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TECHNICAL DATA RECORD

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STATEMENT OF PROBLEM

Establish the reliability of the SNAP 10A fuel element and its components as a function of the severity of the environment, finally yielding the mode of failure and the ultimate capability of the fuel element.

ABSTRACT

Ten fuel elements have completed 4440 hours of endurance testing at 1200°F after receiving:

1. Thermal cycling
2. High level vibration and shock
3. Isothermal ramp heating

There is no evidence that any of these inputs damaged the ceramic hydrogen barrier of these elements. The ten fuel elements have lost an average of 0.2% of their hydrogen during 4440 hours of endurance.

The average permeation rate of seventeen fuel elements, after reference level gradient ramp heating, shows no indication of any degradation of the ceramic hydrogen barrier. However, the permeation of one of the seventeen elements increased from 0.52 to 1.15 after this input.

A tabulation of the data is included in Part 2 of this report. Copies will be available from the classified library.

Previous Monthly Reports: NAA-SR-MEMO 8851 July
9030 August
9094 September
9211 October
9284 November
9461 December
9551 January

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FORM 701-C REV. 10-62

I. INTRODUCTION

The purpose of environmental testing is to establish the reliability of fuel elements by subjecting them to vibration and shock, ramp heating and thermal endurance test inputs in excess to those required for qualification*. These inputs simulate launch conditions, reactor start up, and reactor operation, respectively. The pre-launch check-out is also simulated by subjecting the fuel elements to thermal cycling. The evaluation of the effects of these inputs is based upon the change of the hydrogen loss rate measured before and after each test and during endurance testing. Further evaluation is based upon chemical and metallographic analyses after the completion of endurance testing.

All fuel elements are tested in accordance with "SNAP 10A Fuel Environmental Test Specification," D. H. Stone, NA-0422-005 Rev. A, March 10, 1964. These fuel elements first receive three thermal cycles to 1200°F. The elements are then assigned to one of four test phases:

Phase I (30 elements)

All fuel elements in Phase I receive high level vibration and shock (200 or 250% reference level), design level gradient ramp heating, ** and endurance testing.

Phase II (30 elements)

All fuel elements in Phase II receive reference level vibration and shock, reference level gradient ramp heat, high level gradient ramp heat, and endurance testing.

* NA-0422-006, "SNAP 10A Fuel Element Qualification Test Specification," T. G. Parker, Jr. Rev. 5-7-63.

** The first ten elements received isothermal ramp heating at 150°F/min. to 1200°F.

Phase III (30 elements)

All fuel elements in Phase III receive a combination of high level vibration and shock and high level gradient ramp heat inputs followed by endurance testing.

Phase IV (30 elements)

All fuel elements in Phase IV receive reference level inputs. These elements are to be used to determine the effects of reference level inputs and the subsequent permeation tests.

Endurance testing will be conducted at three test temperatures: 1200°F, 1300°F and 1350°F. Twelve elements from each phase will be tested at 1200°F (two endurance furnaces), twelve elements from each phase at 1300°F (two endurance furnaces), and six elements from each phase at 1350°F (one endurance furnace). If one of the five endurance furnaces is required for other testing, the elements will be removed from the second furnace operating at 1300°F.

II. EQUIPMENT STATUS

1. Permeation Testing: unchanged since December 1963 (c.f. NAA-SR-Memo 9461).
2. Thermal Cycling: Unchanged since August 1963 (c.f. NAA-SR-Memo 9030).
3. Vibration and Shock: Unchanged since August 1963 (c.f. NAA-SR-Memo 9030).
4. Ramp Heating: A second induction heating unit has been profiled for gradient ramp heating to a peak temperature of 1200°F at a rate of 600°F/min at the blind end.
5. Thermal Endurance: Unchanged since October, 1963 (c.f. NAA-SR-Memo 9211).

III. PROGRAM STATUS

The "SNAP 10A Fuel Environmental Test Specification," NA-0422-005, has been revised to incorporate: 1) the gradient ramp heat test, 2) endurance testing at temperatures other than 1200°F, and 3) a fourth testing phase. The gradient ramp heat test was introduced in place of the isothermal ramp heat test because this test more closely simulates the most severe thermal transients and the resulting mechanical stresses in reactor start up. The endurance test temperature was changed to incorporate testing at 1300°F and 1350°F in order to ascertain the behavior of SNAP 10A fuel elements under these conditions. The fourth phase was added as a "control" phase in order to determine the effects of reference level inputs and the subsequent permeation tests. This phase was necessary since the SNAP 10A Qualification Program cannot be used to make these determinations due to the changes in tests listed above.

Thirty one additional elements were received during February and March bringing the number of fuel elements in the program to ninety four. There are thirty fuel elements in each of Phases I and II, twenty seven fuel elements in Phase III, and seven fuel elements in Phase IV. The status of these elements is:

Phase I

a. Ten fuel elements are undergoing endurance testing at 1200°F.
b. Five fuel elements are awaiting endurance testing at 1300°F.
c. Nine fuel elements are awaiting ramp heating.
d. Six fuel elements are awaiting permeation testing after being vibrated and shocked.

Phase II

a. Eleven fuel elements have undergone reference level ramp heating.
b. Three fuel elements are awaiting reference level ramp heating.
c. Five fuel elements are undergoing vibration and shock.
d. Four fuel elements are awaiting vibration and shock.
e. Two fuel elements are awaiting thermal cycling.
f. Five elements are awaiting permeation tests prior to thermal cycling.

Phase III

a. Five fuel elements are awaiting thermal cycling.
b. Twenty two fuel elements are awaiting permeation tests prior to thermal cycling.

Phase IV

Seven elements are awaiting permeation tests prior to thermal cycling.

IV. RESULTS AND DISCUSSION

Ten fuel elements have received 4440 hours of endurance testing at 1200°F. These fuel elements received design level thermal cycling, high level vibration and shock, and design isothermal ramp heats prior to endurance testing. During the 4440 hours of endurance testing, the average permeation rates have fluctuated between 0.08 and 0.16 cc(STP)/hr. However there is no indication that the endurance test has caused any significant degradation of the ceramic hydrogen barrier. The hydrogen loss from these ten elements has been 0.2% of the initial hydrogen present during this 4440 hours at 1200°F.

The endurance data from each retort were fitted with a least squares curve of the form:

$$L = L_o \exp (kt)$$

where L and t are permeation rate and time, respectively, and L_o and K are constants. The table below shows the resulting constants.

Fuel Elements	Lo cc(STP)/hr	k 1/hours
N-137, 146, 159	0.36	-8.25×10^{-3}
N-88, 101, 104	0.74	$+1.14 \times 10^{-5}$
N-105	0.19	-1.17×10^{-2}
N-155	0.11	-1.34×10^{-2}
N-97	0.11	-1.20×10^{-2}
N-165	0.23	-4.89×10^{-3}

An extrapolation of the data, using the least square equations, indicates that the permeation rates of five retorts are decreasing. The constants for the retort containing elements N-88, 101, 104 indicate that the permeation rate will be essentially constant during one year of endurance test.

Two computer programs have been written to aid in data reduction. The programs, outputs, and graphs of the data are tabulated in Part II of this report which is on file at the library.

The programs tabulated the performance and endurance data, compute the hydrogen loss for each element, graph the endurance data, and compute a least squares curve of the endurance data.

In order to calculate the hydrogen loss of an individual element, clustered with other elements during endurance test, two subroutines* (KNØRM 2 and HCORR1) are used. KNORM 2 uses the following equation** for the permeation rates:

* "SNAP FUEL ELEMENT FOR TRAN SUBROUTINES," NAA-SR-MEMO 9564, M. E. Nathan, 3-10-64, p 26.

** "FUEL ELEMENT PARAMETRIC STUDY ADVANCED SNAP 2 REACTOR," NAA-SR-MEMO 8526, M. E. Nathan, J. D. Watrous, 6-6-63, p 17.

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$$L = K_{BLD}\ P\ e^{-12760/T} + \frac{K_{aging}\ P\ T^{5/2}\ e^{-28160/T}}{T^{5/2} + 8.432 \times 10^{13}\ P\ e^{-28160/T}}$$

where

L = permeation rate, cc(STP)/hr.

P = internal hydrogen pressure, atm.

T = temperature, °R

K_{BLD} = constant associated with hydrogen permeation through glass-closure end and ceramic defects.

K_{aging} = constant associated with hydrogen permeation through the ceramic = 7.275×10^5

KNØRM 2 is based on the assumption that the percentage change of K_{BLD} is constant for each element in a retort. From this assumption, the individual permeation rate and hydrogen loss of each element is calculated.

To date, seventeen fuel elements have received reference level gradient ramp heat. Only one element, which had been previously subjected to vibration and shock at 250% of the qualification level, has shown a significant increase in permeation rate after this input, i.e. 0.52 to 1.15 cc(STP)/hr at 1200°F. The table below shows that on an average basis, there is no degradation of the ceramic hydrogen barrier due to gradient ramp heating.

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Permeation Test Temp.	Hydrogen Permeation, cc(STP)/hr Before Test Average	Before Test Range	After Test Average	After Test Range
1100	0.08	0.02-0.31	0.08	0.03-0.29
1200	0.35	0.08-1.24	0.34	0.08-1.27

V. CONCLUSIONS

Ten fuel elements in Phase I (high level vibration and shock, design isothermal ramp heat) have completed 4440 hours of endurance testing at 1200°F with no significant degradation of the ceramic hydrogen barrier. These ten fuel elements, during endurance testing, have lost an average of 0. % of their initial hydrogen.

One element, after receiving high level vibration and shock, has shown a significant increase in permeation rate after reference level gradient ramp heat. However, the average permeation rate of seventeen elements (including the one mentioned above) shows no significant change due to the gradient ramp heat test.