase [cc(STP)/hr]	Normalized Increase $(\frac{L, \text{Position X}}{L, \text{Position 1}})$
250	1	0.0	3	0.09	1.0
	2	1.0	3	0.19	2.1
	3	2.0	3	0.36	4.0
	4	3.0	2	0.63	7.0
	5	2.6	2	0.59	6.6
	6	1.7	2	0.36	4.0
200	1	0.0	3	0.13	1.0
	2	1.0	3	0.35	2.7
	3	2.0	3	0.35	2.7
	4	3.0	3	0.40	3.1
	5	2.6	2	0.36	2.8

*Reference (100%) Level – SNAP 10A Qualification Level (cf Table 1)

Figure 8 shows the data points and the least squares lines.

The magnitude of the g-load amplification, due to the loose fit of the pins in the grid plate, is not known. Therefore, it is not possible to relate the input levels that the elements actually received to the levels which were applied to the test fixture. Thus, the damage which occurred during the input cannot be evaluated in conjunction with other test results.

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IV. CONCLUSIONS

Forty-three SNAP 2 fuel elements (normal uranium) were tested in this program. Two elements completed the tests, including more than 7000 hr of endurance at 1100, 1200, and 1300°F, without damage to the ceramic hydrogen barrier. The barrier of seven elements was severely damaged by 1300°F testing following high-level vibration and shock. However, these seven elements generally were not of as good a quality as subsequent elements. Five elements completed pre-endurance tests (reference level vibration and shock) and 3115 hr (average) of endurance test, all at nominally 1300°F, without damage. Twenty-nine elements were damaged by high levels of vibration and shock; but, even after this damage, the average permeation rate was within the allowable acceptance permeation rate for SNAP 10A reactors.

We conclude that:

- a) A 1300°F environment, per se, is not damaging to SNAP 2 (1-1/4 in. OD, AI-8763-D coated) fuel elements.
- b) Vibration and shock at twice the reference level (Table 1) or higher generally caused increased hydrogen permeation.

Due to program redirection, all SNAP 2 fuel element testing has been discontinued; and the elements have been stored, in case the program is reactivated.

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NAA-SR-10188

24

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