7
APR 11 1973

95368

UNCLASSIFIED

DOCUMENT NUMBER UCID-4449

MASTER

UNIVERSITY OF CALIFORNIA
LAWRENCE RADIATION LABORATORY

Classified Document

~~CONFIDENTIAL~~

~~SECRET~~

Routing Sheet

ROUTING

NAME

COMMENTS

Cy 26A-Technical Infor. Division PIN. No. 257
Copp-62-7

CLASSIFICATION CANCELLED

DATE NOV 26 1973

For The Atomic Energy Commission

Bram C. Feldman

Bram C. Feldman
Chief, Reactor, Space and Technology
Division of Classification

Exempt from CCRP Re-review Requirements
(per 7/22/82 Duff/Caudle memorandum)
H. Kinn 1-23-12

~~CONFIDENTIAL~~

~~RESTRICTED DATA~~

UNCLASSIFIED

This document contains restricted data as defined in Atomic Energy Act of 1954. Its release or the disclosure of its contents in any manner is unauthorized.

This document is not to be left unattended or where an unauthorized person may have access to it. Store in approved repository. It is your responsibility that information contained in this document is not compromised.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

"Materials"

COPP-62-7

~~CONFIDENTIAL~~This document consists of 19 Pages.
No. 26 of 33 Copies, Series A.

MEMORANDUM - February 8, 1962

UNCLASSIFIED**MASTER**

TO: Distribution

FROM: V. E. Hampel, Wm. Moran

SUBJECT: PTN NO. 257 - Final Summary of Impurities in Beryllium Oxide
as Used in the TORY II-A-1 Reactor

PLUTO TECHNICAL NOTE NO. 257

1.0 INTRODUCTION

The fabrication of BeO moderator for the TORY II-A-1 reactor has been subject to stringent fabrication procedures. Detailed requirements were demanded of physical and chemical properties. Distinct specifications, therefore, were written for BeO raw material, for sintered and unfueled components, and especially for the bulk of the core moderator which consisted of numerous sintered and homogeneously fueled hexagonal tube elements. Careful attention was given to assure uniform properties in elements fabricated from different BeO mixtures or batches.

The physical quality of the moderator was ascertained through elaborate inspection procedures and through destructive and non-destructive tests. The chemical quality, i.e. the purity of the moderator, was periodically monitored through chemical and spectrographic analysis. The results have been very gratifying.

It is hoped that this publication will increase the confidence in the use of Beryllium Oxide as a moderator for future types of gas cooled reactors.

It is the purpose of this report to present a final summary of chemical and spectrographic analyses, i.e. of impurities found in all Beryllium Oxide material of the TORY II-A-1 reactor. The data is published by the Neutronics Group which was greatly concerned with the purity of the moderator.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

~~UNCLASSIFIED~~~~CONFIDENTIAL~~

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

document contains
ned in the Atomic
its transmittal or the
tents in any manner
person is prohibited.

unauthorized

~~CONFIDENTIAL~~

2.0 SUMMARY

Distinct specifications were written which defined maximum impurity concentrations in BeO powder, in sintered parts, and in sintered and fueled elements. In this report each BeO category is at first treated separately. Where applicable, impurity levels of parts fabricated by different suppliers are shown side by side. Finally a comparison of impurities in all BeO categories is made. The chronological change of impurity concentrations between raw material and finished product is noted.

The Ledoux Company of Teaneck, New Jersey was contracted by the University of California to perform all chemical analyses. Additional analyses were performed by the Brush Beryllium Company, the manufacturer of the BeO raw material. Spot checks were also made by IRL.

Also, suppliers of BeO parts, e.g. G. E., C. W., N. B. and Brush made analyses to assure conformity with specifications. These records, however, are not in our possession.

2.1 Cost of Analyses

Our records show a total of 1655 analyses made by the Ledoux Company on BeO powder and on structural and fueled components. This number may differ somewhat in other records depending on whether analyses performed on IRL fabricated parts are included.

The cost for each analysis depends on the elements whose impurity concentrations were looked for. Later on it will be mentioned in greater detail that impurity elements have been arranged in three groups, as shown on any of the attached tables. The costs of chemical and/or spectrographic analyses of elements in these groups have been quoted to us as noted:

~~CONFIDENTIAL~~

Element group No. 1	\$ 14.42 ea.
Element group No. 2	\$ 23.06 ea.
Element groups 1, 3	\$ 39.52 ea.
Element groups 2, 3	\$ 45.08 ea.
Element groups 1, 2, 3	\$ 50.68 ea.
Uranium concentration	\$ 8.69 ea.

Presently, the Ledoux Company contract has been extended to cover analyses for the TORY II-C phase of the PLUTO program. Because of overlap it is somewhat difficult to establish with ease the total cost of the TORY-II-A-1 phase. Approximately \$45,260 have been expended for TORY II-A-1 BeO analyses. The average cost per analysis is, therefore, about \$27.40.

2.2 Total Mass of BeO

The above number of analyses assured the quality of 27,000 lbs. of beryllium oxide. This represents on the average one Ledoux analysis for each 16.3 lbs. of BeO, either in powder form or sintered.

The total of purchased fuel tubes amounted to approximately 169,278 pieces. Of this number 30,041 tubes were rejected, and 103,476 tubes were actually used in the core assembly of the reactor. Specifically, every 122nd. fueled BeO tube was analyzed.

2.3 The Nature of Analyses

Analyses were either chemical or spectroscopic. The presence of 29 different elements was checked. In order to facilitate the interpretation of findings, elements were arranged in 3 element groups, depending upon the neutron absorbing properties of the elements concerned. The third group contained many of the rare earths and represented the group with highest neutron absorption.

During the analysis of a particular sample not all three element groups were analyzed simultaneously as a rule. Upon request of our Quality Control Group elements of only one, or two, or three groups would be checked. The presence of specific elements, like calcium, molybdenum and others was determined upon special request.

~~CONFIDENTIAL~~

The number of analyses performed for each element group, and for some specific elements, is noted on the summary tables. We wish to stress that the results are sample weighted, averaged of all performed analyses.

While specific maximum concentrations were specified for elements of group 1, impurities in BeO due to elements of group 2 and 3 were noted in cumulative form. Each element of the latter groups was assigned a certain "q" value and each group in turn was permitted to have a maximum sum of c/q values, where c is seen to be the concentration of a particular element. While BeO powder was allowed to have a c/q value of element groups 2 and 3 of $4 + 4 = 8$, the c/q value for finished sintered parts in these groups was increased to 7 and 8, respectively, or a total c/q of 15.

2.4 Summary of Impurities in Beryllium Oxide Categories I, II, and III

As mentioned, impurity concentrations in Beryllium Oxide powder and parts were found to be far below the maximum allowable levels in nearly all cases. Contaminations in BeO due to those elements whose presence has been investigated were observed to be in general about 2-8 times less than the maximum allowable concentrations.

Resultant c/q values in subject categories are summarized:

Category I	: BeO Powder	: -2.246*
Category II	: Sintered-unfueled BeO parts	: -2.055 to 2.346
Category III	: Sintered-fueled BeO tubes	: -2.08

*-: less than

The total c/q value of sintered fueled BeO as shown represents about 13% of the allowable limit of 15. This is indeed very gratifying and has led to some relaxation of specifications for the TONY II-C moderator material.^(*) Details are shown in Tables I, II, and III.

The attached summaries of impurities in BeO powder, in sintered and in fueled BeO parts permit a ready comparison of contamination levels for specific elements prior to and after the fabrication process. This is shown in Table VI. It is seen that impurity concentrations actually decrease for about one half of the investigated elements during sintering.

** Refer to MEL-292H

~~CONFIDENTIAL~~

The concentrations of iron and sulphur are exceptions. Their concentration was found to be higher than specified at times.

Pertinent data and details concerning analyses and impurities of the BeO categories are found in Section 3, 4, and 5 of this report.

2.5 Summary of Fuel Concentrations in Fuel Classes

Concerning fueled BeO tubes, the deviation of observed versus specified uranium content is noted on Table IV. The root mean square of deviations from nominal is 1.25%.

Also, on Table V a tabulation is given which renders the assignment of fabricated fuel classes into final fuel class categories, according to DXT^{*} inspection methods. A general trend towards higher fuel enrichment by about 1/3 fuel class or 1.7% is observed. This is due primarily to the higher than anticipated effective fueled BeO density.

2.6 Comments

It must be pointed out that impurity concentrations have been investigated for 28 elements only, and that distinction has never been made between isotopes of these elements. The neutron absorbing properties of some isotopes are known to exceed the cumulative absorption of the natural isotope distribution by several orders of magnitude.

It is suggested that occasional analyses of this type be made on future moderator material to guard against the possibility of wilfull contamination.

2.7 The Records

The data was correlated and reduced by Mrs. Merna Engle and Mrs. Virginia Hansen. We thank the ladies for the completion of the tedious task.

All records are kept in the files of Mr. William H. Moran and those of the writer.

* The DXT inspection method utilizes a 50 Kv, or 100 Kv, X-ray tube to compare the Density X Thickness value of a sample against the corresponding value of a known standard.

~~CONFIDENTIAL~~

3.0 BeO CATEGORY I: BeO POWDER

3.1 Specifications:

Reference is taken to specifications:

MEL-292C (Revised 7-23-59), (BeO Powder)

MEL-348B (Revised 3-6-61), (Chemical Analysis)

3.2 General Comments

The Brush Beryllium Company was the manufacturer of BeO raw material. The following account is given concerning BeO powder:

Total amount purchased:	\$ 27,000.0	lbs.
Rejected as class B :	<u>1,020.5</u>	"
Total amount accepted :	<u>25,979.5</u>	"
BeO powder shipped to :		
General Electric :	12,000.2	lbs.
Curtiss-Wright :	6,000.2	"
LRL :	5,776.2	"
National Beryllia :	300.0	" (+ 34 lbs. class B)
Brush Beryllium* :	1,901.9	"

* Brush Beryllium Company retained this balance for fabrication of structural links.

Regarding chemical analyses, Brush was obliged to make one analysis of each drum containing approximately 30 lbs. of BeO powder.

The Ledoux Company, under contract to LRL, performed an independent check on BeO powder samples, taken on the average from each 5th. drum. A total of 152 BeO powder samples were analyzed by Ledoux.

A correlation between drum numbers, sample numbers, and Ledoux reports (LA reports) can be found in the files of William H. Moran.

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

3.3 Comparison between Brush and Ledoux Analyses of BeO Raw Material

A summary and comparison of impurities established by Brush and Ledoux is shown in Table I. Impurities of Brush are listed both as sample and as mass weighted averages while the Ledoux results are sample weighted arithmetic means only. Agreement between the two independent sources is seen to be reasonably close, except for impurity levels of Ni, Li, Na, Ti, and Ag where differences of up to a factor of 5.6 are noted.

3.4 Impurities Due to Elements of Groups 1, 2 and 3

Impurity levels of element group 1 are seen to be always lower than the maximum permissible level.

Similarly, the overall c/q summation for element groups 2 and 3 amounts to less than 2.246. This value is 28% of the maximum allowable concentration in both groups, i.e. a c/q value of $4 + 4 = 8$.

For a comparison of impurities in BeO powder to those of sintered and fueled material the reader is referred to Table VI.

4.0 BeO CATEGORY II: SINTERED UNFUELED BeO PARTS

4.1 Specifications:

Reference is taken to specifications:

MEL-385A	Slats	National Beryllia
MEL-295B	Links	Curtiss Wright, Brush Beryllium
MEL-294D	Sintered-unfueled	General Electric

4.2 General Comments

Sintered and unfueled BeO components fall into 2 types: structural elements and unfueled reflector tubes. While structural links, were fabricated by Brush and Curtiss Wright, the National Beryllia Company supplied the slats which are located as spacers between. Unfueled BeO tubes for the inlet and rear reflector were extruded by the General Electric Company exclusively.

The Ledoux Company analyzed a total of 120 samples.

~~CONFIDENTIAL~~

4.3 Impurities Due to Elements of Groups 1, 2 and 3

Impurities due to elements of group 1 are found to be lower than the maximum permissible level in nearly all cases. Exceptions are concentrations in magnesia, alumina and silica, which were permitted on an individual basis.

Regarding impurities due to elements of groups 2 and 3 we find very good agreement between parts from different suppliers. Differences by a factor of 2 are seen to exist only for Li and Mn, the higher levels being recorded for parts from the National Beryllia Company and the General Electric Company (Table II).

The c/q summation for element groups 2 and 3 of 2.055 - 2.346 is close to that of 2.246 for BeO category I. The maximum allowable c/q value was 15.

5.0 BeO CATEGORY III: SINTERED FUELED BeO TUBES

5.1 Specifications:

Reference is taken to specifications:

MEL-294D (Revised 6-24-60) Rev. III.

5.2 General Comments

The General Electric Company was the sole supplier of all fueled BeO tubes from which the TORY II-A-1 core was assembled. BeO raw material was shipped directly from Brush. Fuel in form of enriched uranium oxide was furnished by Oak Ridge.

The following table shows an account of fuel tubes:

Total number of fuel tubes purchased	169,278
Number of rejected tubes	<u>30,041</u>
Number of accepted tubes	<u>139,237</u>
Number of fueled tubes used in TORY II-A-1 core:	103,476
Surplus	35,761

~~CONFIDENTIAL~~

The Ledoux Company made a total of 1383 analyses of fuel tubes from different fuel classes and batches. This implies that on the average one out of 122 fuel tubes was destructively analyzed for its chemical composition.

Under separate cover* we are releasing a correlation between each analysis of Category III and the batch or shipment number of General Electric. Other pertinent comments concerning the origin of the sample, its fuel concentration etc. are also included. This information should be found valuable in the interpretation of the TORY II-A-1 core disassembly.

5.3 Impurities Due to Elements of Group 1

Individual impurity concentrations in element group 1 were considerably below the 80 ppm maximum level originally specified, except for iron, for which a concentration of 184 ppm is observed. (Table III).

5.4 Impurities Due to Elements of Groups 2 and 3

As to element groups 2 and 3 an overall maximum c/q summation of $7 + 8 = 15$ was specified. The achieved total c/q value, however, was computed to be less than 2.08, which is 14% of the maximum allowable value.

These results improve still further if impurities introduced by the fuel are subtracted. This has been done in the last column of Table III. There impurities due to Oralloy** are subtracted with the understanding that the average fueling in TORY II-A-1 was 5.954 wt%.

At this point an interesting comparison can be made between impurity levels of finished fuel elements and corresponding impurity concentrations of the raw material. This is shown in Table VI. We note a general decrease of impurities except for Cr, Cu, Fe, Ni, Mg, Ca, Ti, and Ag.

* PTN NO. 258

** Oralloy has a 93.15 wt% enrichment of U-235. Impurities in typical Oralloy, as determined from Oak Ridge shipping documents, are shown on Table V.

~~SECRET~~~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

6.0 BeO CATEGORY IV: ANALYSIS OF FUEL ENRICHMENT

6.1 Specifications:

Reference is taken to specifications:

MEL-294 D (Revised 6-24-60) Rev. III

6.2 General Comments

Fuel concentrations, in addition to impurities, were also checked by the Ledoux Company for specific fuel classes. A total of 97 samples from different fuel tube classes were analyzed.

6.3 Analytic Results

Table IV renders a comparison between specified and achieved fuel enrichment. The per cent deviation is shown. Deviations of as much as -2% and +3.3% are observed, although in about one half of all fuel classes the deviation from specified levels is less than $\pm 1\%$. (Ledoux accuracy of analyses: 0.5%)

The rms value of all deviations is ± 1.255 . Fuel classes differ by 5% in fuel from each other. A $\pm 2.5\%$ deviation is therefore, feasible.

6.4 Final Assignment of Fuel Classes Due to DXT Methods

A rather interesting tabulation is shown in Table VII where the final assignment of fuel categories is shown due to DXT inspection. A general trend towards higher fuel classes becomes apparent in most cases. A correlation between Ledoux findings of Table IV and Table V cannot be made, the general trend primarily being determined by the effective density in fueled BeO. While a minimum density of 0.96 of the theoretical maximum was specified* the actual achieved fueled BeO density was found to be about 0.975 of the theoretical maximum.

Some of the class assignments are seen to differ widely from the original class. However, this concerns only a small number of tubes. The writer seems to recall that in most of these sporadic cases incorrect labeling of the tubes could be confirmed.

* cf: Section 3.5 of MEL-294 D

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

This concludes the final summary of impurities in the BeO moderator of TORY II-A-1. It is hoped that this publication will increase the confidence in future construction of similar types of gas cooled reactors.

To the Recipient of this Document:

Now that you have read this document you will have to file it. Quite often we neglect to do this immediately. This results in a not up-to-date reference.

Periodically we ask our secretaries to go through the monthly chore of filing and labeling of documents. Often it takes a whole morning of their time.

Well, on the distribution list of this report we have included for your convenience the label characterizing this report. If you cut it out, the label is ready to be used with any of the standard Celluloid Index Tabs. In particular, the size of the label which we have chosen will fit into the tabs of yellow ringbook indexes.

Should you consider this a time saving method, we would appreciate your cooperation in making this a mutual practice.

~~CONFIDENTIAL~~

SECRET

~~SECRET~~

COPP-62-7
PTN NO. 257
Page Twelve

~~CONFIDENTIAL~~
AL

VEH: jas
DISTRIBUTION:

1. C. Barnett
2. A. Cole
3. R. Finke/J. Hadley
4. E. Goldberg
5. W. Gust
6. R. Freis
7. V. Hampel
8. S. Kellman
9. A. Lorenz
10. T. Merkle
11. T. Merkle/File
12. T. Merkle/File
13. T. Merkle/File
14. H. Reynolds
15. W. B. Myers
16. R. Batzel/B. Rubin/J. Kane
17. A. Rothman
18. J. Foster
19. F. Kloverstrom/W. Gilbert
20. H. Gordon
21. H. McDonald
22. J. Olsen
23. L. Hughes
24. L. Wouters
- 25, 26. Technical Information Division ✓
27. A. O. Mooneyham, Marquardt
28. I. Hoffman, AEC-Washington
29. C. Helfrich, AEC-SAN
30. W. C. Spence, LASL
31. W. Moran
32. J. Cahoon
33. W. Sandholtz

~~SECRET~~

~~CONFIDENTIAL~~

BeO, Summary of
Impurities-Hampel
PTN 257 (SRD)

TABLE I

Impurities in BeO Powder of TORY II-A-1 Moderator: BeO Category I (23,330.4 lbs)

Element Group	Impurity Element	Atomic Number	ppm Sensitivity of Analyses	q Value	MEL-292C Maximum Allowable ppm or C/q	Impurities in BeO Powder Analyzed by		
						Brush		Ledoux
						Sample wtd. ppm	Mass wtd. ppm	Sample wtd. ppm
1	Cr	24	1	--	10	- 10.0	- 10.0	- 1.46
	Cu	29	1	--	10	- 1.26	- 1.45	- 1.02
	Fe	26	2	--	20	- 14.8	- 14.8	- 10.6
	Ni	28	2	--	20	- 10.03	- 10.0	- 1.77
	Mg	12	5	--	50	- 26.2	- 26.4	- 33.8
	Ca	20	5	--	50	- 13.2	- 13.4	- 7.19
	Al	13	10	--	100	- 56.6	- 55.9	46.4
	Si	14	10	--	100	- 21.8	- 22.1	40.1
	S	16	150	--	1500*	794.5	785.9	723.7
	Mo	42	NR	--	50	NA	NA	NA
2	B	5	0.5	4	50	.845	0.844	- 0.839
	Cd	48	0.5	6		- 1.0	- 1.0	- 0.50
	Co	27	1	12		- 1.0	- 1.0	- 1.10
	Li	3	2	20		- 1.03	- 1.0	- 3.64
	Mn	25	2	25		- 2.77	- 2.77	- 3.20
	Na	11	5	50		- 11.4	- 11.2	- 16.5
	Ti	22	5	50		- 20.0	- 20.0	- 5.0
	Ag	47	5	50		- 1.0	- 1.0	- 4.80
						$\Sigma c/q = 4$	$\Sigma c/q = -1.253$	$\Sigma c/q = -1.248$
3	Gd	64	0.1	1	50	NA	NA	- 0.1
	Sm	62	0.5	5		NA	NA	- 0.5
	Eu	63	1	8				- 1.0
	In	49	2	20				- 2.0
	Dy	66	3	30				- 3.0
	Tm	69	3	30				- 3.0
	Hf	72	3	30				- 3.0
	Au	79	3	30				- 3.0
	Rh	45	4	40				- 4.0
	Er	68	5	50		NA	NA	- 5.0
				$\Sigma c/q = 4$	NA	NA	1.025	
Total Number of Samples Analyzed:						798	23,330.4 lbs.	152
Total c/q value for element groups 2 and 3:								$\Sigma c/q = -2.246$

- Symbol indicates concentration to be less than noted.

NA Not Analyzed

wtd. = weighted

* According to MEL-292C, Section 1.3.4 no other element except Be, O, S, shall be present to an extent greater than 50 ppm, unless otherwise noted.

UNCLASSIFIED IF SEPARATED FROM THIS REPORT

TABLE II

Impurities in Unfueled Sintered BeO Moderator of TORY II-A-1: BeO Category II

				Impurities in sintered, unfueled BeO parts analyzed by Ledoux. Parts fabricated by:					
Element Group	Impurity Element	Atomic Number	q Value	Sensitivity of Analyses	MEL-295B Maximum Allowable c ppm	Brush Beryllium Sample Weighted ppm	Curtiss-Wright Sample Weighted ppm	National Beryllia Sample Weighted ppm	General Electric Sample Weighted ppm
1	Cr	24	--	10	80	NA	NA	- 2.0	NA
	Cu	29	--	4	80	NA	NA	- 3.0	NA
	Fe	26	--	20	80	NA	NA	- 45.8	NA
	Ni	28	--	10	80	NA	NA	- 2.0	NA
	Mg	12	--	8	2 wt. %*	3000	133.3	- 308.3	NA
	Ca	20	--	8	80	NA	NA	- 91.65	NA
	Al	13	--	15	2 wt. %*	NA	NA	- 4900	NA
	Si	14	--	15	2 wt. %*	NA	NA	- 248.4	NA
	S	16	--	NR	80	NA	NA	- 15.0	NA
	Mo	42	--	NR	80	NA	NA	- NA	NA
	Zr	40	--	NR	2 wt. %*	NA	NA	- NA	NA
2	B	5	4	0.5	↓	- 0.646	- 0.64	- 0.77	- 0.5
	Cd	48	6	0.5		- 0.586	- 0.552	- 0.5	- 0.5
	Co	27	12	1		- 1.14	- 1.45	- 1.0	- 1.0
	Li	3	20	2		- 2.83	- 2.55	- 4.77	- 4.67
	Mn	25	25	2		- 3.83	- 4.35	- 7.15	- 10.76
	Na	11	50	5		- 9.06	- 10.5	- 9.23	- 8.28
	Ti	22	50	5		- 5.0	- 5.69	- 5.0	- 5.0
	Ag	47	50	5		- 5.0	- 5.0	- 5.0	- 5.0
					Σ c/q = 7	Σ c/q = -1.030	Σ c/q = -1.098	Σ c/q = -1.268	Σ c/q = -1.321
3	Gd	64	1	0.1	↓	- 0.1	- 0.1	- 0.1	- 0.1
	Sm	62	5	0.5		- 0.5	- 0.5	- 0.5	- 0.5
	Eu	63	8	1		- 1.0	- 1.0	- 1.0	- 1.0
	In	49	20	2		- 2.0	- 2.0	- 2.0	- 2.0
	Dy	66	30	3		- 3.0	- 3.0	- 3.0	- 3.0
	Tm	69	30	3		- 3.0	- 3.0	- 3.0	- 3.0
	Hf	72	30	3		- 3.0	- 3.0	- 2.88	- 3.0
	Au	79	30	3		- 3.0	- 3.0	- 3.0	- 3.0
	Rh	45	40	4		- 4.0	- 4.0	- 4.0	- 4.0
	Er	68	50	5		- 5.0	- 5.0	- 5.0	- 5.0
					Σ c/q = 8	Σ c/q = -1.025	Σ c/q = -1.025	Σ c/q = -1.021	Σ c/q = -1.025
Total c/q value for element groups 2 and 3					Σ c/q = 15	Σ c/q = -2.055	Σ c/q = -2.123	Σ c/q = -2.289	Σ c/q = -2.346
Total number of samples analyzed						35	29	17	39
- Symbol indicates concentration to be less than noted NR Not Required NA Not Analyzed * Alumina, silica, magnesia, and zirconia permitted up to 2 wt.						Crp. 1: 0 samples Crp. 2: 35 samples Crp. 3: 35 samples Mg : 2 samples	Crp. 1: 0 samples Crp. 2: 29 samples Crp. 3: 29 samples Mg : 3 samples	Crp. 1: 6 samples Crp. 2: 13 samples Crp. 3: 8 samples Al : 3 samples	Crp. 1: 0 samples Crp. 2: 39 samples Crp. 3: 9 samples

CONFIDENTIAL

CONFIDENTIAL

TABLE III

Impurities in Fueled, Sintered BeO Moderator of TORY II-A-1: BeO Category III

						Impurities in sintered, fueled BeO parts analyzed by Ledoux. Parts fabricated by:	
Element Group	Impurity Element	Atomic Number	q Value	Sensitivity of Analyses	MEL-294D Maximum Allowable c ppm	General Electric Sample Weighted ppm	Same, less impurities due to 5.954 wt % OyO ₂ ppm
1	Cr	24	--	10	80	30.3	29.8
	Cu	29	--	4	80	- 12.7	- 12.2
	Fe	26	--	20	80	184.2	178.0
	Ni	28	--	10	80	- 18.3	- 16.3
	Mg	12	--	8	2 wt %*	62.2	61.8
	Ca	20	--	8	2 wt %*	590.9	587.4
	Al	13	--	15	2 wt %*	- 43.1	- 41.8
	Si	14	--	15	2 wt %	38.4	36.7
	S	16	--	NR	80	108.8	- 108.8
	Mo	42	--	NR	80	- 21.1	- 9.3
	Zr	40	--	NR	2 wt %	NA	NA
2	B	5	4	0.5	↓ Σ c/q = 7	- .544	- .538
	Cd	48	6	0.5		- .506	- .482
	Co	27	12	1		- 1.115	- 1.055
	Li	3	20	2		- 2.67	- 2.66
	Mn	25	25	2		- 3.47	- 3.05
	Na	11	50	5		- 7.88	- 7.34
	Ti	22	50	5		- 5.05	- 5.05
	Ag	47	50	5		- 5.0	- 4.9
						Σ c/q = -1.055	Σ c/q = -0.904
3	Gd	64	1	0.1	↓ Σ c/q = 8	- 0.1	- 0.1
	Sm	62	5	0.5		- 0.5	- 0.5
	Bu	63	8	1		- 1.0	- 1.0
	In	49	20	2		- 2.0	- 2.0
	Dy	66	30	3		- 3.0	- 3.0
	Tm	69	30	3		- 3.0	- 3.0
	Hf	72	30	3		- 3.0	- 3.0
	Au	79	30	3		- 3.0	- 3.0
	Rh	45	40	4		- 4.0	- 4.0
	Er	68	50	5		- 5.0	- 5.0
						Σ c/q = -1.025	Σ c/q = -1.025
Total c/q value for element groups 2 and 3					Σ c/q = 15	Σ c/q = -2.08	Σ c/q = -1.929
Total number of samples analyzed:						1383	1383

- Symbol indicates concentration is less than noted
NR Not required
NA Not analyzed
* Alumina, silica, magnesia, zirconia and calcia are generally singly allowable

Group 1 :	142 Samples
Group 2 :	1076 "
Group 3 :	126 "
Group 4 :	10 "
Group 5 :	12 "
Group 6 :	1 "

CONFIDENTIAL

CONFIDENTIAL

TABLE IV

DEVIATIONS OF FUEL ENRICHMENT IN FUEL CLASSES FROM NOMINAL VALUE: BeO CATEGORY IV

Fuel Class Code Name	Nominal O_2 per Class wt %	Ledoux Findings wt %	% Deviation from Nominal	No. Samples Analyzed
60	3.53	3.456	- 2.11	3
50	3.70	3.728	+ .759	7
40	3.88	3.896	+ .401	3
30	4.07	4.046	- .601	3
20	4.25	4.205	- 1.06	6
0	4.47	4.468	- .056	6
1	4.70	4.594	- 3.31	3
2	4.93	4.937	+ .135	3
3	5.17	5.187	+ .322	3
4	5.41	5.543	+ 2.46	9
5	5.68	5.725	+ .788	3
6	5.95	5.918	- .364	3
7	6.25	6.225	- .404	6
8	6.52	6.508	- .179	6
9	6.87	6.755	- 1.68	6
10	7.16	7.189	+ .402	4
11	7.49	7.562	+ .963	11
12	7.88	7.864	- .197	3
13	8.27	8.177	- 1.12	6
14	8.70			
15	9.12	9.01	- 1.21	3
16	9.53			
17	10.00			
18	0			

rms = $\pm$ 1.255

97

TABLE V

IMPURITIES IN O₂ FUEL, TYPICAL OF FUEL USED IN TORY II-A-1

(Data was originally published in COPP-61-68; PTN-247)

Impurity Element	Concentration ppm	
Be	0.01*	Erratum: Published as 1.0 in PTN 247**
Ni	34*	
Sn	13*	
Si	29*	
Li	0.2*	Erratum: Published as 0.02 in PTN 247**
P	121*	
Na	9*	
Mo	198*	
Mn	7*	
Mg	7*	
K	59*	
Fe	104*	
Cu	8*	
Cr	9*	
Ca	59*	
Ba	12*	
B	0.1*	
Al	21*	
Ag	1*	
Cd	0.4*	
Co	1*	
V	1*	
C	251*	
F	5*	

*Less than

**The reader is asked to correct concentrations of Be and Li, in PTN 247
the above noted value

TABLE VI

Comparison of Impurities in All BeO Materials, Fabricated by Different Suppliers as Analyzed by Ledoux (Sample Weighted)

				MEL-294D Maximum Allowable in Cat. III ppm	CATEGORY I BeO Powder	CATEGORY II Sintered, Unfueled BeO				CATEGORY III Sintered, Fueled BeO	Deviation of Impurities in Category III from Those of Category I ppm
Element Group	Impurity Element	Atomic Number	q-Value Category III		Brush Beryllium ppm	Brush Beryllium ppm	Curtiss-Wright ppm	BeO National Beryllia ppm	General Electric ppm	General Electric ppm	
1	Cr	24	--	80	- 1.46	NA	NA	- 2.0	NA	29.8	+ 27.54
	Cu	29	--	80	- 1.02	NA	NA	- 3.0	NA	- 12.2	+ 11.18
	Fe	26	--	80	- 10.6	NA	NA	- 45.8	NA	178.0	+ 167.4
	Ni	28	--	80	- 1.77	NA	NA	- 2.0	NA	- 16.3	+ 14.55
	Mg	12	--	2 wt %*	- 33.8	3000	133.3	- 308.3	NA	61.8	+ 28.0
	Ca	20	--	2 wt %*	- 7.19	NA	NA	- 91.65	NA	587.4	+ 580.2
	Al	13	--	2 wt %*	46.4	NA	NA	- 4900	NA	- 41.8	- 4.6
	Si	14	--	2 wt %	40.1	NA	NA	- 248.4	NA	36.7	- 3.4
	S	16	--	80	723.7	NA	NA	- 15.0	NA	- 108.8	- 614.9
	Mo	42	--	80	NA	NA	NA	- NA	NA	- 9.3	NA
Zr	40	--	2 wt %		NA	NA	- NA	NA	NA	NA	
2	B	5	4		- 0.839	- 0.646	- 0.64	- 0.77	- 0.5	- .538	- 0.30
	Cd	48	6		- 0.50	- 0.586	- 0.552	- 0.5	0.5	- .482	- 0.02
	Co	27	12		- 1.10	- 1.14	- 1.45	- 1.0	1.0	- 1.055	- 0.05
	Li	3	20		- 3.64	- 2.83	- 2.55	- 4.77	4.67	- 2.66	- 0.98
	Mn	25	25		- 3.20	- 3.83	- 4.35	- 7.15	10.76	- 3.05	- 0.15
	Na	11	50		- 16.5	- 9.06	- 10.5	- 9.23	8.28	- 7.34	- 9.16
	Ti	22	50		- 5.0	- 5.0	- 5.69	- 5.0	5.0	- 5.05	+ 0.05
	Ag	47	50		- 4.80	- 5.0	- 5.0	- 5.0	5.0	- 4.9	+ 0.1
				Σ c/q = 7	Σ c/q = -1.221	Σ c/q = -1.030	Σ c/q = -1.098	Σ c/q = -1.268	Σ c/q = -1.321	Σ c/q = -0.904	Σ c/q = -0.32
3	Gd	64	1		- 0.1	- 0.1	- 0.1	- 0.1	- 0.1	- 0.1	A comparison of group 3 can not be made. Concentrations are recorded as having been less than 1/10 of the specified maximum in all components, of Cat. I and Cat. III
	Sm	62	5		- 0.5	- 0.5	- 0.5	- 0.5	- 0.5	- 0.5	
	Eu	63	8		- 1.0	- 1.0	- 1.0	- 1.0	- 1.0	- 1.0	
	In	49	20		- 2.0	- 2.0	- 2.0	- 2.0	- 2.0	- 2.0	
	Dy	66	30		- 3.0	- 3.0	- 3.0	- 3.0	- 3.0	- 3.0	
	Tm	69	30		- 3.0	- 3.0	- 3.0	- 3.0	- 3.0	- 3.0	
	Hf	72	30		- 3.0	- 3.0	- 3.0	- 2.88	- 3.0	- 3.0	
	Au	79	30		- 3.0	- 3.0	- 3.0	- 3.0	- 3.0	- 3.0	
	Rh	45	40		- 4.0	- 4.0	- 4.0	- 4.0	- 4.0	- 4.0	
	Er	68	50		- 5.0	- 5.0	- 5.0	- 5.0	- 5.0	- 5.0	
				Σ c/q = 8	Σ c/q = -1.025	Σ c/q = -1.025	Σ c/q = -1.025	Σ c/q = -1.021	Σ c/q = -1.025	Σ c/q = .1.025	
Total c/q Value, Element Groups 2,3:				Σ c/q = 15	Σ c/q = -2.246	Σ c/q = -2.055	Σ c/q = -2.123	Σ c/q = -2.289	Σ c/q = -2.346	Σ c/q = -1.929	Σ c/q = -0.32
Total Number of Samples Analyzed :					152	35	29	17	39	1383	

- Symbol indicates concentration to be less than

NR Not Required

NA Not Analyzed

* For a detailed summary as to the number of analyses performed in end element group, or for a particular single element, the reader is referred to the Tables of individual categories.

** Impurities due to fuel are removed in this column.

CONFIDENTIAL

TABLE VII

TORY II-A-1

ASSIGNMENT OF ORIGINAL FUEL TUBE CLASSES INTO FINAL FUEL CLASS CATEGORIES ACCORDING TO DXT INSPECTION

FINAL ASSEMBLY CLASS →

Orig. class	60	50	40	30	20	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Sum
60	2413	419	395																	3227
50	265	2129	2856	539	1												40			5830
40	46	280	1821	1045	168	79														3439
30			9	1779	1499	215	1													3503
20				2	2294	1150	36			8	99	10								3600
0					52	3445	784	12												4293
1					562	764	2077	1158	134											4695
2						204	923	2654	403											4184
3								1	2595	1487	14									4097
4									4	4145	1560	13					11			5733
5						62				374	4063	1036								5535
6										1	308	4866	1129				2			6306
7										93	12	270	4920	1788	33	143				7259
8									66			91	611	5441	1200	80				7489
9													26	358	6489	1783	55			8711
10												8	106	501	539	9721		1		10876
11									6	5					19	891	12362	559		13842
12																49	431	6596	445	7521
13																	2	451	5958	6411
Sum	2724	2828	5081	3365	4577	5919	3821	3825	3208	6113	6056	6294	6792	8088	8280	12667	12903	7607	6403	116551

~~CONFIDENTIAL~~ ~~SECRET~~