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SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801

(TWX: 803-824-0018, TEL: 803-824-6331, WU: AUGUSTA, GA.)

October 13, 1967

Dr. Harold Harty, Manager
Heavy Water Office
Pacific Northwest Laboratory
Battelle Memorial Institute
Richland, Washington 99352

Dear Dr. Harty:

In accord with my letter of 8-4-67, and Dr. Dessauer's of 9-22-67, I am enclosing three copies of a summary of the status of our NaK capsule irradiation tests of uranium metal fuels as of the termination of funding by the Fuels and Materials Branch, DRDT, on 6-30-67. Included in this summary, DPST-67-556, are proposed programs for continuation of this work on one of three alternative bases, the costs for each of which are estimated.

The summary is classified under our local rules. Submittal for declassification has been requested.

Dr. McDonell was at Richland during the week of October 2, and discussed the work with Dr. Last at that time. We hope that the enclosed summary will meet your needs for a written description. We would be glad to have you consider the proposed programs for support by your Heavy Water Office, and we shall be glad to try to answer any questions about the summary or the work.

Very truly yours,

J. W. Morris, Director
Nuclear Engineering and
Materials Section

JWM:bw
Attachments: DPST-67-556 (Copies 1-3)
Copies of Reference Documents 1, 3, and 4 (original only)

NOTE: My letter of August 11 mentioned two manuscrips that we expected to be able to send to you by or before now. The first of these is Reference 4 of the attached memorandum, and a copy is attached. The second is Reference 5, but the manuscript itself is still not available. It will be sent as soon as possible.

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DPST-67-556

[redacted] Number 17

STATUS OF IRRADIATION TESTS OF DILUTE URANIUM ALLOYS IN NaK-CONTAINING STAINLESS STEEL CAPSULES

by

W. R. McDonell

Savannah River Laboratory
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Aiken, South Carolina 29801

To extend experience with uranium metal fuels to the high exposures required for power reactor operation, the Savannah River Laboratory has conducted over several years a series of irradiation tests of small uranium specimens of various alloy compositions in NaK-containing stainless steel capsules. These tests, supported by the Fuels and Materials Branch, Division of Reactor Development and Technology, were designed specifically to establish the limits on exposure that could be reached during irradiation of the alloys at various temperatures without swelling and to determine the metallurgical factors that promoted the stability of the alloys.

The two most recent test groups in this series, denoted NaK V and NaK VI, were conducted respectively (1) to determine the swelling behavior of the alloys with various initial heat treatments on irradiation up to 13,000 MWD/T at temperatures 300-800°C and (2) to correlate the irradiation growth (the basic driving force for cavitational swelling) of the alloys with their swelling behavior. Irradiation of both test groups was completed and post-irradiation examination of the NaK V test specimens was in progress on June 30, 1967, when DRD funding for the program was unexpectedly eliminated from the Laboratory Budget for FY-1968 and work was halted.

The following summarizes the status of results obtained in the irradiation test program and presents proposals for completion of the work on several alternative bases.

GENERAL BACKGROUND

On irradiation at temperatures in the range typically 400-600°C, uranium metal fuels may undergo a marked swelling caused by the formation of cavities in the metal.[1,2] These cavities, which are typically large ($100\ \mu$) and randomly situated at grain boundaries and twin interfaces in the temperature range 400-500°C, or are small and crystallographically aligned within grains at 500-600°C,[2] are

[redacted]

considered to result from mechanical interaction between individual grains in the structure which undergo anisotropic growth (change of shape) during irradiation.

The cavitational swelling of the uranium metal does not occur until a critical exposure dependent upon temperature is reached.[3] Plots of the critical exposures versus temperature yields a temperature-exposure threshold diagram, analogous to a metallurgical TTT diagram, which denotes precisely the stability limits of the fuel.[4]

The temperature-exposure thresholds for swelling of the uranium metal depend upon alloy content, and potentially upon the initial distribution of alloy constituents in the metal.[4] The time-temperature threshold diagrams for a series of very dilute Fe, Si, Al, Cr, and Mo-containing uranium alloys are represented in Figure 1, which summarizes results of irradiation of specimens to 5000 MWD/T at temperatures up to 500°C, conducted previous to the current tests.[4] Most notable features of these results were as follows:

- Alloys containing intermediate (350 ppm) silicon concentrations were generally most swelling-resistant under these irradiation conditions. Some of these compositions resisted swelling up to the limits of temperature and exposure reached in the tests.

- Variation in initial distributions of alloy constituents, as determined by the heat treatments of the dilute alloy specimens, had generally only minor effect on swelling resistance of those alloys that could tolerate relatively long exposures. This result was attributed to the irradiation-induced dissolution and dispersion of the alloy constituents which effectively destroyed the initial structures after extended irradiation.[3]

<u>NaK V Test</u>

This test, utilizing 750 specimens in 450 capsules, was designed to extend data on temperature-exposure thresholds for swelling of dilute Fe, Si, Al, Mo, Cr, and Zr-containing alloys to higher exposures and temperatures. The specimens were irradiated to exposures of 3000, 9000, and 13,000 MWD/T at calculated central temperatures ranging 300 to 800°C. Temperatures were not measured directly during irradiation but will be determined by calibration of swelling behavior of standard specimens with results obtained in previous tests for which temperatures are reliably known. The key specimens required for this calculation were included in the group irradiated to 3000 MWD/T.

[redacted]

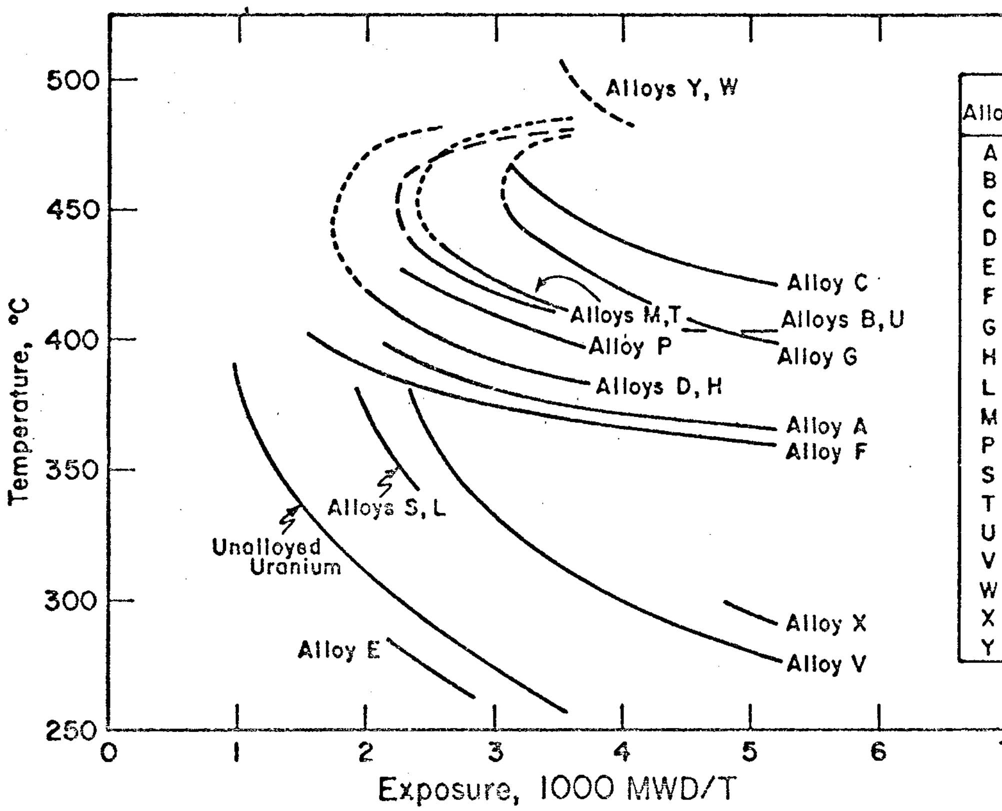
Specimen compositions and heat treatments listed in Table I were selected so as to establish general effects of metallurgical structure on swelling susceptibility, as well as to screen candidate fuels for practical power reactor applications. Included in the test were concentrated alloys (0.5-4%) of Zr, Mo, and Cr, as well as the best of the very dilute Fe, Si, Al, Cr, and Mo alloys represented in the previous tests. The concentrated alloys, for which major modifications in matrix crystal structure (α'_a, α'_b, α''_b, and retained β as contrasted to α) as well as in alloy phase distribution can be imparted by initial heat treatment and presumably by prolonged irradiation, were included in various heat treated conditions to establish their swelling susceptibility relative to the very dilute alpha-matrix alloys. Among the concentrated alloys were compositions containing minor ternary additions; uranium molybdenum-silicon alloys of this type were provided by Atomics International.

At the time the postirradiation examination of specimens from the NaK V test was halted, 435 specimens of the total 750 specimens (contained in 255 of the total 430 capsules) had been examined. Density measurements needed to evaluate the relative swelling resistance of the alloys irradiated to 13,000 MWD/T were complete; a summary of the results of these comparative measurements is given in the attached Appendix.

Most notable feature of these results was that among the very dilute Fe, Si, Al, Cr, and Mo-containing alloys, those containing high (800 ppm) concentrations of aluminum were more resistant to swelling at the high exposures than those containing intermediate (350 ppm) silicon concentrations, which had previously been demonstrated to be the most swelling-resistant material at intermediate exposures. The best alloys of all in the high exposure test were the ternary U-Mo-Si alloys with relatively high (1.5-4%) molybdenum content. Initial heat treatment of the high Mo-containing alloys was an important factor in control of swelling, in contrast to the results for the very dilute alloys; best heat treatment was a fast quench from the gamma phase which retained the alloy constituents in solid solution or otherwise widely dispersed distributions.

The temperature-exposure thresholds of the alloys irradiated to 13,000 MWD/T cannot yet be reliably specified for plotting in Figure 1, pending burnup measurements of selected specimens in the group and density measurements of key compositions in the 3000 MWD/T group where swelling thresholds must be determined for comparison with results of the previous tests to provide actual specimen temperatures.

[redacted]



URANIUM ALLOYS

Alloy	Composition, ppm				
	Fe	Si	Al	Cr	Mo
A	350		800		
B	350	350	800	-	-
C	250	350	-	-	-
D	-	350	800	-	-
E	250	-	-	-	-
F	-	800	800	-	-
G	-	350	-	-	-
H	-	800	-	-	-
L	250	-	250	-	-
M	250	250	250	-	-
P	-	250	250	-	-
S	250	100	-	-	-
T	250	250	250	250	-
U	250	350	800	200	-
V	150	100	-	-	-
W	-	350	-	-	1000
X	125	100	100	-	-
Y	350	350	800	-	1000

FIG. 1 TEMPERATURE-EXPOSURE THRESHOLDS FOR CAVITATIONAL SWELLING

Density measurements to evaluate the swelling resistance of the alloys at 9000 and 3000 MWD/T were only partially completed. Relatively few additional specimens (70) must be measured to determine temperature thresholds for swelling of the 9000 MWD/T specimens; the remaining specimens are, however, critical to the assignment of the swelling thresholds for the various alloys.

A major fraction (245 specimens) of the specimens remaining to be measured are in the group irradiated to 3000 MWD/T; measurement of the density changes of about 50 specimens representing the alloys in this group is required to calibrate temperatures of the high exposure specimens, by comparison of swelling thresholds with results of previous tests in the low exposure range. The low exposure group also includes most of the alloy specimens with alternative heat treatments included for evaluation of the effects of initial metallurgical structure on irradiation swelling.

All of the remaining specimens in the NaK V test also require photographing to obtain dimensional changes; highest temperature specimens (over swelling thresholds) for which no density measurements were made are of special interest.

NaK VI Test

This test, utilizing 180 specimens in 156 capsules, was aimed at determining the relative resistance of the dilute uranium alloys to anisotropic growth (change of shape), which is the basic driving force for cavitational swelling. Preliminary data from previous tests[5] had indicated that growth susceptibility depends upon alloy composition, and that compositions most susceptible to irradiation growth are also susceptible to cavitational swelling. The irradiation growth of the specimens in the NaK VI test would be correlated with the swelling susceptibility of the alloys as determined in the previous tests. The test specimens were dilute Fe, Si, Al, Cr, and Mo-containing alloys of compositions given in Table II, irradiated in the as-extruded (not heat treated) condition with texture sufficient to cause anisotropic growth.

Postirradiation examination of the NaK VI specimens has not begun. The specimens, mostly irradiated at low temperatures, must be photographed for dimensional changes to determine their susceptibility to anisotropic growth; a few specimens irradiated in high temperatures also require density measurement to evaluate swelling and metallographic examinations to establish the orientation of cavities that cause swelling of the textured metal.

PROGRAM ALTERNATIVES

Basis A. Completion of all the postirradiation examinations is required to realize the objectives originally anticipated. Completion of the work would ensure maximum return for a previous expenditure of about $200,000 on these tests. The cost of the remaining work is estimated as follows:

NaK V Test	approximately	$ 80,000
NaK VI Test		30,000
		$110,000

Most but possibly not all of the work on NaK V specimens could be completed during fiscal year 1968 if it is resumed promptly. Some or possibly all of the work on NaK VI test specimens could extend into next fiscal year.

Basis B. Only the work on NaK V test specimens could be completed. NaK VI test specimens would be stored pending final disposition. The cost of this program would be about $80,000. Again, we believe that most of this program probably could be completed within FY-1968.

Basis C. Alternatively, the portion of the postirradiation examinations required to obtain calibrated temperature-exposure thresholds for compositions irradiated to 13,000 MWD/T and 9000 MWD/T only could be completed. This would require completion of the density measurements for specimens irradiated to 9000 MWD/T and for specimens of the reference compositions irradiated to 3000 MWD/T as necessary to provide calibration data applicable to the higher exposure tests.

Assessment of the stability of 3000 MWD/T specimens with alternative heat treatments would be sacrificed.

Specimens of the NaK VI test would be stored pending final disposition.

The cost of this reduced program including final disposal of all NaK V test specimens is estimated to be $50,000. We believe that this work could be completed during FY-1968 if it is started promptly.

The work on any of these three bases would include preparation of progress reports (presumably fairly brief and informal monthly letter-documents) and a final formal report after all work is completed and all results are appraised.

The lack of a firmer schedule for forecasting rates of accomplishing this work results from uncertainties 1) as to starting time and 2) as to scheduling in our High Level Caves. Important production problems at Savannah River necessarily take priority, but we believe that this work will be done at approximately the indicated rates. If desirable for budgetary scheduling, the work could be extended over longer priods than those shown.

References

1. C. L. Angerman and G. R. Caskey. "Swelling of Uranium by Mechanical Cavitation." J. Nucl. Mat. 13, No. 12, 182 (1964) (Copy enclosed).

2. R. D. Leggett, T. K. Bierlein, and B. Mastel. Irradiation Behavior of High Purity Uranium. USAEC Report HW-79559, Hanford Atomic Products Operation, Richland, Washington, November 1963;
R. D. Leggett, T. K. Bierlein, B. Mastel, and H. A. Taylor. Basic Swelling Studies Preprint for AIME Symposium on Radiation Effects, Asheville, N. C., September 1965. USAEC Report BNWL-SA-154, Battelle-Northwest, Richland, Washington.

3. W. R. McDonell and C. L. Angerman. "Effect of Microstructure on Cavitational Swelling of Dilute Uranium Alloys." AIME Symposium on Radiation Effects, Asheville, N. C., September 1965. USAEC Report CONF-650904-4, February 1966 (Copy enclosed).

4. W. R. McDonell, W. N. Rankin, C. L. Angerman, and R. T. Huntoon. "Temperature-Exposure Thresholds for Cavitational Swelling of Dilute Uranium Alloys." Presented at Inst. of Metals Discussion "The Irradiation Effects in Uranium Alloys and Compounds." London, April 1966 (Copy of manuscript enclosed). To be submitted for publication in J. Inst. Metals.

5. W. R. McDonell, W. N. Rankin, and R. T. Huntoon. "Irradiation Growth of Dilute Uranium Alloys." Presented at Inst. of Metals Discussion "The Irradiation Effects in Uranium Alloys and Compounds." London, April 1966 (manuscript in preparation for publication).

APPENDIX

IRRADIATION STABILITY OF URANIUM ALLOYS AT HIGH EXPOSURES (13,000 MWD/T)

Postirradiation examinations were begun of a series of unrestrained dilute uranium alloy specimens irradiated to exposures up to 13,000 MWD/T in NaK-containing stainless steel capsules. This test, part of a program of development of uranium metal fuels for desalination and power reactors sponsored by the Division of Reactor Development and Technology, has the objective of defining the temperature and exposure limits of swelling resistance of the alloyed uranium. The uranium specimens contain small additions of Fe, Si, Al, Cr, Mo, or Zr, and were heat treated by various procedures to determine the stabilizing effects of different microstructural distributions of the alloy constituents. The specimens were irradiated to three exposures (3000, 9000, and 13,000 MWD/T) at calculated central temperatures from 300 to 800°C. The results at 13,000 MWD/T are summarized in the following paragraphs. Examination of specimens irradiated to 9000 MWD/T and 3000 MWD/T is incomplete.

Among the production-type alloys irradiated, the compositions that had best stability at high exposures (13,000 MWD/T) were those containing high Al and Si (800 ppm), in contrast to the better performance of intermediate Si compositions (350 ppm) in previous tests at lower exposures (5000 MWD/T).

The swelling data for the specimens irradiated to 13,000 MWD/T are arranged in the following table in the order of decreasing stability as determined by the threshold temperature for cavitation swelling. The threshold temperature for cavitation swelling at this exposure was taken as the temperature at which the total swelling was 6% -- 2% in excess of the volume increase due to solid fission products. In most cases, density was not measured for those specimens that had obviously swelled a great deal more than 6%. The listed temperatures are the nominal values and are subject to downward revision by 50-150°C when the swelling of calibration specimens at lower exposures is compared to the results of previous tests. The following principal conclusions were drawn:

> The highest stability is exhibited by U - 1.5 to 4.0% Mo - 0.1% Si alloys (Alloys 1, 2, and 3) that were solution-treated in the high gamma phase region (1050°C) and quenched in water. However, a U - 0.5% Mo - 0.1% Si (Alloy 24) swelled severely - probably due to internal cracking during the severe water quench.

Among the very dilute alloys, the specimens containing high Al or Si additions (800 ppm) (Alloys 5,6,8,9,10, 11,12) were more stable at 13,000 MWD/T than those containing intermediate (250-350 ppm) Si without high Al (Alloys 15, 17, 19). This contrasts with the results from a previous test at 5000 MWD/T, in which the intermediate Si alloys were the most stable.

U - 350 ppm Si - 1000 ppm Mo (Alloy 13), which was the most stable in the previous tests, was the best of the intermediate Si specimens in the present test, but was less stable than those containing 800 ppm Al (Alloys 5, 6,8,9,10,12).

Among the beta-treated, oil-quenched alloys with 800 ppm aluminum, those containing Si, Mo, and possibly Cr, as well as Fe (Alloys 5,6,8,9,10) were somewhat more stable than the alloy containing only Fe and Al (Alloy 12). As expected, the very dilute alloys of Fe and Si (100-150 ppm) (Alloy 21) and unalloyed ingot uranium (Alloy 22) swelled more than the alloys containing larger amounts of additives.

A high-temperature treatment of the dilute alloys in the gamma phase, designed to produce finely dispersed carbide in the metal, effectively increased the stability of U - Fe - Al alloy (Alloy 4) as well as that of unalloyed ingot uranium (500 ppm C) (Alloy 18).

The binary U - 1.5% Mo alloy without Si (Alloy 14) swelled more than the similar composition with 0.1 wt % Si (Alloy 3). Oil quenching the U - 1.5% Mo (Alloy 7) from 800°C (low-temperature region of the gamma phase) produced better stability than cooling slowly from the same temperature (Alloy 16). This test demonstrated that, in relatively concentrated alloys, the effect of heat treatment may persist to high exposures, whereas in dilute alloys little persistent effect of heat treatment was observed.

The U - 2% Zr binary (Alloy 23) was less stable than U - 1.5% Mo (Alloy 16); little difference was noted between U - 2% Zr (Alloys 20, 23) quenched or cooled slowly from 800°C.

Alloy	Decrease in Density After Irradiation at Indicated Nominal Temperature, %[a] 300°C	450°C	550°C	590-660°C	700-830°C	Alloy Composition, ppm[b] Fe	Si	Al	Cr	Mo	Heat Treatment Phase	°C	Time	Cooling
1	2.8	2.7		2.6	7.2		0.1 wt %			4.0 wt %	γ	1050	24 hr	Water
2	3.3	2.6		4.8	10.3		0.1 wt %			2.25 wt %	γ	1050	24 hr	Water
3	1.2	3.2	4.6		10.3		0.1 wt %			1.5 wt %	γ	1050	24 hr	Water
4	3.6	4.1	7.2	S	S	350		800			γ	950	20 min	Oil
5	3.8	3.4	15.6	15.3	18.4	350	350	800		1000	β	725	10 min	Oil
6	3.7	3.9	S	-	-	250	300	800	200		β	725	10 min	Oil
7	3.5	4.8	S	-	S					1.5 wt %	γ	800	20 min	Oil
8	5.1	4.2	25.6	43.5	S	350	350	800			β	725	10 min	Oil
9	4.1	3.9	31.0	38.8	S		800	800			β	725	10 min	Oil
10	4.4	3.7	35.0	-	-		350	800			β	725	10 min	Oil
11	4.5	5.4	38.4	-	-		800				β	725	10 min	Oil
12	4.5	5.0	41.5	-	-	350		800			β	725	10 min	Oil
13	4.6	9.4	S	-	-		350			1000	β	725	10 min	Oil
14	3.4	10.6	S	-	-					1.5 wt %	γ	1050	24 hr	Water
15	5.0	13.7	-	-	S	250	350				β	725	10 min	Oil
16	3.9	17.0	-	-	-					1.5 wt %	γ	800	20 min	Furnace to 500°C, Oil
17	4.4	19.0	-	S	-	250	250	250			β	725	10 min	Oil
18	4.4	26.0	S	-	-	(Unalloyed ingot uranium)					γ	950	20 min	Oil
19	4.9	26.0	-	S	-		350				β	725	10 min	Oil
20	5.7	S	-	S	-	(2 wt % Zr)					γ	800	20 min	Water
21	6.1	S	S	-	-	150	100	100			β	725	10 min	Oil
22	6.1	S	-	-	-	(Unalloyed ingot uranium)					β	725	10 min	Oil
23	6.3	48.0	S	-	-	(2 wt % Zr)					γ	800	20 min	Furnace to 500°C, Oil
24	19.1	21.4	-	-	21.7		0.1 wt %			0.5 wt %	γ	1050	24 hr	Water

(a) Actual temperatures probably 50-150°C lower.
(b) Composition in ppm, except as noted.
S Specimen obviously swelled more than 6%.
\- Specimen not examined since threshold had been found at lower temperature.

TABLE I

SPECIMENS FOR NaK V CAPSULE TEST OF URANIUM ALLOYS

Code	Nominal Composition, ppm Fe	Si	Al	Cr	Mo	Heat Treatment*	Code	Nominal Composition, ppm Fe	Si	Al	Cr	Mo	Heat Treatment*
I00	-	-	-	-	-	0	IG0	-	350	-	-	-	0
I01						1	IG1						1
I09						9	IG6						6
I011						11	IH1	-	800	-	-	-	1
I012						12	IH6						6
I013						13	IM1	250	250	250	-	-	1
I013A						13A	IU1	250	300	800	200	-	1
I014						14	IV1	150	100	-	-	-	1
I015						15	IW0	-	350	-	-	1000	0
IA1	350	-	800	-	-	1	IW1						1
IA3						3	IW3						3
IA11						11	IW6						6
IA12						12	IW9						9
IA13						13	IW10						10
IA13A						13A	IW11						11
IA14						14	IW14						14
IA15						15	IW15						15
IB1	350	350	800	-	-	1	IY1	350	350	800	-	1000	1
IB2						2	CK9	0.3 wt % Cr-0.3 wt % Mo					9
IB9						9	CK9A						9A
IB10						10	CK2C						2C
IB10A						10A	CL1	0.2 wt % Al					1
IB10B						10B	CN0B	1.5 wt % Mo					0B
IB11						11	CN4						4
IB12						12	CN4A						4A
IB13						13	CN9						9
IB13A						13A	CN9A						9A
IB14						14	CR9	0.3 wt % Al-0.5 wt % Si					9
IB15						15	CR10A						10A
IC0	250	350	-	-	-	0	CS1	1 wt % Si					1
IC1						1	CZ0A	2 wt % Zr					0A
IC6						6	CZ3						3
ID1	-	350	800	-	-	1	CZ4						4
IF0	-	800	800	-	-	0	CZ9A						9A
IF1						1	MA16	1.5 wt % Mo-0.1 wt % Si					16
IF3						3	MB16	2.25 wt % Mo-0.1 wt % Si					16
IF9						9	MC16	4.0 wt % Mo-0.1 wt % Si					16
IF10						10	MD16	0.5 wt % Mo-0.1 wt % Si					16
							ME16	1.5 wt % Mo					16
							MF16	0.1 wt % Mo-0.1 wt % Si					16

* See next page for heat treatments.

[redacted]

TABLE I (Continued)

*Heat Treatments:

0	β treated 725°C 10 min, water quenched
0A	β treated 710°C 2 hr, water quenched
0B	β treated 690°C 2 hr, water quenched
1	β treated 725°C 10 min, oil quenched
2C	β treated 720°C 6 hr, oil quenched; α annealed 500°C 2 hr, oil quenched
3	γ treated 800°C 20 min, water quenched
4	γ treated 800°C 20 min, water quenched; α annealed 600°C 5 hr, water quenched
4A	γ treated 800°C 20 min, water quenched; α annealed 600°C 10 min, water quenched
6	β treated 725°C 10 min, air cooled
9	γ treated 800°C 20 min, oil quenched
9A	γ treated 800°C 20 min, furnace cooled to 500°C, oil quenched
10	γ treated 800°C 20 min, oil quenched; α annealed 520°C 1 hr
10A	γ treated 800°C 20 min, oil quenched; α annealed 600°C 5 hr
10B	γ treated 800°C 20 min, oil quenched; α annealed 400°C 7 hr
11	γ treated 950°C 20 min, oil quenched
12	γ treated 950°C 20 min, oil quenched; β treated 725°C 10 min, oil quenched
13	γ treated 950°C 20 min, oil quenched; α annealed 520°C 1 hr
13A	γ treated 950°C 20 min, oil quenched; α annealed 600°C 5 hr
13B	γ treated 950°C 20 min, oil quenched; α annealed 400°C 7 hr
14	γ treated 950°C 20 min, water quenched
15	γ treated 950°C 20 min, furnace cooled to 725°C, hold 10 min, oil quenched
16	γ treated 1050°C 24 hr, water quenched

[redacted]

TABLE II

SPECIMENS FOR NaK VI CAPSULE TEST OF URANIUM ALLOYS

Code	Nominal Composition, ppm						Condition*
	Fe	Si	Al	Cr	Mo	C	
DA77X	350	-	800	-	-	50	77X
IA77X	350	-	800	-	-	500	77X
IB77X	350	350	800	-	-	500	77X
DC77X	250	350	-	-	-	50	77X
IC77X	250	350	-	-	-	500	77X
DD77X	-	350	800	-	-	50	77X
ID77X	-	350	800	-	-	500	77X
DE77X	250	-	-	-	-	50	77X
IE77X	250	-	-	-	-	500	77X
IF01X	-	800	800	-	-	500	01X
IG77X	-	350	-	-	-	500	77X
IH77X	-	800	-	-	-	500	77X
IU77X	250	300	800	200	-	500	77X
DW77X	-	350	-	-	1000	50	77X
IW77X	-	350	-	-	1000	500	77X
IY77X	350	350	800	-	1000	500	77X
IV77X	150	100	-	-	-	500	77X
IO77X	-	-	-	-	-	500	77X

* Conditions:
01X β treated 725°C 10 min, oil quenched
77X As-extruded

DISTRIBUTION: DPST-67-556, with transmittal letter from J. W. Morris to Dr. Harold Harty, October 13, 1967.

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