CONF-970926--4

CRITICALITY SAFETY CONSIDERATIONS FOR MSRE FUEL DRAIN TANK URANIUM AGGREGATION

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Submitted to
American Nuclear Society
Nuclear Criticality Safety Division Topical Meeting on
Criticality Safety Challenges in the Next Decade
Chelan, Washington
September 7-12, 1997

MASTER

*Managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

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ABSTRACT

This paper presents the results of a preliminary criticality safety study of some potential effects of uranium reduction and aggregation in the Molten Salt Reactor Experiment (MSRE) fuel drain tanks (FDTs) during salt removal operations. Since the salt was transferred to the FDTs in 1969, radiological and chemical reactions have been converting the uranium and fluorine in the salt to UF_6 and free fluorine. Significant amounts of uranium (at least 3 kg) and fluorine have migrated out of the FDTs and into the off-gas system (OGS) and the auxiliary charcoal bed (ACB). The loss of uranium and fluorine from the salt changes the chemical properties of the salt sufficiently to possibly allow the reduction of the UF_4 in the salt to uranium metal as the salt is remelted prior to removal. It has been postulated that up to 9 kg of the maximum 19.4 kg of uranium in one FDT could be reduced to metal and concentrated. This study shows that criticality becomes a concern when more than 5 kg of uranium concentrates to over 8 wt % of the salt in a favorable geometry.

I. INTRODUCTION

The Molten Salt Reactor Experiment (MSRE), which operated from June 1965 to December 1969, investigated the viability of using a molten homogeneous fluoride salt containing uranium in a graphite lattice as a power reactor.[1] After the experiment was terminated, 4708.8 kg of fluoride salt containing ~36.4 kg (84 wt % ^{233}U) of uranium and 675 g of plutonium was transferred into two fuel drain tanks (FDTs). An FDT is a vertical cylindrical vessel, with spherical segment ends containing 32 steam downcomer cooling bayonet tubes positioned in two concentric circles within the salt. Both the tank and tubes are composed of Hastelloy-N. Over half the salt, 53.3% (2509.8 kg), was transferred to FDT-1, and the remainder was transferred to FDT-2. The salt, less the uranium and plutonium, is assumed to be composed of $LiF\text{-}BeF_2\text{-}ZrF_4$, with approximate mole percentages of 64.7, 30.1, and 5.2, respectively. The uranium, in the form of UF_4, makes up about 0.75 wt % of the salt.

II. PREVIOUS ANALYSES

An earlier criticality safety study examined the FDT cell using the best estimates of the fuel and flush salt compositions in a realistic model of the cell.[2] The FDT cell was examined in its normal and most reactive credible upset condition. Basic assumptions for that study are that the salt is homogeneous and that no water is present. The FDT cell remains well subcritical given these assumptions. Since the composition of the salt and the exact amount of salt in each FDT is not precisely known, a sensitivity study of the salt composition and location was performed. Varying the salt density or uranium content by 5% or the amount of salt in each FDT by 10% results in less than a 5% change in k_{eff}. The analysis showed that the k_{eff} of the system is driven by the tank containing the most salt. FDT-1 alone, which is assumed to contain 53.3% of the salt, with its thermal shield, a steel liner, and a concrete reflector, has the same k_{eff} as the entire FDT cell.

In 1994 a gas sample from the MSRE off-gas system (OGS) indicated uranium had migrated out of the FDT salt in the form of UF_6 and through the OGS. Further investigation revealed the likelihood of up to 3.0 kg of uranium accumulation in the auxiliary charcoal bed (ACB). A criticality assessment of the ACB indicated that water in and around the ACB presented an unsafe condition.[3] The ACB cell, which was initially flooded with water, was drained, thus removing any immediate criticality concern.

The presence of uranium in the ACB also indicates that the chemical composition of the FDT salt is not stable. Chemical and radiological reactions have been converting the UF_4 in the FDT salt to other chemical compositions of uranium and free fluorine. It is also possible that the salt is not homogeneous but has a uranium density gradient that formed when it was initially cooled. Through the years, uranium and fluorine have escaped from the FDTs through the OGS, changing the chemical characteristics of the salt. As long as the salt remains unmelted, the uranium should either (1) stay in the salt as UF_4 or (2) convert to UF_6, migrate out of the salt, and deposit in either the upper section of the FDTs, the OGS, or the ACB. Neither of these scenarios presents a criticality concern unless water is present.

III. REDUCTION/AGGREGATION ANALYSIS

A possible solution to the problem of what to do with the MSRE fuel salt involves melting the salt, drawing it out of the tanks, and reprocessing it to remove the uranium and limited quantities of plutonium. The process of melting the salt in the FDTs raises some criticality concerns due to the possible inhomogeneity of the uranium and alteration of the salt's chemical properties. If the fluorine content in the salt has been lowered sufficiently, upon melting of the salt, uranium could come out of the liquid salt as metal and aggregate into clumps.

A hypothetical physical chemistry scenario assumes that enough free fluorine has been formed and escaped from the FDT to allow up to 9 kg of uranium to reduce to metal if all the salt in a drain tank is melted prior to removal. It is also possible that instead of a uniform homogeneous mixture, a uranium density gradient formed in the FDT when it was initially cooled. This gradient could be further concentrated as the salt is remelted, thus forming a region of high uranium concentration, which could present a criticality concern. This criticality safety study examines the effects uranium concentration may have on the criticality of an FDT by dividing the analysis into three phases.

Phase I develops an overall understanding of the effect uranium reduction has on the FDTs. The purpose is to develop a feel for how much uranium must concentrate for criticality to become a concern. The model used in this phase contains FDT-1 along with its thermal shield, a steel liner, and a concrete reflector. The FDT contains 53.3% of the salt, which includes 19.4 kg of uranium (84 wt % ^{233}U) and 400 g of plutonium. The FDT is modeled with and without bayonet tubes. First, the worth of the bayonet tubes is determined so that future analyses can be simplified by removing them. Then, progressively more uranium is reduced to metal and aggregated as the core. The results from these cases are contained in Table 1.

Phase II examines the core-reflector interaction of the system by simplifying the system to a concentrated spherical uranium core surrounded by a spherical salt reflector. The total masses of the salt, uranium, and plutonium in the system are maintained unless otherwise stated. The basic model for this phase of the analysis is a 9-g uranium core with various salt concentrations and different salt reflectors. The average energy of fissions, the percentage of fissions in the core and reflector, and the cross-section library effects are examined for trends. The results are contained in Table 2.

Phase III forms the actual basis for the final recommendations. It examines the effects concentrating uranium from a homogeneous uranium/salt mixture to uranium metal in the center of the FDT have on the system. This analysis is done for a 5-kg uranium sphere, a 9-kg uranium sphere, a 19-kg uranium sphere, and a 9-kg uranium slab. The model uses the same FDT-1 as in phase I without the bayonet tubes. The total fissions, fission densities, and k_{eff} values versus core uranium weight percent are plotted. The results of this phase are contained in plots 1, 2, and 3.

A. Phase I: General Overview

The cases in Table 1 use KENO-V.a and the 27GROUPNDF4 cross-section library to analyze various uranium concentrations and configurations in FDT-1.[4] The model contains FDT-1, its thermal insulation, and a close-fitting stainless steel liner and thick concrete reflector. Cases 1–3 contain bayonet tubes in the FDT. In the remaining cases, the model was simplified by removing the bayonet tubes, thus increasing the total amount of salt in the FDT. Case 1, the base case representing a good approximation of FDT-1's current state, contains a homogeneous mixture of uranium and salt. The energy of the average lethargy causing fission (EALCF) is 3.17 eV, and the k_{eff} of the system is 0.8651. There is no criticality concern as long as the salt is homogeneous and no water is present. In case 2, 9 kg of uranium is placed in a central sphere (the core) containing a 60/40 wt % uranium/salt mixture. The k_{eff} rises to 0.9710, thus presenting a criticality concern. The EALCF rises to 17.92 eV due to the spectral hardening of the neutron flux. Case 3 shows that the system is well above critical (k_{eff} = 1.1424) when the 9 kg of uranium removed from the salt reflector is reduced and concentrated as a metal sphere in the center of the FDT. The EALCF increases to 140.2 eV due to the neutrons that are born and cause fission without leaving the uranium metal core. Almost 41% of the fissions occur in the 9-kg uranium metal sphere, with the remaining fissions occurring in the salt.

Cases 4–6 correspond to cases 1–3 without bayonet tubes. The 32 bayonet tubes are located in two rings centered in the FDT; the first ring, containing 12 bayonet tubes, has a radius of 30.48 cm; the second ring, containing 20 bayonet tubes, has a radius of 46.99 cm. The volume in the salt that previously contained the bayonet tubes is assumed as salt. The salt reflector, uranium, and plutonium densities are decreased to account for the added salt volume so their total masses remain constant. When the uranium is homogeneously distributed throughout the salt, as in case 4, removing the bayonet tubes increases the k_{eff} approximately 10%, to 0.9519, and decreases the EALCF to 2.43 eV compared with case 1. Replacing the bayonet tubes with salt replaces a net absorber with a net scatterer, thus increasing the overall system k_{eff}. The relative negative worth of the tubes is strongly dependent on the fraction of fissions that occur in the volume containing them. If most of the fissions occur inside a radius of 30 cm, the bayonet tubes will not significantly reduce the system k_{eff}. Case 5 contains 9 kg of uranium in a 60/40 wt % uranium/salt sphere centered in the FDT. The removal of the tubes caused the k_{eff} to increase ~5.6% over case 2, to 1.0259. Removing the bayonet tubes caused a larger percentage of fissions to occur in the reflector. In case 6, the 9 kg of uranium has reduced to a metal sphere centered in the FDT. The lack of bayonet tubes has little effect, increasing the k_{eff} just 1.0%, to 1.1543.

Cases 7–10 examine the system as progressively more uranium reduces to metal and forms a sphere in the bottom of the FDT. The total amount of uranium in the FDT remains constant in these cases. As the amount of uranium metal in the sphere increases, three effects are observed. First, the percentage of fissions occurring in the uranium metal core increases from 6.31% for a 4-kg core to 41.3 % for a 9-kg core. Second, the EALCF increases from 3.46 eV to 138.4 eV due to the increased fissions occurring in the core. Finally, the system k_{eff} increases from 0.9284 to 1.0447. There are no experiments containing these materials at intermediate energies. Experiments containing highly enriched ^{233}U have been done for fast and thermal systems. Given the uncertainty associated with the cross sections, model, and materials, all these cases present a significant criticality concern.

Cases 11 and 12 also contain 9 kg of uranium metal in the bottom of the FDT; however, all the uranium has been removed from the salt reflector. Although over half the uranium has been removed the system, k_{eff} drops less than 2%, to 1.0265, between cases 10 and 11. For a metal core, the majority of the salt's worth comes from it being a reflector, not from the uranium that is present. Approximately 93% of the fissions occur in the uranium metal sphere with the remaining fissions in the salt due to its residual plutonium. Since most of the fissions now occur in the core, removing the uranium from the salt results in a very fast system (EALCF = 1.28E+5). Case 12 is the same as case 11 but with the 9-kg uranium sphere replaced by a 9-kg uranium slab in the bottom hemisphere of the FDT. Altering the core from a favorable to an unfavorable geometry reduced the k_{eff} to 0.5889. The plutonium in the salt contributes about 0.07 to the system k_{eff}, although a larger percentage of fissions occur in the salt in case 12 than in case 11.

The last case in Table 1, case 13, represents all 19.4 kg of uranium as UF_6 placed on top of the salt as a right circular cylinder. The system k_{eff} is 0.6891, with 95.1% of the fissions occurring in the UF_6. This is a very fast system, with the salt contributing only about 0.034 to the overall k_{eff}. Clearly, if the uranium migrates out of the system, it is no longer a criticality concern as long as no moderator is present.

B. Phase II: Core/Reflector Interaction

Table 2 contains much simpler models than those in Table 1. All cases consist of an inner sphere, called the core, composed of either void, uranium metal, or a uranium/salt mixture, surrounded by a sphere of salt, called the reflector. The results in Table 2 were obtained using KENO-V.a with the 27GROUPNDF4 cross-section library and XSDRN with the 238GROUPNDF5 cross-section library.[4] The objective of these cases is to determine the relative worth of the core and reflector for different configurations and determine if the 27GROUPNDF4 library produces the most conservative results for cases whose EALCF spans the energy range from a few eV to 1MeV.

Case 14 is a 62.36-cm-radius homogeneous uranium/salt sphere containing 19.4 kg of uranium with the same salt mass and volume as the salt in case 1. Both the EALCF and system k_{eff} fall between those for the reference case with bayonet tubes (case 1) and the reference case without bayonet tubes (case 4) but are significantly closer to the case containing bayonet tubes. The effect on the reactivity from the bayonet tubes is offset by the lack of a concrete reflector surrounding the system as in the cases in Table 1. Using the 27GROUPNDF4 library produces results about 1.6% higher than using the 238GROUPNDF5 library.

Cases 15 and 16 involve a void in the center of a 62.36- cm-radius uranium/salt sphere containing 10.4 kg of uranium. These two cases represent the reflectors for 9 kg of uranium in either an all-metal core (case 19) or a 60/40 wt % uranium/salt core (case 22). Neutrons in this problem slow down and fission in the reflector, producing an EALCF of ~0.88 eV. In addition to being good reflectors, cases 15 and 16 are significantly reactive on their own, having k_{eff} values of ~0.75. Using the 27GROUPNDF4 library produces conservative results about 1.8% higher than using the 238GROUPNDF5 library results.

Cases 17–19 involve a 4.8358-cm sphere containing 9 kg of uranium metal. Case 17 is a bare sphere, case 18 has a salt reflector with no uranium, and case 19 has a salt reflector containing 10.4 kg of uranium. These cases show the trend from a very fast system (EALCF ≈ 1 MeV) to an epithermal system (EALCF ≈ 74 eV) as the percentage of fissions in the reflector increases. The 27GROUPNDF4 library is no longer conservative relative to the 238GROUPNDF5 library, producing results from 1.3% lower for case 18 to 4.1% lower for case 17. Up to this point the k_{eff} calculated using the 27GROUPNDF4 library was always higher than the one calculated using the 238GROUPNDF5 library. With the potential for the uranium in the salt to reduce to metal and aggregate, results of calculations containing uranium metal could be up to 4% lower using the 27GROUPNDF4 library than when using the 238GROUPNDF5 library. Adding a salt reflector to the bare sphere increases the system k_{eff} 41%, to 1.1005. Adding 10.4 kg of uranium to the reflector increases the system k_{eff} only another 6%, to 1.1468. The contribution to the system k_{eff} from the reflector is primarily due to its thermalizing and reflecting capabilities and not its uranium content.

Cases 20–22 involve a 8.87-cm sphere containing 9 kg of uranium in a 60/40 wt % uranium/salt mixture. Case 20 is a bare sphere, case 21 has a salt reflector with no uranium, and case 22 has a salt reflector containing 10.4 kg of uranium. These cases span the range from fast, for the bare case having an EALCF of 424 keV, to epithermal, for the uranium/salt reflector having an EALCF of 12.38 eV. As shown in case 20, the two libraries calculate the same k_{eff} for a 60/40 wt % uranium/salt mixture. For case 21, the 27GROUPNDF4 library produces results ~4% higher than the 238GROUPNDF5 library. Since both libraries produce the same k_{eff} for the 60/40 wt % uranium/salt core as shown in case 20, the difference in case 21 is due entirely to the salt reflector. When uranium is added to the salt reflector, as in case 22, the difference drops from ~4% to ~1%.

Case 23 involves a 5.9483-cm sphere containing 9 kg of uranium in a 90/10 wt % uranium/salt mixture, surrounded by a 62.36-cm-radius salt sphere containing 10.4 kg of uranium. The neutrons in this problem slow down both in the reflector and the core, thus producing an EALCF of 29.48 eV. The 27GROUPNDF4 library produces approximately the same results as the 238GROUPNDF5 library. In this case, the differences between the salt and the uranium in the two libraries balance. For uranium concentrations above 90%, the 238GROUPNDF5 library should produce more conservative results for problems having uranium/salt reflectors.

C. Phase III: Uranium Concentration

This phase provides a more detailed analysis for four specific cases. The cases contain a uranium/salt core in FDT-1 without bayonet tubes. The cores for the four cases consist of a 9-kg uranium/salt slab, a 5-kg uranium/salt sphere, a 9-kg uranium/salt sphere, and a 19.4-kg uranium/salt sphere. The uranium content in the salt reflector is adjusted so that the total mass of uranium in the system is 19.4 kg. The core uranium/ salt mixture weight percent varies from 1% (homogeneous is 0.75%) to 100% (uranium metal). Plots 1, 2, and 3 contain the analysis for these cases.

Plot 1 contains the core/reflector fission density ratios for the four cases versus core uranium weight percent. As expected, the fraction of fissions occurring in the core increases and the importance of the uranium in the reflector decreases as the uranium weight percent in the core increases. It is interesting that the relative difference in fission density ratios between the 5-kg sphere and the 9-kg sphere is small and stays fairly constant over a very wide range. It is also interesting that the 9-kg slab case is lower than both the 5- and 9-kg sphere cases below ~10 wt % and the 9-kg sphere above 90 wt %. This is probably related in part to the changing surface areas. For the spheres, the surface area increases as the sphere volumes increase, creating a larger core/reflector interface. For the slab, the core/reflector interface area is constant.

Plot 2 contains the core/reflector total fission ratios for the four cases versus core uranium weight percent. The behavior of the total fission ratios is significantly different from that of the fission density ratios. There is an initial steep drop as the core size decreases (i.e., uranium weight percent increases) up to about 20 wt % uranium. For the spherical cases, the total fissions are approximately constant between 20 and 80 wt % uranium and begin to rise above 80 wt % uranium. The slab exhibits a steady gradual decline above 20 wt % uranium. Plots 1 and 2 might lead one to overweight the importance of fission in the reflector. Recall from Table 2 that adding a reflector can increase the system k_{eff} almost 50%, but to 100 wt % only about 6% of that increase is related to the fissile material in the reflector.

Plot 3 contains the system k_{eff} values for the four cases versus core uranium weight percent. All cases show an initial sharp increase in k_{eff} as the core uranium weight percent increases, followed by a dip. For the slab, after a peak at about 2 wt % uranium the system k_{eff} steadily decreases. Since these cases do not include the bayonet tubes, which could decrease the system k_{eff} by 10%, the 9-kg slab never presents a criticality concern. The 5-, 9-, and 19.4-kg spheres all behave similarly. As with the slab case, the k_{eff} initially rises to a peak between 4 and 8 wt %, dips, levels out for a stretch, and then increases sharply.

Several things must be considered while interpreting this plot. First, the absence of bayonet tubes increases the results. Second, as the uranium weight percent increases, the size of the core decreases, thus decreasing the negative worth of the bayonet tubes. Also, as the core size decreases, the core fission density increases, concentrating more fissions in the core and the immediate surrounding volume, thus decreasing the importance of the uranium in the reflector.

IV. CONCLUSIONS

It is not clear which cross-section library produces the best results. During a previous study,[3] a set of fast and thermal experiments were analyzed using the 27GROUPNDF4 and 238GROUPNDF5 cross-section libraries. The analysis showed that for fast systems (EALCF ≈ 1 MeV), using the 27GROUPNDF4 produced results up to 3% higher than using the 238GROUPNDF5, and for thermal systems (EALCF ≈ 0.1 eV), using the 238GROUPNDF5 produced results up to 3% higher than using the 27GROUPNDF4 results. A previous study on the MSRE FDTs[2] showed that the k_{eff} for FDT-1 was 4% higher using the 27GROUPNDF4 library than using the 238GROUPNDF5 library. The homogeneous FDT-1 case has the lowest energy of all the FDT modeled cases, EALCF = 3.17 eV. However, for case 17, a fast metal uranium sphere, the 238GROUPNDF5 library results are about 4% higher than the 27GROUPNDF4 library results. The two libraries seem to cross at about a 60/40 wt % uranium/salt mixture, although the presence and composition of a reflector can increase the uranium content to about 90 wt %. Since there are no experiments with these materials in the energy range of interest, a very conservative approach must be taken when determining a safe limit for k_{eff}.

The FDTs present no criticality concern in their presumed present state. Uranium that migrates out of the FDTs does not present a criticality concern. The bayonet tubes act as poison, having negative reactivity worth up to 10%. The amount of negative reactivity depends on the amount, location, and weight percent of uranium that densifies. As long as the uranium does not reduce to metal or concentrate in significant quantities, criticality is not a concern. Uranium masses up to 5 kg may densify up to 8 wt % uranium without posing a criticality concern. At densifications above 8 wt %, the uranium can lie entirely within the rings of bayonet tubes, thus decreasing their effectiveness as an absorber or poison. Uranium masses up to 9 kg may densify up to 2 wt % uranium without criticality becoming a concern. For uranium densities above 2 wt %, taking full credit for the bayonet tubes does not reduce the system k_{eff} values to an acceptable value. Finally, any amount of uranium, up to the full 19.4 kg, may densify to 1 wt % without posing a criticality concern. The homogeneous uranium/salt case containing 19.4 kg of uranium contains 0.74 wt % uranium.

REFERENCES

1. R. C. Robertson, *MSRE Design and Operations Report, Part I: Description of Reactor Design*, ORNL/TM-728, Union Carbide Corp., Nucl. Div., Oak Ridge Natl. Lab., January 1965.
2. D. F. Hollenbach and C. M. Hopper, *Criticality Safety Study of the MSRE Fuel Drain Tank Cell in Building 7503*, ORNL/TM-12642, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., January 1994.
3. D. F. Hollenbach and C. M. Hopper, *Criticality Safety Study of the MSRE Auxiliary Charcoal Bed*, ORNL/M-5450, Lockheed Martin Energy Research Corp., Oak Ridge Natl. Lab., September 1996.
4. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, Vols. I-III*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), April 1995. Available from Radiation Shielding Information Center as CCC-545.

TABLE 1
INITIAL SCOPING CASES OF FDT-1 USING THE 27GROUPNDF4 LIBRARY

CASE[a]	DESCRIPTION	EALCF[b] (eV)	k_{eff} ($\pm\sigma$)[c]
1	Reference fuel drain tank with bayonet tubes in tank, 19.4 kg U homogenized in 1.016E+6 cc of salt	3.17	0.8651 (.0013)
2	Reference fuel drain tank with bayonet tubes in tank, 9 kg U+salt (60/40 wt %) sphere in center of tank, radius = 8.87 cm 10.4 kg U in 1.013E+6 cc of salt reflector	17.92	0.9710 (.0020) % TFC = 30.5
3	Reference fuel drain tank with bayonet tubes in tank, 9 kg U metal sphere in center of tank, radius = 4.8358 cm 10.4 kg U in 1.015E+6 cc of salt reflector	140.2	1.1424 (.0022) % TFC = 40.7
4	Reference fuel drain tank w/o bayonet tubes in tank, 19.4 kg U homogenized in 1.052E+6 cc of salt	2.43	0.9519 (.0012)
5	Reference fuel drain tank w/o bayonet tubes in tank, 9 kg U+salt (60/40 wt %) sphere in center of tank, radius = 8.87 cm 10.4 kg U in 1.049E+6 cc of salt	7.686	1.0259 (.0020) % TFC = 24.8
6	Reference fuel drain tank w/o bayonet tubes in tank, 9 kg U metal sphere in center of tank, radius = 8.87 cm 10.4 kg U in 1.049E+6 cc of salt reflector	42.16	1.1543 (.0017) % TFC = 32.7
7	4 kg U metal sphere in bottom of tank, radius = 3.6904 cm 15.4 kg U in 1.052E+6 cc of salt reflector	3.46	0.9284 (.0014) % TFC = 6.31
8	5 kg U metal sphere in bottom of tank, radius = 3.9754 cm 14.4 kg U in 1.052E+6 cc of salt reflector	4.79	0.9331 (.0017) % TFC = 11.2
9	6.4 kg U metal sphere in bottom of tank, radius = 4.3163 cm 13 kg U in 1.052E+6 cc of salt reflector	15.73	0.9707 (.0022) % TFC = 21.9
10	9 kg U metal sphere in bottom of tank, radius = 4.8358 cm 10.4 kg U in 1.052E+6 cc of salt reflector	138.4	1.0447 (.0019) % TFC = 41.3
11	9 kg U metal sphere in bottom of tank, radius = 4.8358 cm No U in 1.052E+6 cc of salt reflector	1.28E+5	1.0265 (.0013) % TFC = 93.1
12	9 kg U metal slab in bottom of tank No U in 1.052E+6 cc of salt reflector	2.74E+4	0.5889 (.0011) % TFC = 88.1
13	36.4 kg UF6 cylinder on top of salt, density = 4.85g/cc, H/D = 1, radius = 12.114 cm, no U in 1.052E+6 cc of salt reflector	8.98E+4	0.6891 (.0012) % TFC = 95.1

[a] Cases 1–3 represent FDT-1 with the canning, stainless steel liner, and concrete reflector. Cases 4–13 are the same as FDT-1 with the bayonet tubes replaced with salt and the plutonium density decreased to account for the increased salt.

[b] EALCF = energy of the average lethargy causing fission.

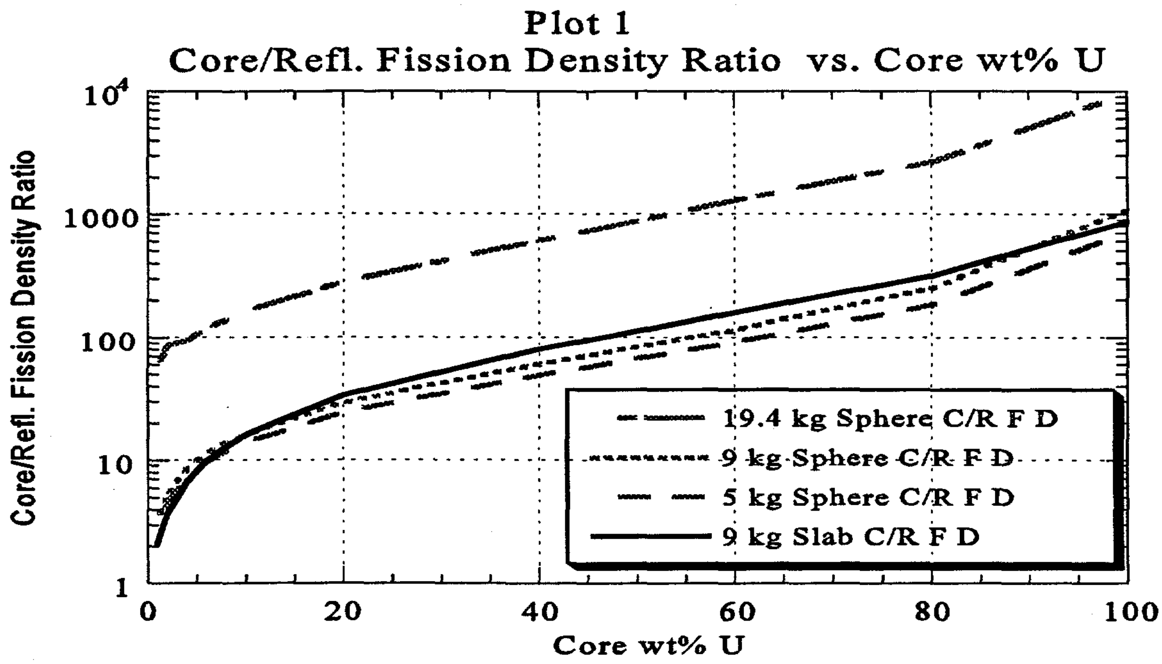
[c] % TFC = percentage of total fission occurring in the core.

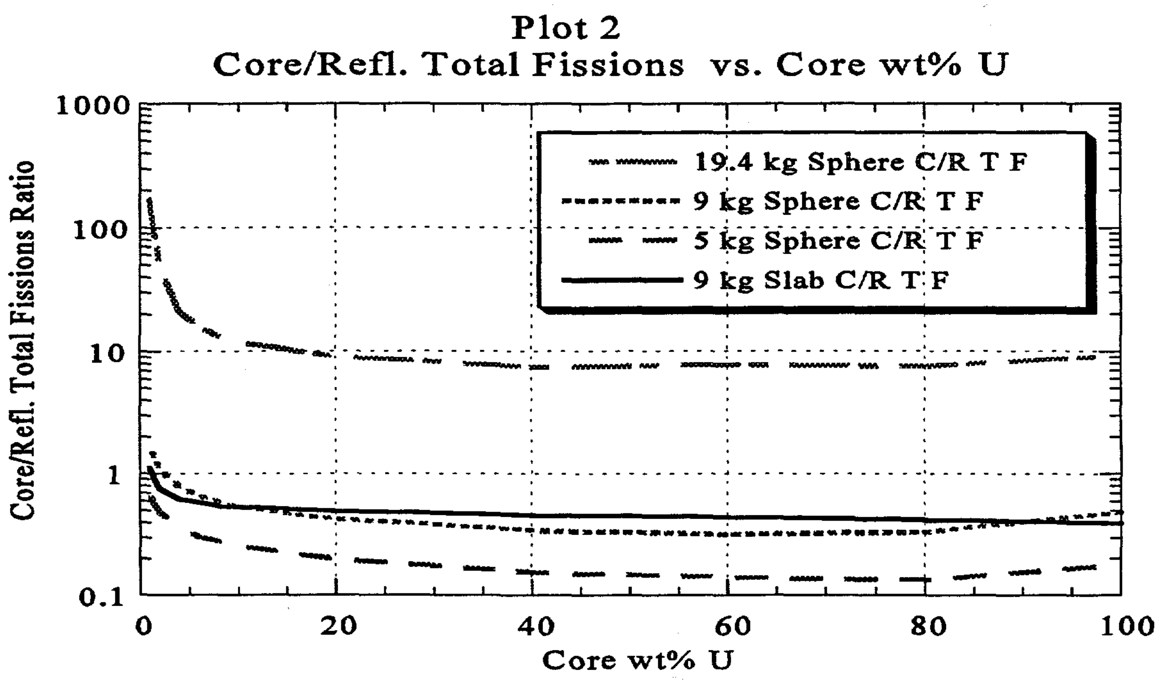
TABLE 2
COMPARISON OF URANIUM-SALT SPHERES USING
THE 27GROUPNDF4 AND 238GROUPNDF5 CROSS-SECTION LIBRARIES

CASE	DESCRIPTION	EALCF[a] (eV)	k_{eff} ($\pm\sigma$) {Lambda}[b]
14	Reference sphere containing 1.016E+6 cc of homogenized U + salt, 19.4 kg U, radius = 62.36 cm	2.88	0.8729 (.0015) {0.8585}
15	Void sphere, radius = 4.8358 cm 10.4 kg of U in spherical salt reflector, radius = 62.36 cm	0.872	0.7563 (.0015) {0.7421}
16	Void sphere, radius = 8.87 cm 10.4 kg of U in spherical salt reflector, radius = 62.36 cm	0.885	0.7473 (.0016) {0.7346}
17	9 kg U-metal sphere, radius = 4.8358 cm No reflector	9.86E+5	0.7793 (.0012) {0.8120}
18	9 kg U-metal sphere, radius = 4.8358 cm, No U in spherical salt reflector, radius = 62.36 cm	2.94E+4	1.1005 (.0014) {1.1148} % TFC = 86.0
19	9 kg U-metal sphere, radius = 4.8358 cm 10.4 kg of U spherical salt reflector, radius = 62.36 cm	73.95	1.1468 (.0025) {1.1633} % TFC =36.7
20	9 kg U/salt (60/40 wt %) sphere, radius = 8.87 cm No reflector	4.24E+5	0.3805 (.0007) {0.3814}
21	9 kg U/salt (60/40 wt %) sphere, radius = 8.87 cm No U in spherical salt reflector, radius = 62.36 cm,	1,100	0.8548(.0012) {0.8157} % TFC =81.5
22	9 kg U/salt (60/40 wt %) sphere, radius = 8.87 cm 10.4 kg of U in spherical salt reflector, radius = 62.36 cm	12.38	0.9967 (.0017) {0.9852} % TFC = 28.7
23	9 kg U + salt (90/10 wt %) sphere, radius = 5.9483 cm 10.4 kg of U in spherical salt reflector, radius = 62.36 cm	12.38	1.0616 (.0020) {1.0651} % TFC = 31.8

[a] EALCF = energy of the average lethargy causing fission.

[b] k_{eff} ($\pm\sigma$) is the k_{eff} and standard deviation of the case from KENO-V.a using the 27GROUPNDF4 library. {Lambda} is lambda of the case from XSDRN using the 238GROUPNDF5 library. % TFC = percentage of total fission occurring in the core.


Plot 1
Core/Refl. Fission Density Ratio vs. Core wt% U
Core/Refl. Fission Density Ratio
Core wt% U
19.4 kg Sphere C/R F D
9 kg Sphere C/R F D
5 kg Sphere C/R F D
9 kg Slab C/R F D


Plot 2
Core/Refl. Total Fissions vs. Core wt% U
Core/Refl. Total Fissions Ratio
Core wt% U
19.4 kg Sphere C/R T F
9 kg Sphere C/R T F
5 kg Sphere C/R T F
9 kg Slab C/R T F

Plot 3
k-eff vs. core wt% U