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DOE NCSP Review of TRUPACT-II/HalfPACT Fissile Limits

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ACKNOWLEDGMENTS

This report was produced under the general guidance of the U.S. Department of Energy (DOE) Nuclear Criticality Safety Program (NCSP) Criticality Safety Support Group. This report provides the results of a scoping study that was performed with current developmental tools from the NCSP Applicable Ranges of Bounding Curves and Data (AROBCAD) Task at the Oak Ridge National Laboratory. The initiation of the study is discussed in the January 8, 2002 memorandum from the U.S. DOE Environmental Management Office of Nuclear Material & Spent Fuel, EM-21 to EM-20. The scoping study was performed as part of the AROBCAD Task 3, "Apply S/U methods to application(s) of interest to DOE," as described in the October 2001 draft of the U.S. DOE NCSP Five-Year Plan.

EXECUTIVE SUMMARY

The memorandum from the U.S. DOE Environmental Management (EM) Office of Nuclear Material & Spent Fuel, EM-21, provides the tasking statement for the Criticality Safety Support Group (CSSG) of the DOE NCSP to perform a scoping study to examine the possibility of increasing the ^{239}Pu fissile gram equivalent (fge) for some of the TRUPACT-II and HalfPACT Packages. The DOE EM Member and Co-chair of the DOE NCSP Project Management Team (PMT) was integral to the initiation of the work.

This report provides the results of the scoping study to investigate the potential for increased fissile mass limits beyond those in the Safety Analysis Reports for Packaging (SARP) for the TRUPACT-II and HalfPACT Packages and authorized by the U.S. Nuclear Regulatory Commission (NRC) Certificates of Compliances (CoC). The results of the scoping study may provide insights and technical guidance for establishing fissile mass loading limits at waste generator sites and at the waste repository. The scoping study exercised the CSSG member judgments and four of the currently developing features (see Appendix B) of the U.S. DOE NCSP that could benefit the DOE regarding shipping efficiencies of waste to the U.S. DOE Waste Isolation Pilot Plant (WIPP). Additionally, considerations and alternatives for amending or updating the SARPs to obtain revised authorized contents are provided.

The current CoCs have the following fissile material limitations relative to the 55-gal. drum, standard 6-in. pipe overpack container (POC), and standard 12-in. POC as loaded within the TRUPACT-II and HalfPACT packages. Though the TRUPACT-II package is designed to hold 14 of the payload containers and the HalfPACT package is designed to hold 7 of the payload containers, the maximum total ^{239}Pu fge in these packages is limited to 325 g for the 55-gal. drum payload containers.

Payload container type	**fge per payload container (g)**	**fge per package (g)**
55-gal. drum	200	325
standard 6-in. POC	200	2,800[a]
standard 12-in. POC	200	2,800[a]

[a] 1,400 g for the HalfPACT package

Results of the scoping study indicate that substantial gains in the ^{239}Pu fge mass limits could be realized for the 55-gal. drum, standard 6-in. POC, and the standard 12-in. POC payload containers with the following **Categorical Improvements**:

A. the use of more realistic safety analysis models,

B. the use of developmental products from the U.S. DOE NCSP as applied in Appendix B of the report, and

C. the qualification/certification of waste matrixes.

Those gains are shown as follows:

Payload container type	**Current fge mass limit (g)**	**fge mass limit (g) categorical improvements**		
		A	**B**	**C**
55-gal. drum	200	200[a]	215[b]	545[c]
standard 6-in. POC	200	934	1,127	-------
standard 12-in. POC	200	334	363	-------

[a] 345 g if waste matrix can be qualified to be “fixed” within the payload containers and the minimum waste net weight is about 205 kg

[b] 373 g if waste matrix can be qualified to be “fixed” within the payload containers and the minimum net weight is about 205 kg

[c] 574 g if authorized for 478 kg gross weight and as dispersed and fixed within about 2.299 g Concrete/cm^3

Based on the above values and expected waste containment within the 55-gal. drums, potential gains with the TRUPACT-II and HalfPACT shipping packages are shown as follows:

Shipping package	**Current fge mass limit (g)**	**fge mass limit (g) categorical improvements**		
		A	**B**	**C**
TRUPACT-II				
55-gal. drums	325	2,800[a]	3,010[b]	7,630[c]
standard 6-in. POC	2,800	13,076	15,778	-------
standard 12-in. POC	2,800	4,676	5,082	-------
HalfPACT				
55-gal. drums	325	1,400[d]	1,505[e]	3,815[f]
standard 6-in. POC	1,400	6,538	7,889	-------
standard 12-in. POC	1,400	2,338	2,541	-------

[a] 4,830 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum waste net weight is about 205 kg/container

[b] 5,222 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum net weight is about 205 kg/container

[c] 8,036 g if authorized for 478 kg gross weight and as dispersed and fixed within about 2.299 g Concrete/cm^3

[d] 2,415 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum waste net weight is about 205 kg/container

[e] 2,611 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum net weight is about 205 kg/container

[f] 4,018 g if authorized for 478 kg gross weight/container and as dispersed and fixed within about 2.299 g Concrete/cm^3

As used in the above tables, "fixed" refers to the homogeneously distributed fissile material in the waste matrix such that the fissile material cannot be unintentionally redistributed either inside or outside the payload container.

These gains could potentially result in the reduction of the number of required payload containers by factors of about 3 for 55-gal. drums, 6 for standard 6-in. POCs, and 2 for standard 12-in. POCs. Additionally, these gains could potentially result in a reduction of TRUPACT-II (HalfPACT) across-the-road transfers by factors of about 24 (12) for 55-gal. drums, 6 (6) for standard 6-in. POCs, and 2 (2) for standard 12-in. POCs.

With or without the significant gains to be realized from using the more realistic analysis models, the products of the U.S. DOE NCSP Tasks could reduce the number of required payload containers and across-the-road transfers by about 7% for 55-gal. drum, 17% for standard 6-in. POC, and 8% for standard 12-in. POC payload containers. Finally, it should be noted that these potential cost savings are based only on a criticality safety feasibility study and do not take into account other technical factors from other disciplines that may or may not impact the final approved loadings.

Based upon the above results it is recommended that EM should:

1. task the originator of the TRUPACT-II and HalfPACT SARPs to
    a. submit SARP supplements to the U.S. NRC for increasing the payload container and package limits by using more realistic safety assumptions, and
    b. avail themselves of the NCSP Task products for improved computational methods and data that will remain defensible for certification purposes,
2. take a more active role in the identification of
    a. costly and excessively conservative safety analysis assumptions, and
    b. improved methods, data, and experiments that can reduce overall EM operating costs.

The CSSG concurs that the results of this scoping study address the tasking statement provided by EM-21.

ABSTRACT

The U.S. Department of Energy (DOE) Environmental Management (EM) Office of Nuclear Material & Spent Fuel, EM-21, tasked the CSSG to perform a scoping study to determine the feasibility of increasing the fissile mass loading limits for specified TRUPACT-II and HalfPACT packages and containers. The results of the scoping study may provide insights and technical guidance for establishing fissile mass loading limits at waste generator sites and at the waste repository. The goal is to reduce costs of transporting fissile material to the WIPP from EM's various closure sites.

This report documents the results of the scoping study and demonstrates that it is feasible to significantly increase the fissile mass loading limits in the TRUPACT-II and HalfPACT packages and containers. Depending upon the particular payload containers used, the number of shipments to WIPP could be reduced by at least a factor of 2 and as much as a factor of 16 and the number of total payload containers required “down-hole” at WIPP could be reduced by at least a factor of 2 and as much as about 6. These cost savings result simply from applying a more realistic criticality analysis model rather than the very conservative, hypothetical, bounding analysis used to support the existing fissile mass loading limits. However, the applications of existing and developmental computational tools, nuclear data, and experiments from the DOE Nuclear Criticality Safety Program have the potential to further reduce transportation and disposal container costs on the order of 7% to 17%.

It is suggested that EM proceed with an effort to do the required formal analyses and pursue SARP supplements to take advantage of these savings. The success of these analyses are dependent upon the availability of the majority of the infrastructure supported by the DOE Nuclear Criticality Safety Program as defined in the Five-Year Plan for the program. Finally, it should be noted that these potential cost savings are based only on a criticality safety feasibility study and do not take into account other technical factors from other disciplines that may or may not impact the final approved loadings.

The CSSG concurs that the results of this scoping study addresses the tasking statement provided by EM-21.

1. INTRODUCTION

The memorandum from the U.S. Department of Energy (DOE) Environmental Management (EM) Office of Nuclear Material & Spent Fuel,[1] EM-21, provides the tasking statement for the Criticality Safety Support Group (CSSG) of the DOE Nuclear Criticality Safety Program[2] (NCSP) to perform a scoping study to examine the possibility of increasing the ^{239}Pu fissile gram equivalent (fge) for some of the TRUPACT-II[3] and HalfPACT[4] Packages. The DOE EM Member and Co-chair of the DOE NCSP Project Management Team (PMT) was integral to the initiation of the work.

This report provides the results of the scoping study to investigate the potential for increased fissile mass limits beyond what is currently allowed by the TRUPACT-II and HalfPACT Packages Certificates of Compliance (CoC) on the bases of the Safety Analysis Reports for Packaging (SARP) of the TRUPACT-II[5] and HalfPACT[6] packages. The scoping study exercised the CSSG member judgments and four of the currently developing features (see Appendix B) of the U.S. DOE NCSP that could benefit the DOE regarding shipping efficiencies of waste to the U.S. DOE Waste Isolation Pilot Plant (WIPP). Additionally, this report provides considerations and alternatives for amending or updating the TRUPACT-II SARP to obtain revised authorized contents.

The current CoC appears to be predicated upon conservative, generic safety evaluations that were developed, designed, and performed to reduce or minimize the potential for regulatory and/or compliance difficulties during the certification process and user loading of potentially non-certified matrixes. Those types of certification difficulties could have extended the regulatory approval process for package certification and thereby could have interfered with packaging/shipping schedules. An additional consideration may have been the current loading constraints[7] for emplacements in the Carlsbad, New Mexico WIPP. Irrespective of the reasons, substantially conservative nuclear criticality safety assumptions were used in the SARPs (e.g., ignoring payload container construction materials impacting neutron absorption, general payload container confinement that impedes reconfiguration of material within the package, limited-mobility of the fissile material contamination within the waste matrices, etc.).

The CSSG concurs that the results of this scoping study address the tasking statement provided by EM-21.

2. NUCLEAR CRITICALITY SCOPING RESULTS

The following scoping study results are predicated upon the calculated results that are provided in Appendices A and B. Appendix A provides the computational descriptions and models as well as the calculated effective (k_{eff}) and infinite (k_{inf}) neutron multiplication factors for the considered payload containers. Appendix B provides a summary of the results obtained using the developmental products of the NCSP Applicable Ranges of Bounding Curves and Data (AROBCAD) sensitivity and uncertainty methods for determining the bias and uncertainty of the calculated safety applications based upon a suite of selected critical experiment benchmarks. All sensitivity calculations were performed with the SEN1 and SEN3 sensitivity and uncertainty modules that are planned for release in a future version of SCALE.[8] The modeling assumptions were based upon the actual payload container descriptions provided within the package SARP. Those descriptions included the dimensions and materials of construction and minimum/maximum weights and densities of those materials.

2.1. PAYLOAD CONTAINER INCREASES FROM REALISTIC SAFETY ANALYSIS MODELING

Using more realistic safety analysis assumptions for the computational safety analyses, it is judged from these scoping studies that the various package payload container contents:

1. could be increased from 200 g to 345 g for 55-gal. drums with no standard pipe overpack containment (POC) providing there is waste matrix qualification/certification during loading (i.e., general waste distribution and net weight),

2. could be increased from 200 g to about 948 g for the 55-gal. drums with the standard 6-in. POC, and

3. could be increased from 200 g to about 335 g for the 55-gal. drums with the standard 12-in. POC.

Using these values, fge payloads of packages for each of the above three payload containers could be increased as shown in Table 1.

Table 1. Potential maximum payload container and package mass limit increases using realistic safety analysis modeling

Payload container type	fge per payload container (g)		fge per package (g)	
	from	to	from	to
1. 55-gal. drum	200	200[a]	325	2,800[b]
2. standard 6-in. POC	200	934	2,800	13,076
3. standard 12-in. POC	200	334	2,800	4,676

[a] 345 g if waste matrix can be qualified to be "fixed" within the payload containers and if minimum waste net weight is about 205 kg

[b] 4,830 g if waste matrix can be qualified to be "fixed" within the payload containers and if waste minimum net weight is about 205 kg

The payload increases shown in Table 1 are based upon nuclear criticality safety calculations of various assumed realistic conditions that will require compelling arguments or physical evidence to satisfy the certification processes. Examples of required compelling arguments or physical evidence for the individual numbered container types in Table 1 include, but are not limited to:

1a. Increasing the individual payload container limit from 200 g ^{239}Pu fge will likely require a commitment to "certification" of fissile material distribution and waste matrix form/density. This certification may not be desirable or possible given the circumstances of the waste forms intended for the 55-gal. drum payload container.

1b. The increase of the package contents from 325 g ^{239}Pu fge to 2,800 g ^{239}Pu fge (4,830 g if the waste can be qualified as fixed) is based upon the assumption that the fissile material within each of the 14 55-gal. drums will remain within the waste matrix within each drum. This assumption may be supported by the recognition of limited space/volume within the package thereby preventing or significantly limiting the release of the 55-gal. drum contaminated waste matrix contents, even in the event of lids opening.

2a. Though it can be demonstrated that the standard 6-in. POC could be loaded with about 948 g ^{239}Pu fge and can be safely subcritical in transit in the package, it may require operational constraints or justifications to assure the subcriticality of a single package during loading. This is to say, it may be necessary to consider the form and density of the waste matrix if volume limitation provided by the pipe overpack dimensions or the monitoring of the ^{239}Pu fge mass for loading is used for criticality control.

2b. The increase of the package contents from 2,800 g ^{239}Pu fge to 13,270 g ^{239}Pu fge is based upon the assumption that the contents of the standard 6-in. POC will remain contained throughout the normal conditions of transport and the hypothetical accident conditions of transport for the package.

3a. Though it can be demonstrated that the standard 12-in. POC could be loaded with about 335 g ^{239}Pu fge and can be safely subcritical in transit in the package, it may require operational constraints or justifications to assure the subcriticality of a single package during loading. This is to say, it may be necessary to consider the form and density of the waste matrix if volume limitation provided by the pipe overpack dimensions or the monitoring of the ^{239}Pu fge mass for loading is used for criticality control.

3b. The increase of the package contents from 2,800 g ^{239}Pu fge to 4,690 g ^{239}Pu fge is based upon the assumption that the contents of the standard 12-in. POC will remain contained throughout the normal conditions of transport and the hypothetical accident conditions of transport for the package.

The above assumptions, though pragmatic, may require demonstrated justification or assurances. Further constraints on the package contents could include, but not be limited to, other limitations such as the 40 watts maximum decay heat per package and the maximum gross weights of the payload containers.

2.2. PAYLOAD INCREASES FROM NCSP TASK PRODUCTS

As acknowledged in the SARPs of the CoC applicants, their computational methods and nuclear data, as validated against available critical experiment benchmarks, showed computational biases on the order of –0.004 to +0.039 in k_{eff} with the “Hansen-Roach” 16-energy group and on the order of –0.004 to +0.0255 in k_{eff} with the 238-energy group neutron cross-section libraries in SCALE 4.3.[9] Because the observed biases for the critical experiments were overwhelmingly positive, the applicants proposed no credit for those biases. This scoping study confirms these large positive biases relative to the experiments but also provides more realistic biases for the safety analyses models relative to the critical experiments used for validation.

It has been determined from this scoping study that the more realistically modeled payload container mass limits given in Sect. 2.1 could be increased as shown in Table 2 by using the improved products of the NCSP Tasks (e.g., improved computational methods for determination of validation bias and uncertainty, nuclear data and critical experiments).

Table 2. Potential maximum payload container and package mass limit increase using NCSP capabilities

Payload container type	fge per payload container (g)		fge per package (g)	
	from	to	from	to
1. 55-gal. drum	345[a]	373	4,830[a]	5,230
2. standard 6-in. POC	934	1,127	13,076	15,778
3. standard 12-in. POC	334	363	4,676	5,080

[a] If waste matrix can be qualified to be "fixed" within the payload container and the minimum net weight is about 205 kg

The results shown in Table 2 are based upon computational models for the TRUPACT-II SARP payload containers and package materials of construction. Specific payloads were modeled as ^{239}Pu optimally moderated with a mixture of 60 volume percent polyethylene and 40 volume percent water. Specific array configurations were modeled as either infinite arrays of 55-gal. drum containers, or standard 6-in. POC, or standard 12-in. POC, or TRUPACT-II Packages loaded with 14 of the afore mentioned three types of payload containers.

2.3. INCREASED SHIPPING EFFICIENCIES

The foregoing results demonstrate that potentially substantial gains in the ^{239}Pu fge mass limits could be realized for the 55-gal. drum, standard 6-in. POC, and the standard 12-in. POC payload containers with the following **Categorical Improvements**:

A. the use of more realistic safety analysis models,

B. the use of developmental products from the U.S. DOE NCSP as applied in Appendix B of the report, and

C. the qualification/certification of waste matrixes (i.e., general waste distribution and net weight).

Those gains are shown in Table 3.

Table 3. Categorical payload container fge improvements

Payload container type	Current fge mass limit (g)	fge mass limit (g) categorical improvements		
		A	B	C
55-gal. drum	200	200[a]	215[b]	545[c]
standard 6-in. POC	200	934	1,127	-------
standard 12-in. POC	200	334	363	-------

[a] 345 g if waste matrix can be qualified to be “fixed” within the payload containers and the minimum waste net weight is about 205 kg

[b] 373 g if waste matrix can be qualified to be “fixed” within the payload containers and the minimum net weight is about 205 kg

[c] 574 g if authorized for 478 kg gross weight and as dispersed and fixed within about 2.299 g concrete/cm^3

Using the payload container fge improvements, potential gains for the TRUPACT-II and HalfPACT shipping packages are shown in Table 4.

Table 4. Potential categorical improvements in fge mass limits for the packages

Shipping package	Current fge mass limit (g)	fge mass limit (g) categorical improvements A	B	C
TRUPACT-II				
55-gal. drums	325	2,800[a]	3,010[b]	7,630[c]
standard 6-in. POC	2,800	13,076	15,778	-------
standard 12-in. POC	2,800	4,676	5,080	-------
HalfPACT				
55-gal. drums	325	1,400[d]	1,500[e]	3,810[f]
standard 6-in. POC	1,400	6,538	7,889	-------
standard 12-in. POC	1,400	2,338	2,540	-------

[a] 4,830 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum waste net weight is about 205 kg/container

[b] 5,230 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum net weight is about 205 kg/container

[c] 8,036 g if authorized for 478 kg gross weight and as dispersed and fixed within about 2.299 g concrete/cm^3

[d] 2,415 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum waste net weight is about 205 kg/container

[e] 2,615 g if waste matrix can be qualified to be "fixed" within the payload containers and the minimum net weight is about 205 kg/container

[f] 4,020 g if authorized for 478 kg gross weight/container and as dispersed and fixed within about 2.299 g concrete/cm^3

These gains could potentially result in the reduction of the number of required payload containers by factors of about 3 for 55-gal. drums, 6 for standard 6-in. POCs, and 2 for standard 12-in. POCs. Additionally, these gains could potentially result in a reduction of TRUPACT-II or (HalfPACT) across the road transfers by factors of between about 24 (12) for 55-gal. drums, 6 (6) for standard 6-in. POCs, and 2 (2) for standard 12-in. POCs.

With or without the significant gains to be realized from using the more realistic analysis models, the products of the U.S. DOE NCSP Tasks could reduce the number of required payload containers and across-the-road transfers by about 7% for 55-gal. drum, 17% for standard 6-in. POC, and 8% for standard 12-in. POC payload containers. Finally, it should be noted that these potential cost savings are based only on a criticality safety feasibility study and do not take into account other technical factors from other disciplines that may or may not impact the final approved loadings.

Neglecting other potential limitations of the TRUPACT-II package with 55-gal. drum contents (e.g., allowable gross weights, thermal heat sources, radioactive source terms, etc.) shippers' or receivers' constraints (e.g., Los Alamos National Laboratory, the U.S. DOE Waste

Isolation Pilot Plant, etc.) and depending upon the waste configurations desired for shipments, the number of package across-the-road shipments and number of payload containers could potentially be reduced by factors of between about 1.6 and 15.6 for shipments and about 5.7 and 18 for payload containers. It is further judged that if specific waste matrices (e.g., dirt without plastics, glass, metal, etc.) could be "certified," larger gains in plutonium fge package payloads could be realized.

2.4. PATH FORWARD

Based upon the above scoping evaluation results and potentially improved transportation efficiencies, it is suggested that EM should task the originator of the SARPs and the applicant of the TRUPACT-II and HalfPACT CoCs to use more realistic computational models that will remain defensible for certification purposes. The purpose for using more realistic computational models is to permit the revision of the TRUPACT-II and HalfPACT SARPs in order to obtain authorization for increased plutonium fissile gram equivalent payloads. With continuing fiscal support for the U.S. DOE NCSP Tasks, technical support could be provided to the originator of a revised SARP. It is further suggested that the CSSG collaborate with the originator of the SARP in developing the computational models used in the SARP. Additionally, consideration should be given to using the NCSP and the CSSG as a resource for guidance and information.

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5. Safety Analysis Report for the TRUPACT-II Shipping Package, May 2001, Rev. 19, Westinghouse TRU Solutions, LLC, P.O. Box 2078, Carlsbad, NM 88221.

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8. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 7 (ORNL/NUREG/CSD-2/R7), Vols. I, II, and III, in preparation. Will be available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-545.

9. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 5 (ORNL/NUREG/CSD-2/R5), Vols. I, II, and III, March 1997. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-545.

APPENDIX A

CRITICALITY MODELS AND COMPUTED $k_{eff,\ inf}$ RESULTS

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CRITICALITY MODELS AND COMPUTED $k_{\mathbf{eff,\ inf}}$ RESULTS

A.1. MODELING AND ANALYSIS OF TRUPACT-II PAYLOAD CONTAINERS

As stated in the SARP for the TRUPACT-II shipping packages, the waste that can be transported within the TRUPACT-II package is in a variety of forms that are identified as contact-handled transuranic materials. Therefore, the criticality models must assume some representative waste matrix in the worst (yielding highest k_{eff}) geometric configuration attainable within the confines of the structural components. Based on the TRUPACT-II SARP, the waste matrix, which provides the primary moderation in all criticality models, was assumed to be 60% polyethylene and 40% water (by volume). Other moderator materials that might result in higher k_{eff} values may exist as part of the inventory of waste materials to be shipped within TRUPACT-II payload containers. Investigation of such materials is outside the scope of this study. It must be noted, however, that due to the small volume available for waste inside the 6-in. and 12-in. pipe components, moderators other than hydrogen are not likely to yield higher k_{eff} values because of being undermoderated for the allowed maximum fissile content. Therefore, it is believed that the limits that are established in the following sections are realistic and close to the actual limits that would be determined through an exhaustive study that investigates the available waste inventory from a moderation and fissile content point of view.

A.2. STANDARD 6-IN. PIPE OVERPACK CONTAINER

An infinite (in three dimensions) square-pitched array of standard 6-in. POC payload containers with a ^{239}Pu bearing spherical mixture in the center is modeled as shown in Fig. A.1. The POC is surrounded by fiberboard/plywood dunnage, which is modeled as redwood at the density specified for fiberboard/plywood dunnage. The payload containers are modeled as close to the actual specifications as possible (within tolerances; only insignificant structural materials such as nuts, bolts, and protrusions are ignored). The waste matrix is modeled as composed of ^{239}Pu and moderator material. The moderator material is assumed to be 60% by volume polyethylene and 40% water. The POC is filled with a reflector having the same contents as the moderator material (60% polyethylene, 40% water). The results are given in Table A.1 and shown in Fig. A.2. The highest k_{eff}, 0.6002 ($k_{eff}+2\sigma$), is obtained with 300 g ^{239}Pu in a sphere with 7.8-cm radius (inside radius of standard 6-in. POC). H/^{239}Pu for this configuration is 194. Higher loadings of ^{239}Pu result in lower k_{eff} values for spheres of radii greater than 4-cm due to undermoderation resulting from limited sphere size. Note that as the sphere radius decreases, the mixture becomes all ^{239}Pu metal and k_{eff} starts increasing again. However, the maximum fissile amount for a sphere radius of 2-cm is approximately 650 g, which is well below the minimum critical mass for a reflected ^{239}Pu sphere (~5.4 kg).

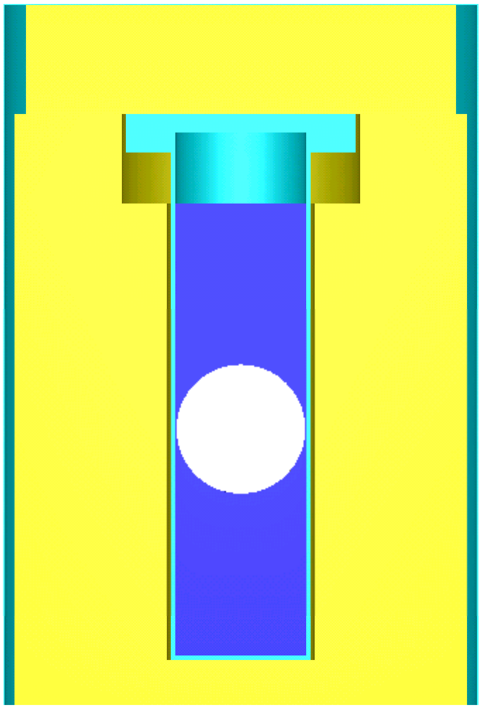


Fig. A.1. Axial view of 55-gal. drum with standard 6-in. POC (sphere fuel/moderator matrix).

Table A.1. Infinite array of 55-gal. drums with standard 6-in. POC (sphere fuel/moderator matrix)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-6in-250g-r2	250	2	0.1813	0.0004	0.1821	2
pop-6in-250g-r3	250	3	0.1955	0.0004	0.1963	12
pop-6in-250g-r4	250	4	0.2704	0.0005	0.2714	30
pop-6in-250g-r5	250	5	0.3634	0.0006	0.3646	60
pop-6in-250g-r6	250	6	0.4600	0.0006	0.4612	105
pop-6in-250g-r7	250	7	0.5450	0.0007	0.5464	168
pop-6in-250g-r7.8	250	7.8	0.6010	0.0006	0.6022	233
pop-6in-300g-r2	300	2	0.2081	0.0003	0.2087	2
pop-6in-300g-r3	300	3	0.1981	0.0003	0.1987	10
pop-6in-300g-r4	300	4	0.2659	0.0004	0.2667	25
pop-6in-300g-r5	300	5	0.3539	0.0005	0.3549	50
pop-6in-300g-r6	300	6	0.4498	0.0006	0.4510	87
pop-6in-300g-r7	300	7	0.5364	0.0006	0.5376	139

Table A.1 (continued)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	k_{eff}+2σ	H/^{239}Pu
pop-6in-300g-r7.8-vac[*]	300	7.8	0.5576	0.0006	0.5588	194
pop-6in-300g-r7.8	**300**	**7.8**	**0.5988**	**0.0007**	**0.6002**	**194**
pop-6in-400g-r2	400	2	0.2744	0.0004	0.2752	1
pop-6in-400g-r3	400	3	0.2066	0.0004	0.2074	7
pop-6in-400g-r4	400	4	0.2592	0.0004	0.2600	18
pop-6in-400g-r5	400	5	0.3408	0.0005	0.3418	37
pop-6in-400g-r6	400	6	0.4311	0.0006	0.4323	65
pop-6in-400g-r7	400	7	0.5196	0.0006	0.5208	104
pop-6in-400g-r7.8	400	7.8	0.5847	0.0006	0.5859	145
pop-6in-500g-r2	500	2	0.3600	0.0004	0.3608	0.5
pop-6in-500g-r3	500	3	0.2171	0.0004	0.2179	5
pop-6in-500g-r4	500	4	0.2568	0.0004	0.2576	14
pop-6in-500g-r5	500	5	0.3287	0.0005	0.3297	29
pop-6in-500g-r6	500	6	0.4155	0.0005	0.4165	52
pop-6in-500g-r7	500	7	0.5031	0.0005	0.5041	83
pop-6in-500g-r7.8	500	7.8	0.5715	0.0006	0.5727	116
pop-6in-650g-r2	650	2	0.5176	0.0005	0.5186	0.03
pop-6in-650g-r3	650	3	0.2398	0.0004	0.2406	4
pop-6in-650g-r4	650	4	0.2574	0.0004	0.2582	11
pop-6in-650g-r5	650	5	0.3184	0.0005	0.3194	22
pop-6in-650g-r6	650	6	0.3964	0.0005	0.3974	39
pop-6in-650g-r7	650	7	0.4800	0.0006	0.4812	64
pop-6in-650g-r7.8	650	7.8	0.5490	0.0007	0.5504	89

[*] Single 55-gal. drum with vacuum boundary conditions

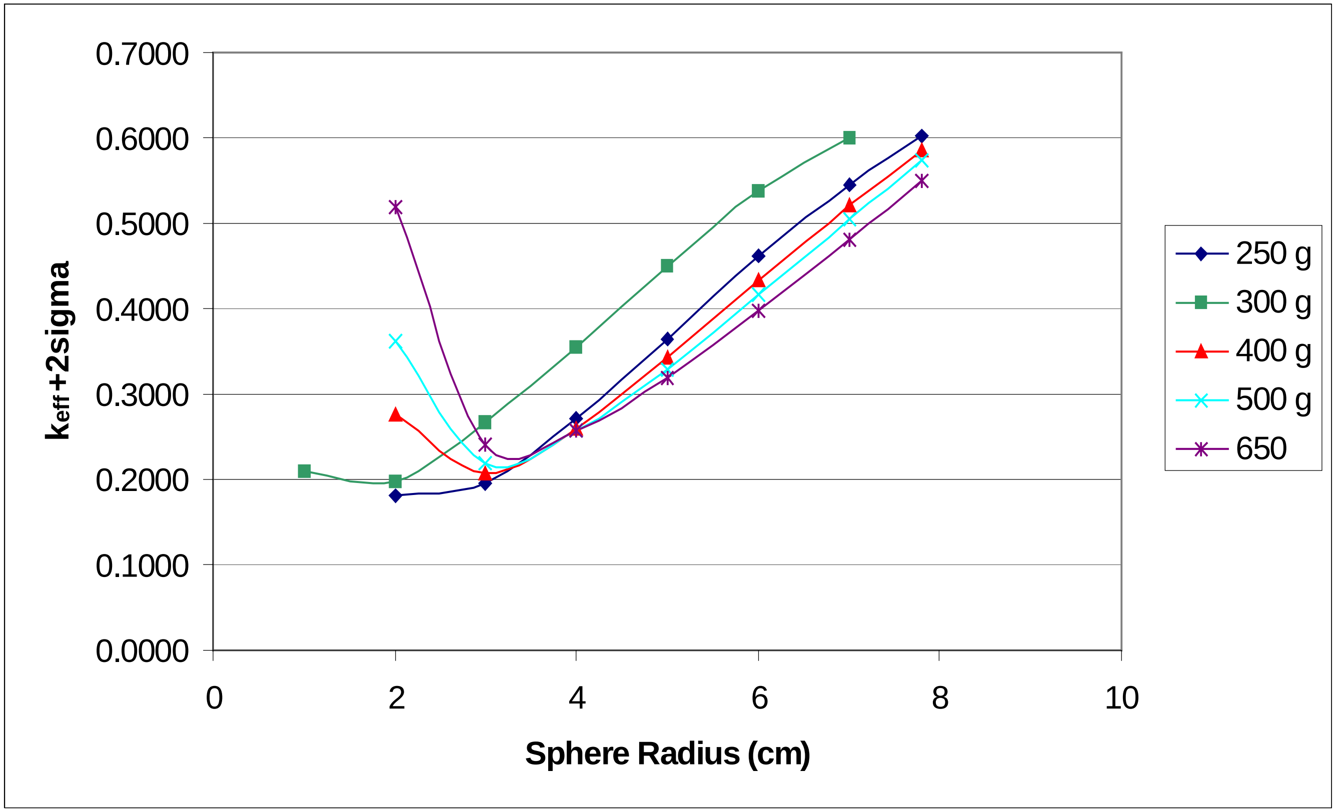


Fig. A.2. k_{eff} vs. sphere radius for an infinite array of 55-gal. drums with standard 6-in. POC.

When the sphere in the previous configuration is replaced with a cylinder with height to diameter ratio of 1 (see Fig. A.3), the highest k_{eff}, 0.7006, is again obtained with 300 g ^{239}Pu in a cylinder with 7.8-cm radius and H/^{239}Pu of 291. The results for this configuration are given in Table A.2 and shown in Fig. A.4. A cylinder-shaped fuel/moderator mixture yields a higher k_{eff} value despite higher leakage from the cylinder since the mixture is undermoderated and the cylinder mixture is 1.5 times greater in volume than the sphere mixture having the same radius. As with the sphere case, higher plutonium loadings result in lower k_{eff} values.

Since previous configurations are all undermoderated, another configuration in which the waste matrix is allowed to fill the entire inside cavity of the standard 6-in. POC as shown in Fig. A.5 is analyzed. The results are given in Table A.3 and shown in Fig. A.6. The highest k_{eff}, 0.9463, is obtained with 900 g ^{239}Pu loading having an H/^{239}Pu of 378. The interpolated results for a k_{eff} of 0.95 is about 948 g ^{239}Pu in each standard 6-in. POC. Fig. A.7 shows the system k_{eff} as a function of ^{239}Pu mass. The increases of k_{eff} values with respect to increases in the amounts of ^{239}Pu level out. This is due to the limited volume available for the fuel/moderator mixture, which results in an undermoderated system for higher plutonium loadings. Adding water with varying density in between the 55-gal. drums decreases k_{eff}, indicating the units start to become isolated. When fiberboard is mixed with water with varying volume fractions (to simulate flooding in which fiberboard absorbs water) the system k_{eff} is reduced. A single 55-gal. drum with standard 6-in. POC containing 900 g ^{239}Pu yields a k_{eff} of 0.7762 when reflected by 30 cm water and a k_{eff} of 0.7563 without any reflectors.

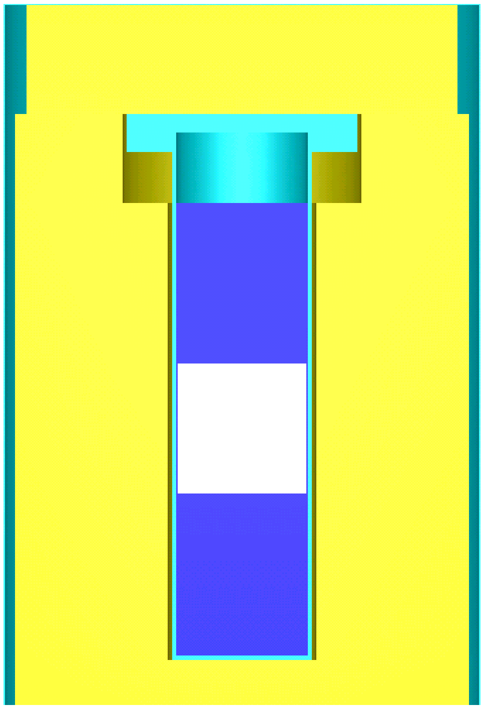


Fig. A.3. Axial view of 55-gal. drum with standard 6-in. POC (cylinder fuel/moderator matrix with H/D=1).

Table A.2. Infinite array of 55-gal. drums with standard 6-in. POC (cylinder fuel/moderator matrix with H/D=1)

Case name	^{239}Pu mass (g)	Cylinder radius (cm)	k_{eff}	σ	k_{eff}+2σ	H/^{239}Pu
pop-6in-250g-cyl-r6	250	6	0.5415	0.0007	0.5429	158
pop-6in-250g-cyl-r7	250	7	0.6199	0.0006	0.6211	252
pop-6in-250g-cyl-r7.8	250	7.8	0.6654	0.0007	0.6668	350
pop-6in-300g-cyl-r6	300	6	0.5343	0.0006	0.5355	132
pop-6in-300g-cyl-r7	300	7	0.6173	0.0007	0.6187	210
pop-6in-300g-cyl-r7.8	300	7.8	0.6694	0.0006	0.6706	291
pop-6in-350g-cyl-r6	350	6	0.5284	0.0006	0.5296	113
pop-6in-350g-cyl-r7	350	7	0.6140	0.0007	0.6154	180
pop-6in-350g-cyl-r7.8	**350**	**7.8**	**0.6700**	**0.0006**	**0.6712**	**249**
pop-6in-400g-cyl-r6	400	6	0.5189	0.0006	0.5201	98
pop-6in-400g-cyl-r7	400	7	0.6083	0.0006	0.6095	157
pop-6in-400g-cyl-r7.8	400	7.8	0.6684	0.0006	0.6696	218
pop-6in-450g-cyl-r6	450	6	0.5123	0.0006	0.5135	87
pop-6in-450g-cyl-r7	450	7	0.6037	0.0007	0.6051	139
pop-6in-450g-cyl-r7.8	450	7.8	0.6663	0.0006	0.6675	194

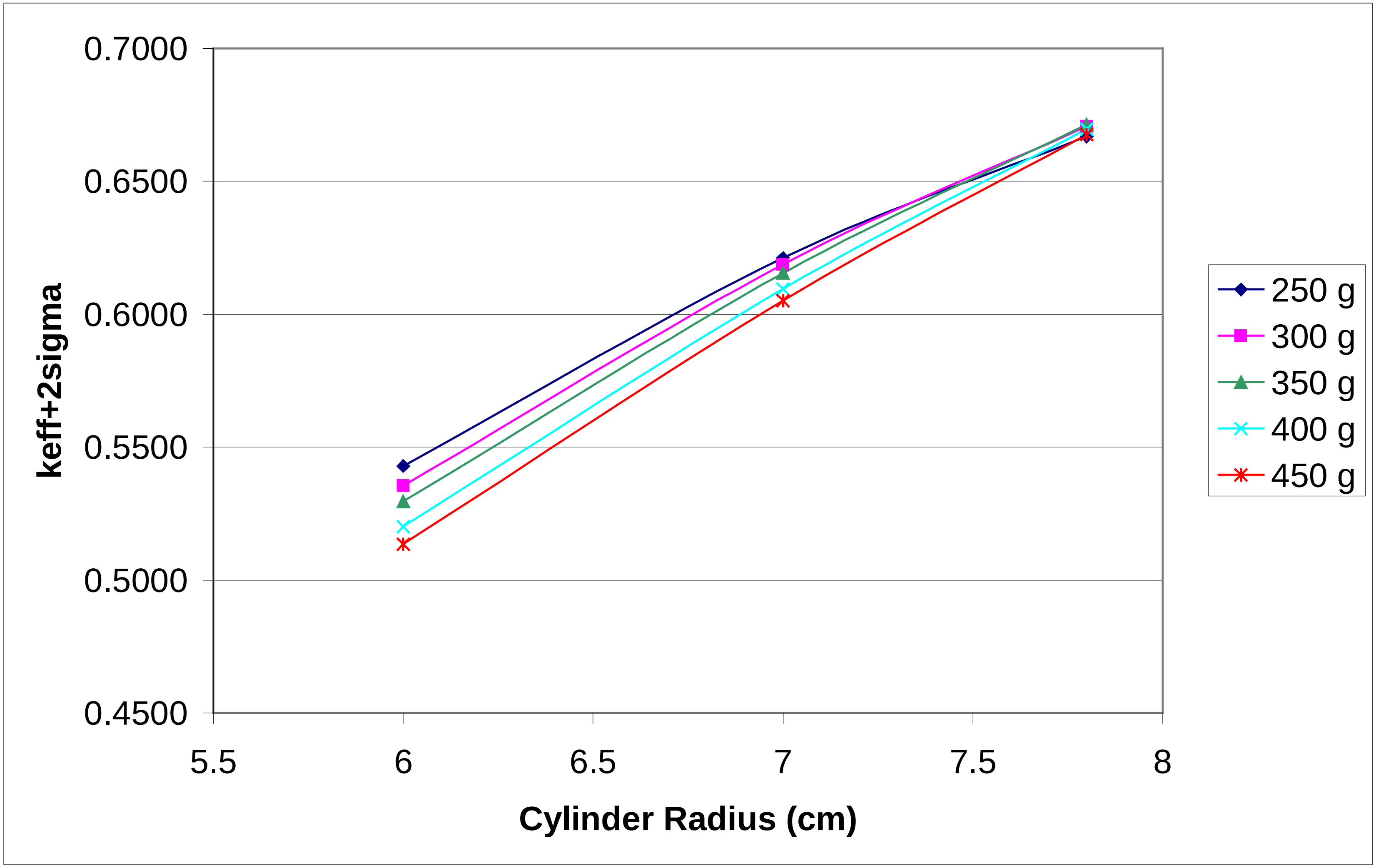


Fig. A.4. k_{eff} vs. cylinder radius for an infinite array of 55-gal. drums with standard 6-in. POC (H/D=1).

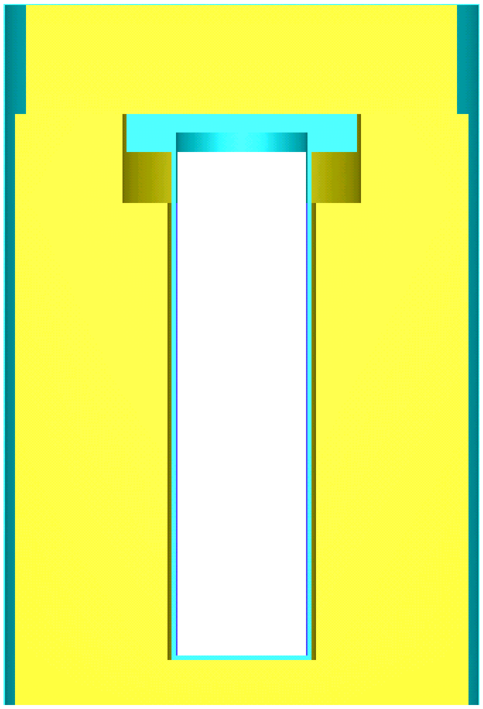


Fig. A.5. Axial view of 55-gal. drum with standard 6-in. POC (cylinder fuel/moderator matrix).

Table A.3. Infinite array of 55-gal. drums with standard 6-in. POC (cylinder fuel/moderator matrix with H/D>1)

Case name	^{239}Pu mass (g)	Cylinder height (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-6in-450g-cyl-h40	450	40	0.8326	0.0007	0.8340	499
pop-6in-450g-cyl-h45	450	45	0.8426	0.0006	0.8438	561
pop-6in-450g-cyl-h50	450	50	0.8499	0.0006	0.8511	624
pop-6in-450g-cyl-h54	450	54	0.8517	0.0006	0.8529	674
pop-6in-450g-cyl2-h1	450	55.7	0.8520	0.0006	0.8532	695
pop-6in-450g-cyl2-h2	450	56.7	0.8501	0.0006	0.8513	708
pop-6in-450g-cyl2-h3	450	57.7	0.8506	0.0006	0.8518	720
pop-6in-450g-cyl2-h4	450	58.7	0.8498	0.0007	0.8512	733
pop-6in-450g-cyl2-h5	450	59.7	0.8501	0.0007	0.8515	745
pop-6in-450g-cyl2-h6	450	60.7	0.8494	0.0006	0.8506	758
pop-6in-500g-cyl-h40	500	40	0.8420	0.0006	0.8432	449
pop-6in-500g-cyl-h45	500	45	0.8554	0.0007	0.8568	505
pop-6in-500g-cyl-h50	500	50	0.8651	0.0007	0.8665	561
pop-6in-500g-cyl-h54	500	54	0.8687	0.0008	0.8703	606

Table A.3 (continued)

Case name	^{239}Pu mass (g)	Cylinder height (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-6in-500g-cyl2-h1	500	55.7	0.8685	0.0007	0.8699	626
pop-6in-500g-cyl2-h2	500	56.7	0.8682	0.0006	0.8694	637
pop-6in-500g-cyl2-h3	500	57.7	0.8686	0.0006	0.8698	648
pop-6in-500g-cyl2-h4	500	58.7	0.8686	0.0006	0.8698	659
pop-6in-500g-cyl2-h5	500	59.7	0.8668	0.0006	0.8680	671
pop-6in-500g-cyl2-h6	500	60.7	0.8676	0.0007	0.8690	682
pop-6in-600g-cyl-h40	600	40	0.8582	0.0006	0.8594	374
pop-6in-600g-cyl-h45	600	45	0.8745	0.0007	0.8759	420
pop-6in-600g-cyl-h50	600	50	0.8869	0.0006	0.8881	467
pop-6in-600g-cyl-h54	600	54	0.8939	0.0007	0.8953	505
pop-6in-600g-cyl2-h1	600	55.7	0.8939	0.0006	0.8951	521
pop-6in-600g-cyl2-h2	600	56.7	0.8963	0.0006	0.8975	530
pop-6in-600g-cyl2-h3	600	57.7	0.8964	0.0006	0.8976	540
pop-6in-600g-cyl2-h4	600	58.7	0.8970	0.0007	0.8984	549
pop-6in-600g-cyl2-h5	600	59.7	0.8972	0.0007	0.8986	559
pop-6in-600g-cyl2-h6	600	60.7	0.8963	0.0006	0.8975	568
pop-6in-700g-cyl2-h1	700	55.7	0.9154	0.0006	0.9166	446
pop-6in-700g-cyl2-h2	700	56.7	0.9147	0.0006	0.9159	454
pop-6in-700g-cyl2-h3	700	57.7	0.9157	0.0006	0.9169	463
pop-6in-700g-cyl2-h4	700	58.7	0.9163	0.0007	0.9177	471
pop-6in-700g-cyl2-h5	700	59.7	0.9189	0.0006	0.9201	479
pop-6in-700g-cyl2-h6	700	60.7	0.9194	0.0006	0.9206	487
pop-6in-800g-cyl-h45	800	45	0.8931	0.0006	0.8943	315
pop-6in-800g-cyl-h50	800	50	0.9117	0.0007	0.9131	350
pop-6in-800g-cyl-h54	800	54	0.9251	0.0006	0.9263	378
pop-6in-800g-cyl2-h1	800	55.7	0.9262	0.0007	0.9276	390
pop-6in-800g-cyl2-h2	800	56.7	0.9288	0.0006	0.9300	397
pop-6in-800g-cyl2-h3	800	57.7	0.9291	0.0007	0.9305	405
pop-6in-800g-cyl2-h4	800	58.7	0.9300	0.0006	0.9312	412
pop-6in-800g-cyl2-h5	800	59.7	0.9323	0.0007	0.9337	419
pop-6in-800g-cyl2-h6	800	60.7	0.9325	0.0007	0.9339	426
pop-6in-900g-cyl-h45	900	45	0.8988	0.0007	0.9002	280
pop-6in-900g-cyl-h50	900	50	0.9204	0.0006	0.9216	311
pop-6in-900g-cyl-h54	900	54	0.9337	0.0007	0.9351	336

Table A.3 (continued)

Case name	^{239}Pu mass (g)	Cylinder height (cm)	k_{eff}		$k_{eff}+2\sigma$	H/^{239}Pu
pop-6in-900g-cyl2-h1	900	55.7	0.9367	0.0007	0.9381	347
pop-6in-900g-cyl2-h2	900	56.7	0.9396	0.0006	0.9408	353
pop-6in-900g-cyl2-h3	900	57.7	0.9403	0.0007	0.9417	359
pop-6in-900g-cyl2-h4	900	58.7	0.9415	0.0007	0.9429	366
pop-6in-900g-cyl2-h5	900	59.7	0.9436	0.0006	0.9448	372
pop-6in-900g-cyl2-h6	**900**	**60.7**	**0.9449**	**0.0007**	**0.9463**	**378**
pop-6in-900g-cyl2-h6-10%*	900	60.7	0.9106	0.0007	0.9120	378
pop-6in-900g-cyl2-h6-30%*	900	60.7	0.8729	0.0007	0.8743	378
pop-6in-900g-cyl2-h6-50%*	900	60.7	0.8557	0.0007	0.8571	378
pop-6in-900g-cyl2-h6-70%*	900	60.7	0.8449	0.0007	0.8463	378
pop-6in-900g-cyl2-h6-90%*	900	60.7	0.8383	0.0006	0.8395	378
pop-6in-950g-cyl-h45	950	45	0.9005	0.0007	0.9019	265
pop-6in-950g-cyl-h50	950	50	0.9227	0.0007	0.9241	295
pop-6in-950g-cyl-h54	950	54	0.9362	0.0007	0.9376	318
pop-6in-950g-cyl2-h1	950	55.7	0.9411	0.0006	0.9423	329
pop-6in-950g-cyl2-h2	950	56.7	0.9425	0.0007	0.9439	334
pop-6in-950g-cyl2-h3	950	57.7	0.9441	0.0006	0.9453	340
pop-6in-950g-cyl2-h4	950	58.7	0.9468	0.0007	0.9482	346
pop-6in-950g-cyl2-h5	950	59.7	0.9485	0.0006	0.9497	352
pop-6in-950g-cyl2-h6	950	60.7	0.9512	0.0007	0.9526	358
pop-6in-1000g-cyl-h45	1000	45	0.9018	0.0006	0.9030	252
pop-6in-1000g-cyl-h50	1000	50	0.9239	0.0007	0.9253	280
pop-6in-1000g-cyl-h54	1000	54	0.9394	0.0007	0.9408	302
pop-6in-1000g-cyl2-h1	1000	55.7	0.9441	0.0007	0.9455	312
pop-6in-1000g-cyl2-h2	1000	56.7	0.9465	0.0008	0.9481	318
pop-6in-1000g-cyl2-h3	1000	57.7	0.9492	0.0007	0.9506	323
pop-6in-1000g-cyl2-h4	1000	58.7	0.9507	0.0007	0.9521	329
pop-6in-1000g-cyl2-h5	1000	59.7	0.9520	0.0006	0.9532	335
pop-6in-1000g-cyl2-h6	1000	60.7	0.9540	0.0006	0.9552	340

* Last part of case name indicates the density of water as percent of nominal water density between the 55-gal. drums

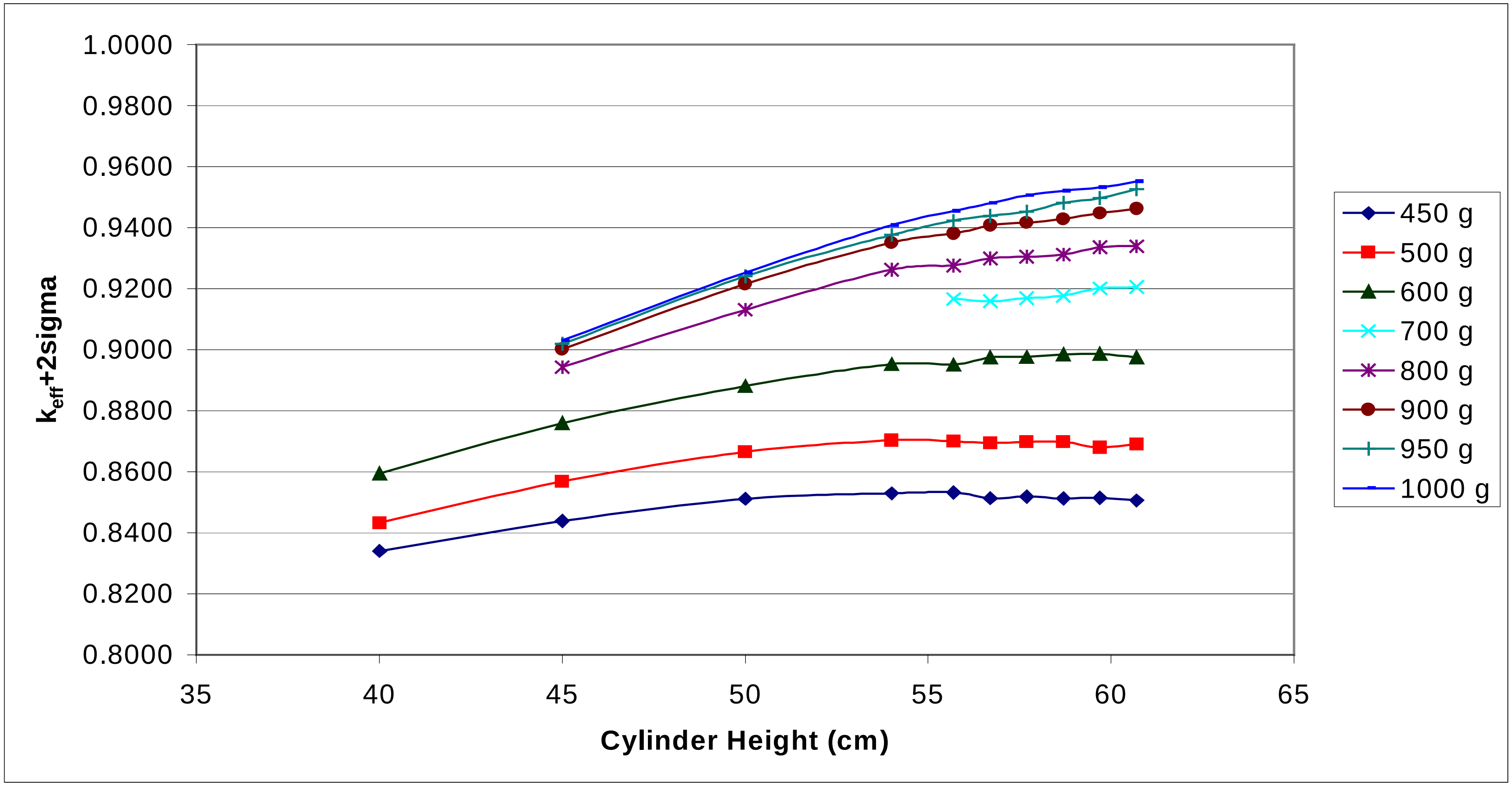


Fig. A.6. k_{eff} vs. cylinder height for an infinite array of 55-gal. drums with standard 6-in. POC (H/D>1).

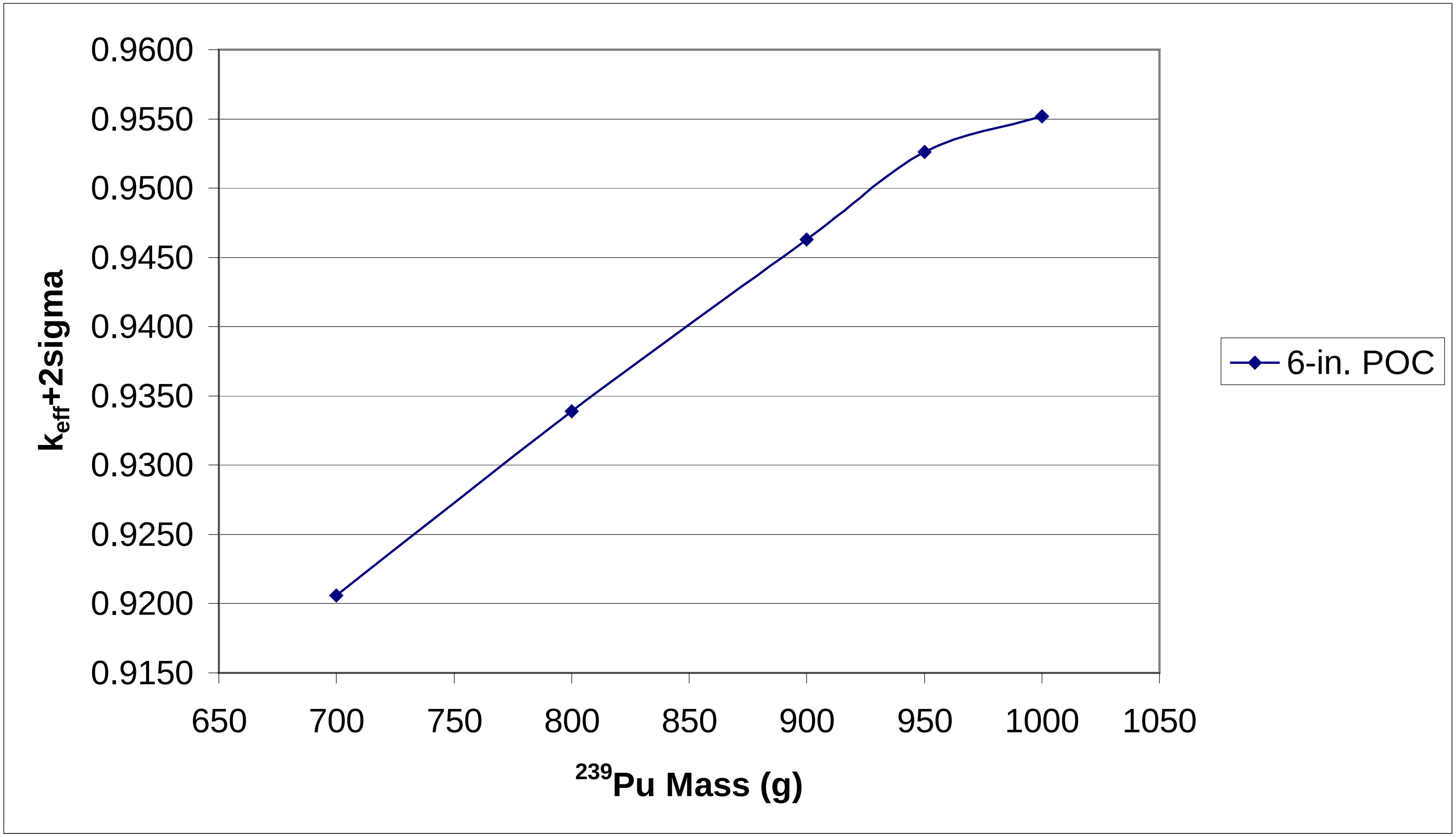


Fig. A.7. k_{eff} vs. ^{239}Pu mass for an infinite array of 55-gal. drums with standard 6-in. POC (cylindrical fuel/moderator mixture with H/D>1).

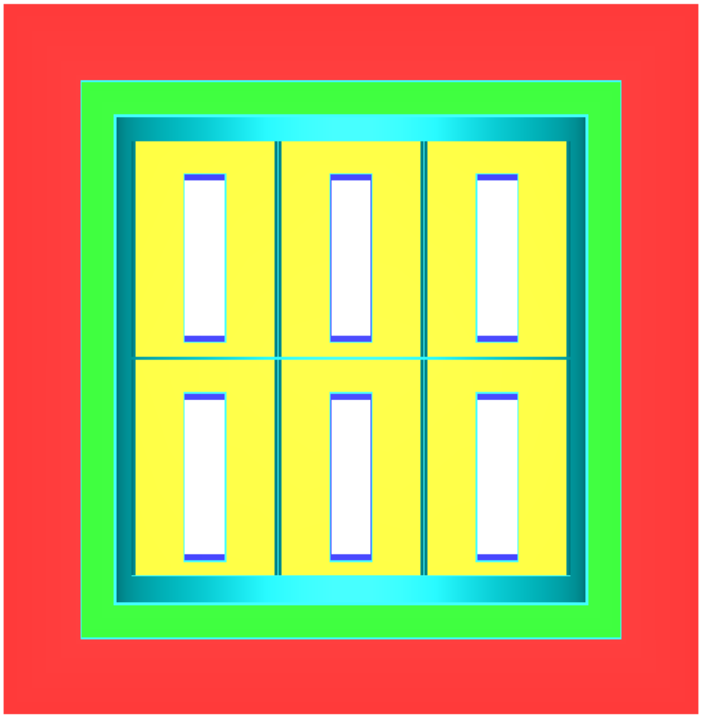
To address concerns with double batching, several cases with 1800 g plutonium are modeled. The results are given in Table A.4 and indicate that a single 55-gal. drum reflected by 30 cm water yields a k_{eff} of 0.7702 with a standard 6-in. POC containing 1800 g ^{239}Pu. H/^{239}Pu for this configuration is 188. Although the amount of plutonium is higher, the corresponding k_{eff} is lower due to undermoderation. Another case with 1500 g plutonium is also run to demonstrate the undermoderated nature of the mixture. This case results in a k_{eff} of 0.7775 with H/^{239}Pu of 226.

Finally, the TRUPACT-II package loaded with 14 standard 6-in. POC (two-tier, each with 7 close-packed standard 6-in. POC) as shown in Fig. A.8 is analyzed. The results are given in Table A.5. For normal conditions of transport, an infinite close-packed square array of TRUPACT-II packages results in a k_{eff} of 0.8698. When water is introduced into the void space either inside the package or between the packages, the k_{eff} of the system is reduced. A single TRUPACT-II package surrounded by 30-cm water yields a k_{eff} of 0.8428.

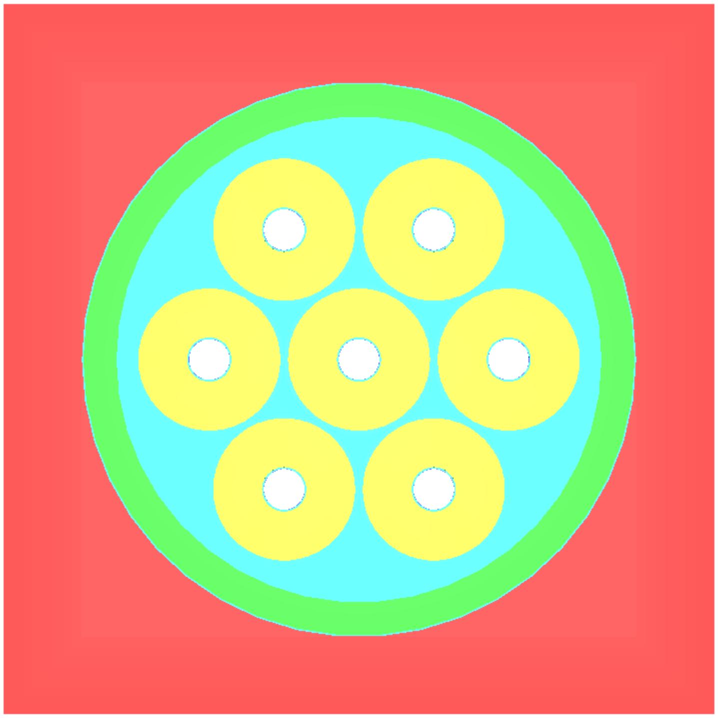
In the infinite array calculations, if the individual units are not isolated by the structural components (i.e., fiberboard/plywood dunnage) the reflector material that is used to fill the remainder of the standard 6-in. POC may prevent the interaction between the units of the array, thereby reducing the system k_{eff}. To investigate the effects of the presence of this reflector fill material, some representative cases with sphere fuel/moderator matrix are modeled without the reflector material and compared against the original cases. The results are listed in Table A.6 and shown in Fig. A.9. The results indicate that without the reflector material the system k_{eff} is reduced drastically. Other configurations with 6-in pipe component are not investigated since they have very little or no reflector material.

Table A.4. Infinite array of 55-gal. drums with standard 6-in. POC (cylinder fuel/moderator matrix with H/D>1, double batch)

Case name	^{239}Pu mass (g)	Cylinder height (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-6in-1800g-single-cyl2-h1-water	1800	55.7	0.7570	0.0006	0.7582	173
pop-6in-1800g-single-cyl2-h2-water	1800	56.7	0.7601	0.0007	0.7615	176
pop-6in-1800g-single-cyl2-h3-water	1800	57.7	0.7611	0.0007	0.7625	179
pop-6in-1800g-single-cyl2-h4-water	1800	58.7	0.7653	0.0006	0.7665	182
pop-6in-1800g-single-cyl2-h5-water	1800	59.7	0.7673	0.0008	0.7689	185
pop-6in-1800g-single-cyl2-h6-water	**1800**	**60.7**	**0.7688**	**0.0007**	**0.7702**	**188**



side view



top view

Fig. A.8. Single TRUPACT-II package with 14 standard 6-in. POC.

Table A.5. TRUPACT-II filled with 14 55-gal. drums containing standard 6-in. POC (900 g ^{239}Pu in each POC, fuel cylinder height of 60.7 cm)

Case name	Description	k_{eff}	σ	$k_{eff}+2\sigma$
tp2-1-10%	water at 10% nominal density between TRUPACT-II packages in an infinite array	0.8535	0.0008	0.8551
tp2-1-30%	water at 30% nominal density between TRUPACT-II packages in an infinite array	0.8414	0.0007	0.8428
tp2-1-50%	water at 50% nominal density between TRUPACT-II packages in an infinite array	0.8356	0.0006	0.8368
tp2-1-70%	water at 70% nominal density between TRUPACT-II packages in an infinite array	0.8287	0.0007	0.8301
tp2-1-90%	water at 90% nominal density between TRUPACT-II packages in an infinite array	0.8252	0.0007	0.8266
tp2-1	**Infinite array of TRUPACT-II packages**	**0.8684**	**0.0007**	**0.8698**
tp2-2	Infinite array of TRUPACT-II packages with water in interstitial spaces of packages	0.8240	0.0006	0.8252
tp2-3	Infinite array of TRUPACT-II packages with water between the packages	0.8491	0.0006	0.8503
tp2-4	Infinite array of TRUPACT-II packages with water in both interstitial spaces and between the packages	0.8250	0.0006	0.8262
tp2-5	Single TRUPACT-II package, vacuum boundary conditions	0.8373	0.0006	0.8385
tp2-1-single-water	Single TRUPACT-II package reflected by 30-cm water	0.8414	0.0007	0.8428

Table A.6. Infinite array of 55-gal. drums with standard 6-in. POC without reflector material (sphere fuel/moderator matrix)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$
pop-6in-500g-noref-r2	500	2	0.2616	0.0003	0.2622
pop-6in-500g-noref-r3	500	3	0.0751	0.0002	0.0755
pop-6in-500g-noref-r4	500	4	0.0852	0.0002	0.0856
pop-6in-500g-noref-r5	500	5	0.1299	0.0003	0.1305
pop-6in-500g-noref-r6	500	6	0.2209	0.0004	0.2217
pop-6in-500g-noref-r7	500	7	0.3522	0.0005	0.3532
pop-6in-500g-noref-r7.8	**500**	**7.8**	**0.4706**	**0.0006**	**0.4718**
pop-6in-650g-noref-r2	650	2	0.4273	0.0004	0.4281
pop-6in-650g-noref-r3	650	3	0.0951	0.0002	0.0955
pop-6in-650g-noref-r4	650	4	0.0893	0.0002	0.0897
pop-6in-650g-noref-r5	650	5	0.1271	0.0003	0.1277
pop-6in-650g-noref-r6	650	6	0.206	0.0003	0.2066
pop-6in-650g-noref-r7	650	7	0.3295	0.0005	0.3305
pop-6in-650g-noref-r7.8	650	7.8	0.4471	0.0006	0.4483

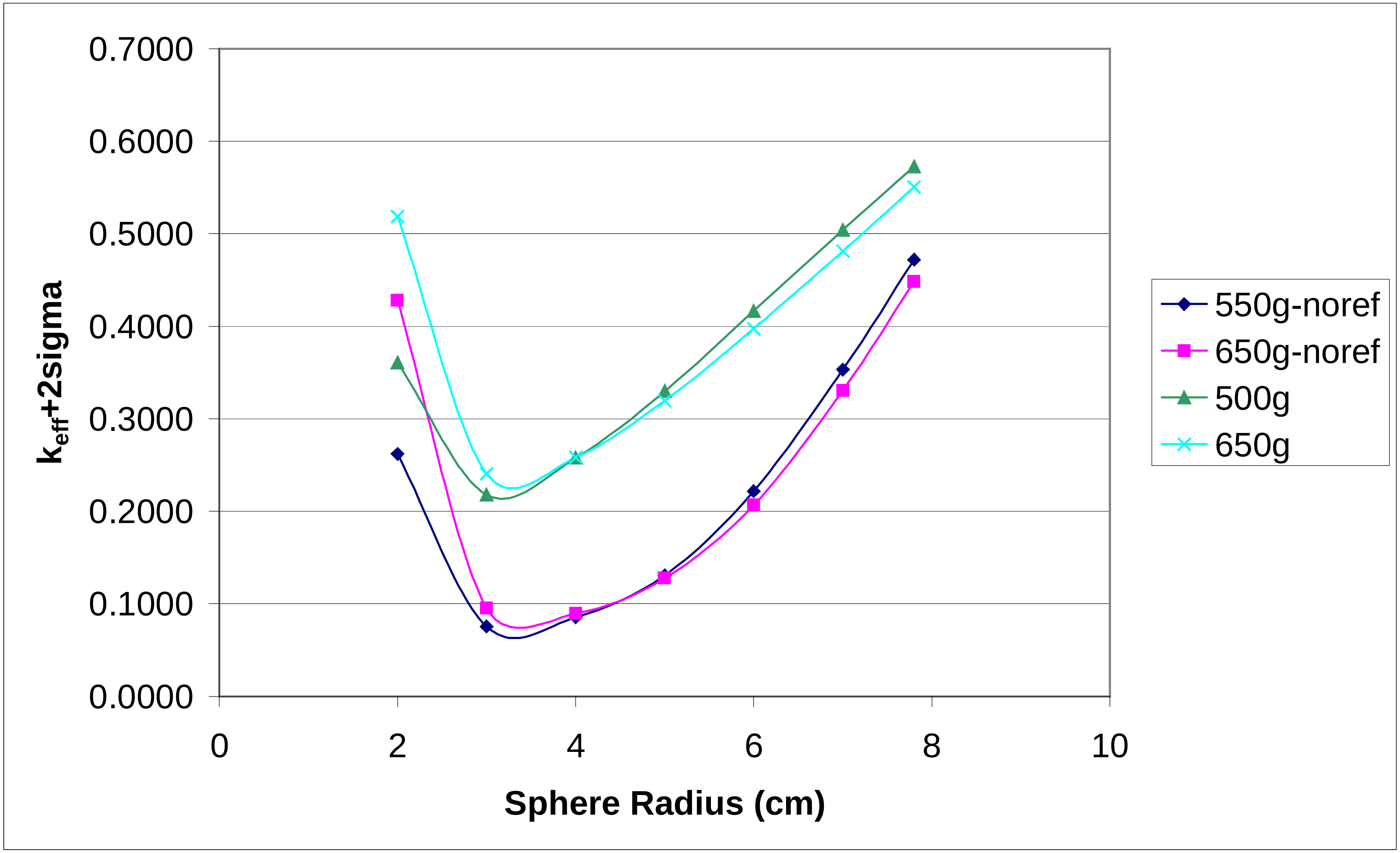


Fig. A.9. Comparison of reflector material effects inside standard 6-in. pipe component.

A.3. STANDARD 12-IN. PIPE OVERPACK CONTAINER

As with the standard 6-in. POC payload container, an infinite array of 55-gal. drums containing standard 12-in. POC is modeled with almost all structural components (except for bolts, nuts, and other protruding components). The models are identical to the 55-gal. drums with standard 6-in. POC except for the size of the pipe component and associated structural material thickness.

An infinite (in three dimensions) square-pitched array of the standard 12-in. POC payload containers with a fissile bearing spherical mixture in the center is modeled as shown in Fig. A.10. The results are given in Table A.7 and shown in Fig. A.11. The highest permissible (permissible is defined as below 0.95 and may not be the actual limit established in the safety analysis report) k_{eff}, 0.9267, for this configuration is obtained with 300 g ^{239}Pu in each standard 12-in. POC. The interpolated results for a k_{eff} of 0.95 is about 335 g ^{239}Pu in each standard 12-in. POC. In this configuration, the fuel/moderator matrix is modeled as a sphere with 13.5 cm radius and corresponds to optimum moderation radius (larger or smaller radii result in lower k_{eff}). A single element of this infinite array yields a k_{eff} of 0.9084 when surrounded by 30-cm water. Fig. A.12 shows the system k_{eff} as a function of ^{239}Pu mass. As the amount of ^{239}Pu increases, the system k_{eff} increases almost linearly. If the calculations were performed with even higher loadings of plutonium, the increase in k_{eff} values would eventually level out before rising again as the fuel/moderator matrix becomes solid ^{239}Pu metal. When fiberboard is mixed with water with varying volume fractions (to simulate flooding in which fiberboard absorbs water) the system k_{eff} is reduced.

When the fuel/moderator matrix region is modeled as a cylinder as shown in Fig. A.13 with height to diameter ratio of 1, the highest k_{eff} for 300 g ^{239}Pu is obtained with a radius of 12 cm and is 0.9190. The results of this configuration are given in Table A.8 and shown in Fig. A.14.

An infinite square-pitched array of standard 12-in. POC payload containers with twice the maximum load determined in the above configurations was also analyzed. The results are given in Table A.9 and shown in Fig. A.15. In this case of a double batch, the resulting highest k_{eff} is 1.0343 with 600 g ^{239}Pu in a sphere of 15 cm radius.

Finally, the TRUPACT-II package loaded with 14 standard 12-in. POCs as shown in Fig. A.16 (two-tier, each with 7 close-packed standard 12-in. POC) each with 300 g ^{239}Pu is analyzed. The results for this configuration are given in Table A.10 and shown in Fig. A.17. For normal conditions of transport, an infinite close-packed square array of TRUPACT-II packages results in a k_{eff} of 0.9181. This highest k_{eff} is obtained with a sphere of radius 13 cm. A single TRUPACT-II container surrounded by 30-cm water yields a k_{eff} of 0.9171 indicating that each container is almost completely isolated from the others.

To investigate the effects of the presence of the reflector fill material in 12-in. pipe component, some representative cases with sphere fuel/moderator matrix are modeled without the reflector material and compared against the original cases. The results are listed in Table A.11 and shown in Fig. A.18. The results indicate that without the reflector material the system k_{eff} is generally reduced. As the fuel/moderator sphere radius increases the results from the cases without the reflector material approach the results from the cases with the reflector material due to smaller amount of reflector material available for larger radii.

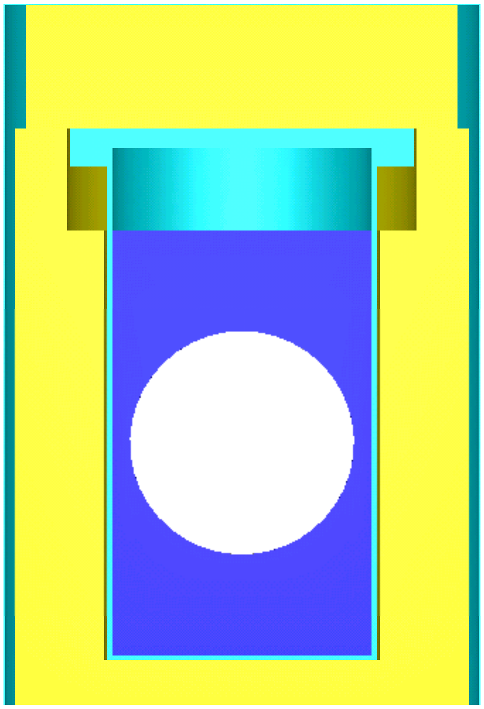


Fig. A.10. Axial view of 55-gal. drum with standard 12-in. POC (sphere fuel/moderator matrix).

Table A.7. Infinite array of 55-gal. drums with standard 12-in. POC (sphere fuel/moderator matrix)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-12in-250g-r8	250	8	0.6968	0.0007	0.6982	251
pop-12in-250g-r9	250	9	0.7700	0.0006	0.7712	358
pop-12in-250g-r10	250	10	0.8253	0.0007	0.8267	492
pop-12in-250g-r11	250	11	0.8601	0.0006	0.8613	655
pop-12in-250g-r12	250	12	0.8826	0.0006	0.8838	851
pop-12in-250g-r13	250	13	0.8877	0.0007	0.8891	1082
pop-12in-250g-r14	250	14	0.8784	0.0005	0.8794	1352
pop-12in-250g-r15	250	15	0.8596	0.0005	0.8606	1663
pop-12in-250g-r15.6	250	15.6	0.8420	0.0005	0.8430	1871
pop-12in-300g-r8	300	8	0.6967	0.0006	0.6979	209
pop-12in-300g-r9	300	9	0.7749	0.0007	0.7763	298
pop-12in-300g-r10	300	10	0.8387	0.0006	0.8399	409
pop-12in-300g-r11	300	11	0.8830	0.0008	0.8846	545
pop-12in-300g-r12	300	12	0.9106	0.0007	0.9120	709
pop-12in-300g-r12.5	300	12.5	0.9200	0.0007	0.9214	801
pop-12in-300g-r13	300	13	0.9246	0.0006	0.9258	901
pop-12in-300g-r13.5	**300**	**13.5**	**0.9255**	**0.0006**	**0.9267**	**1010**
pop-12in-300g-r13.5-vac	300	13.5	0.9052	0.0007	0.9066	1010
pop-12in-300g-r13.5-water	300	13.5	0.9072	0.0006	0.9084	1010
pop-12in-300g-r13.5-10%	300	13.5	0.9231	0.0006	0.9243	1010
pop-12in-300g-r13.5-30%	300	13.5	0.9181	0.0006	0.9193	1010
pop-12in-300g-r13.5-50%	300	13.5	0.9187	0.0007	0.9201	1010
pop-12in-300g-r13.5-70%	300	13.5	0.9171	0.0006	0.9183	1010
pop-12in-300g-r13.5-90%	300	13.5	0.9156	0.0006	0.9168	1010
pop-12in-300g-r14	300	14	0.9231	0.0006	0.9243	1126
pop-12in-300g-r14.5	300	14.5	0.9197	0.0006	0.9209	1251
pop-12in-300g-r15	300	15	0.9124	0.0006	0.9136	1385
pop-12in-300g-r15.6	300	15.6	0.9004	0.0006	0.9016	1559
pop-12in-350g-r12	350	12	0.9324	0.0007	0.9338	607
pop-12in-350g-r13	350	13	0.9535	0.0007	0.9549	772
pop-12in-350g-r14	350	14	0.9602	0.0007	0.9616	965
pop-12in-350g-r15	350	15	0.9533	0.0006	0.9545	1187
pop-12in-350g-r15.6	350	15.6	0.9448	0.0006	0.9460	1336
pop-12in-400g-r8	400	8	0.6898	0.0006	0.6910	156
pop-12in-400g-r9	400	9	0.7776	0.0007	0.7790	223
pop-12in-400g-r10	400	10	0.8519	0.0006	0.8531	307
pop-12in-400g-r11	400	11	0.9074	0.0007	0.9088	409
pop-12in-400g-r12	400	12	0.9476	0.0006	0.9488	531
pop-12in-400g-r13	400	13	0.9752	0.0006	0.9764	676
pop-12in-400g-r14	400	14	0.9878	0.0007	0.9892	844
pop-12in-400g-r15	400	15	0.9874	0.0006	0.9886	1039
pop-12in-400g-r15.6	400	15.6	0.9808	0.0006	0.9820	1169

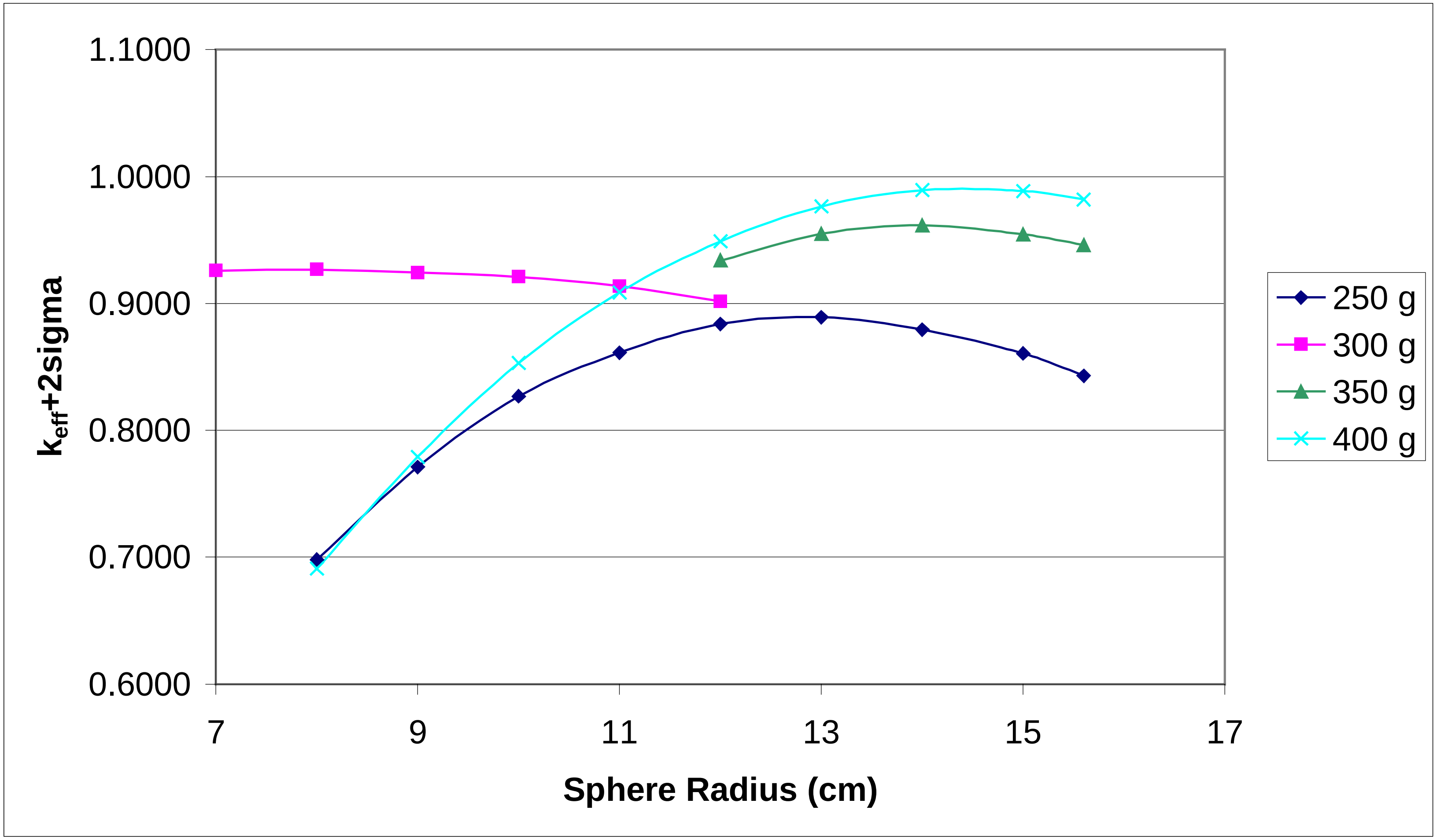


Fig. A.11. k_{eff} vs. sphere radius for an infinite array of 55-gal. drums with standard 12-in. POC.

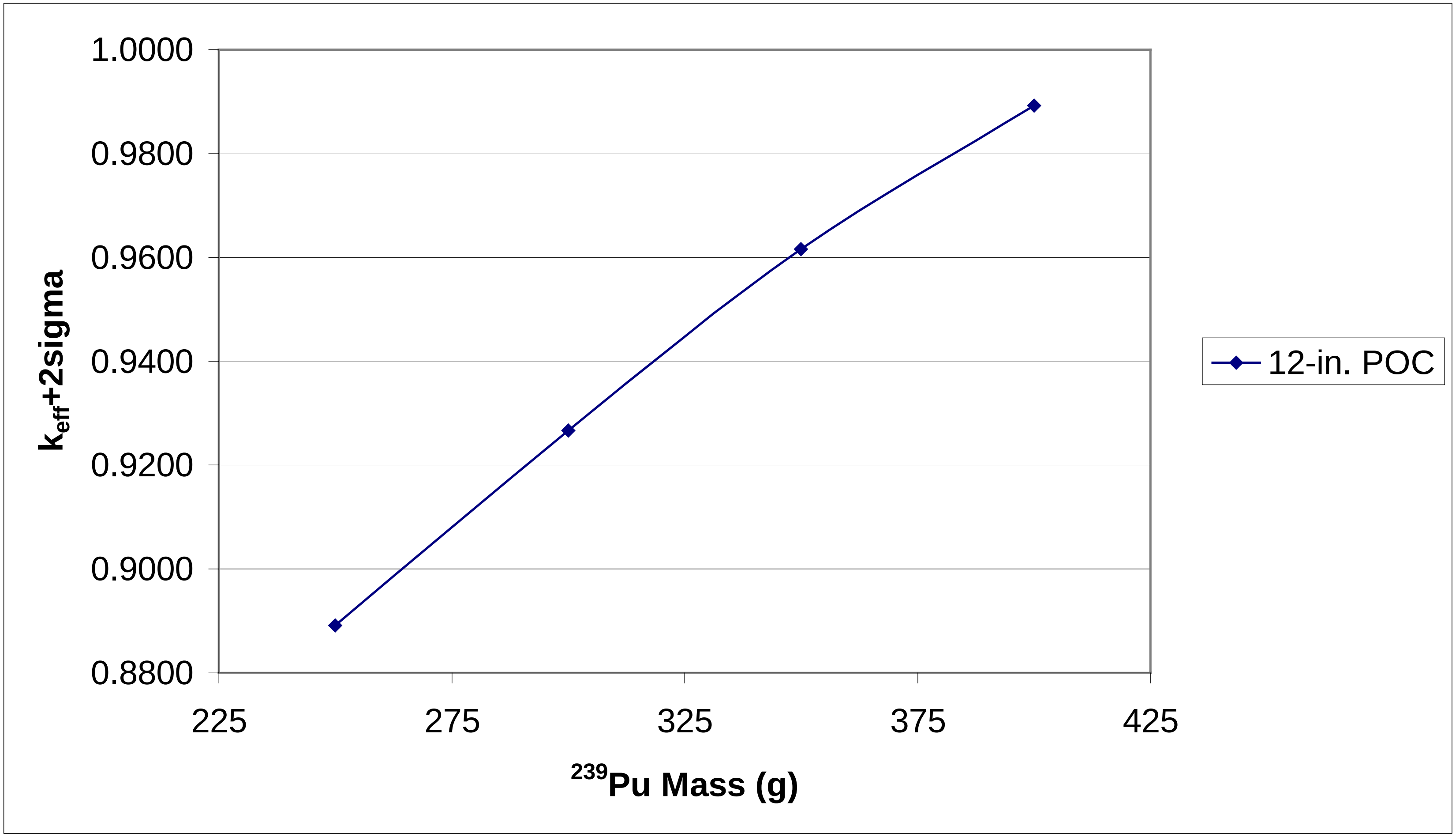


Fig. A.12. k_{eff} **vs.** ^{239}**Pu mass for an infinite array of 55-gal. drums with standard 12-in. POC (sphere fuel/moderator mixture).**

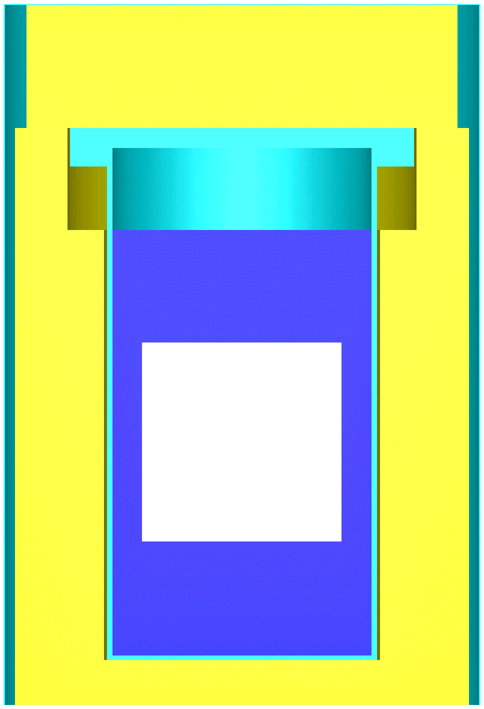


Fig. A.13. Axial view of 55-gal. drum with standard 12-in. POC (cylinder fuel/moderator matrix with H/D=1).

Table A.8. Infinite array of 55-gal. drums with standard 12-in. POC (cylinder H/D=1)

Case name	^{239}Pu mass (g)	Cylinder radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-12in-300g-cyl-r11	300	11	0.9119	0.0007	0.9133	819
pop-12in-300g-cyl-r12	**300**	**12**	**0.9178**	**0.0006**	**0.9190**	**1064**
pop-12in-300g-cyl-r13	300	13	0.9077	0.0006	0.9089	1353
pop-12in-300g-cyl-r14	300	14	0.8863	0.0005	0.8873	1690
pop-12in-300g-cyl-r15	300	15	0.8544	0.0005	0.8554	2079
pop-12in-300g-cyl-r15.6	300	15.6	0.8292	0.0004	0.8300	2339

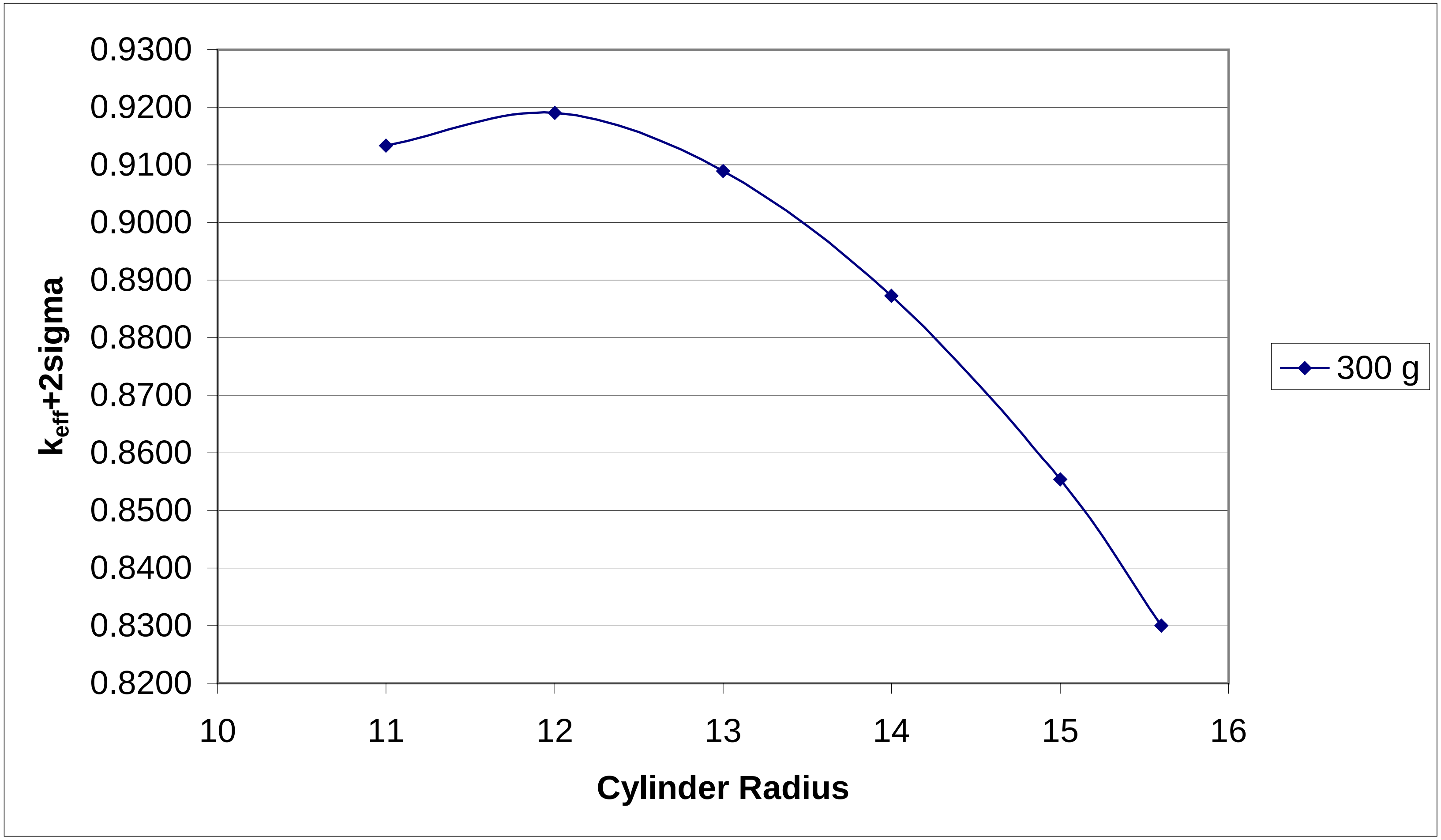


Fig. A.14. k_{eff} vs. cylinder radius for an infinite array of 55-gal. drums with standard 12-in. POC (H/D=1).

Table A.9. Infinite array of 55-gal. drums with standard 12-in. POC (double batch)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
pop-12in-600g-single-r13-water	600	13	1.0008	0.0007	1.0022	450
pop-12in-600g-single-r14-water	600	14	1.0233	0.0007	1.0247	562
pop-12in-600g-single-r15-water	**600**	**15**	**1.0331**	**0.0006**	**1.0343**	**692**
pop-12in-600g-single-r15.6-water	600	15.6	1.0311	0.0007	1.0325	779

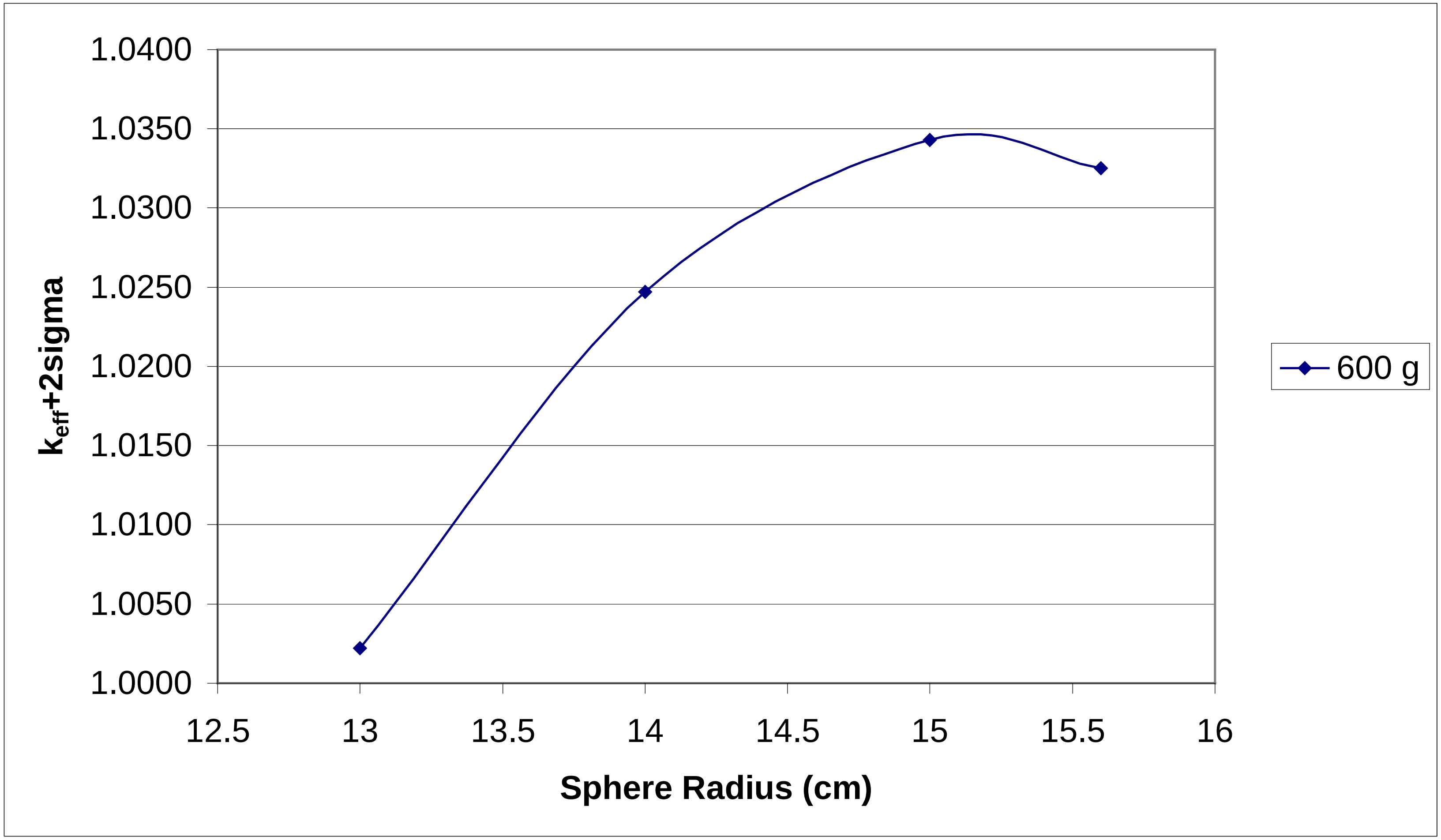
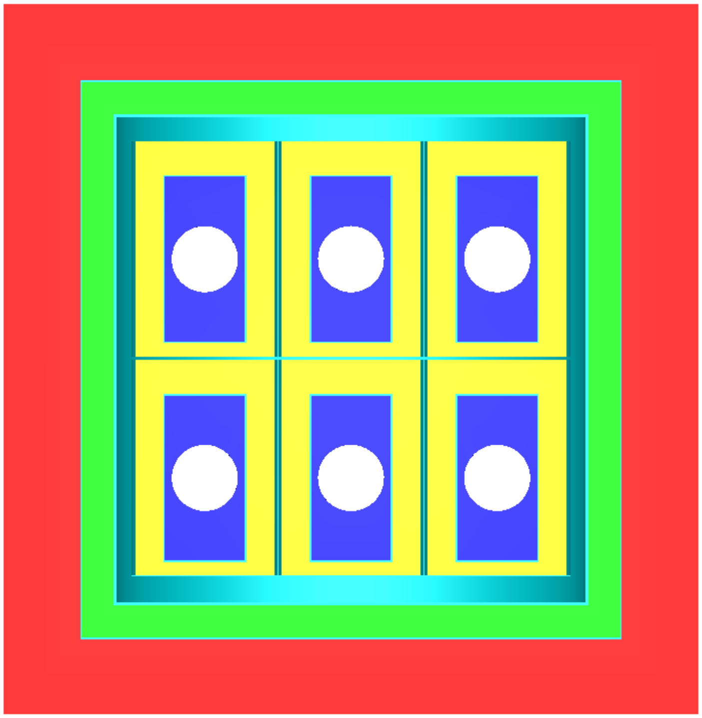
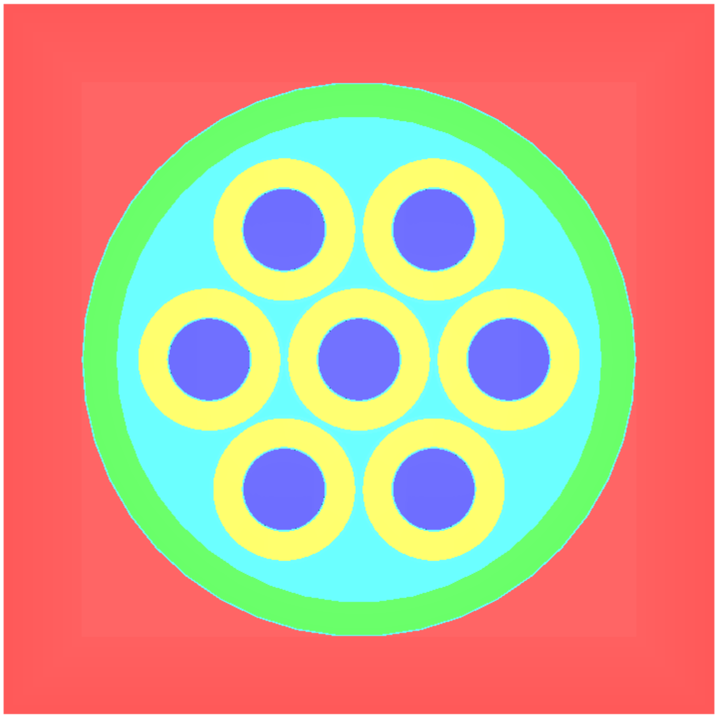


Fig. A.15. k_{eff} vs. sphere radius for an infinite array of 55-gal. drums with standard 12-in. POC (double batch).



side view



top view

Fig. A.16. Single TRUPACT-II package with 14 standard 12-in. POCs.

Table A.10. TRUPACT-II filled with 14 55-gal. drums containing standard 12-in. POC (300 g ^{239}Pu in each POC)

Case name	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
tp2-12in-300g-1-r10	10	0.8358	0.0006	0.8370	409
tp2-12in-300g-1-r11	11	0.8800	0.0006	0.8812	545
tp2-12in-300g-1-r12	12	0.9069	0.0006	0.9081	709
tp2-12in-300g-1-r13-vac[*]	13	0.9166	0.0007	0.9180	901
tp2-12in-300g-1-r13-water[**]	13	0.9159	0.0006	0.9171	901
tp2-12in-300g-1-r13	**13**	**0.9169**	**0.0006**	**0.9181**	**901**
tp2-12in-300g-1-r14	14	0.9168	0.0005	0.9178	1126
tp2-12in-300g-1-r15	15	0.9007	0.0005	0.9017	1385
tp2-12in-300g-1-r15.6	15.6	0.8873	0.0006	0.8885	1559

[*] Single TRUPACT-II, vacuum boundary conditions

[**] Single TRUPACT-II reflected by 30-cm water

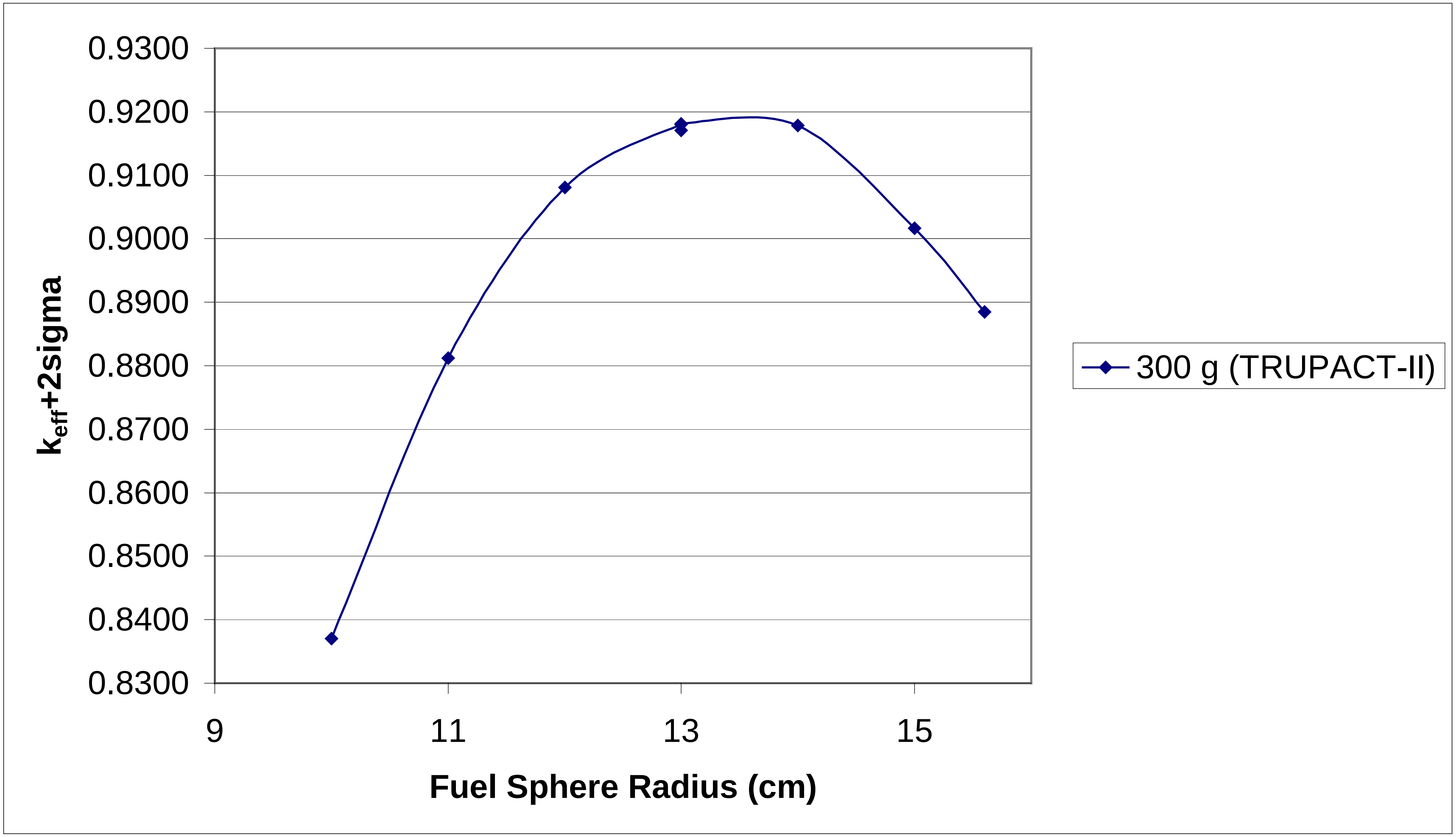


Fig. A.17. k_{eff} **vs. fuel sphere radius for an infinite array of TRUPACT-II packages containing 14 55-gal. drums with standard 12-in. POC.**

Table A.11. Infinite array of 55-gal. drums with standard 12-in. POC without reflector material (sphere fuel/moderator matrix)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$
pop-12in-250g-noref-r8	250	8	0.5037	0.0007	0.5051
pop-12in-250g-noref-r9	250	9	0.6138	0.0006	0.6150
pop-12in-250g-noref-r10	250	10	0.7030	0.0007	0.7044
pop-12in-250g-noref-r11	250	11	0.7697	0.0006	0.7709
pop-12in-250g-noref-r12	250	12	0.8165	0.0007	0.8179
pop-12in-250g-noref-r13	250	13	0.8440	0.0006	0.8452
pop-12in-250g-noref-r14	250	14	0.8525	0.0006	0.8537
pop-12in-250g-noref-r15	250	15	0.8496	0.0005	0.8506
pop-12in-250g-noref-r15.6	250	15.6	0.8412	0.0005	0.8422
pop-12in-300g-noref-r8	300	8	0.5006	0.0006	0.5018
pop-12in-300g-noref-r9	300	9	0.6175	0.0007	0.6189
pop-12in-300g-noref-r10	300	10	0.7149	0.0006	0.7161
pop-12in-300g-noref-r11	300	11	0.7900	0.0008	0.7916
pop-12in-300g-noref-r12	300	12	0.8462	0.0006	0.8474
pop-12in-300g-noref-r12.5	300	12.5	0.8663	0.0006	0.8675
pop-12in-300g-noref-r13	300	13	0.8830	0.0006	0.8842
pop-12in-300g-noref-r13.5	300	13.5	0.8943	0.0007	0.8957
pop-12in-300g-noref-r14	300	14	0.9001	0.0006	0.9013
pop-12in-300g-noref-r14.5	300	14.5	0.9040	0.0005	0.9050
pop-12in-300g-noref-r15	300	15	0.9041	0.0006	0.9053
pop-12in-300g-noref-r15.6	300	15.6	0.9007	0.0005	0.9017
pop-12in-350g-noref-r12	350	12	0.8694	0.0007	0.8708
pop-12in-350g-noref-r13	350	13	0.9108	0.0006	0.9120
pop-12in-350g-noref-r14	350	14	0.9370	0.0006	0.9382
pop-12in-350g-noref-r15	**350**	**15**	**0.9472**	**0.0005**	**0.9482**
pop-12in-350g-noref-r15.6	350	15.6	0.9466	0.0006	0.9478

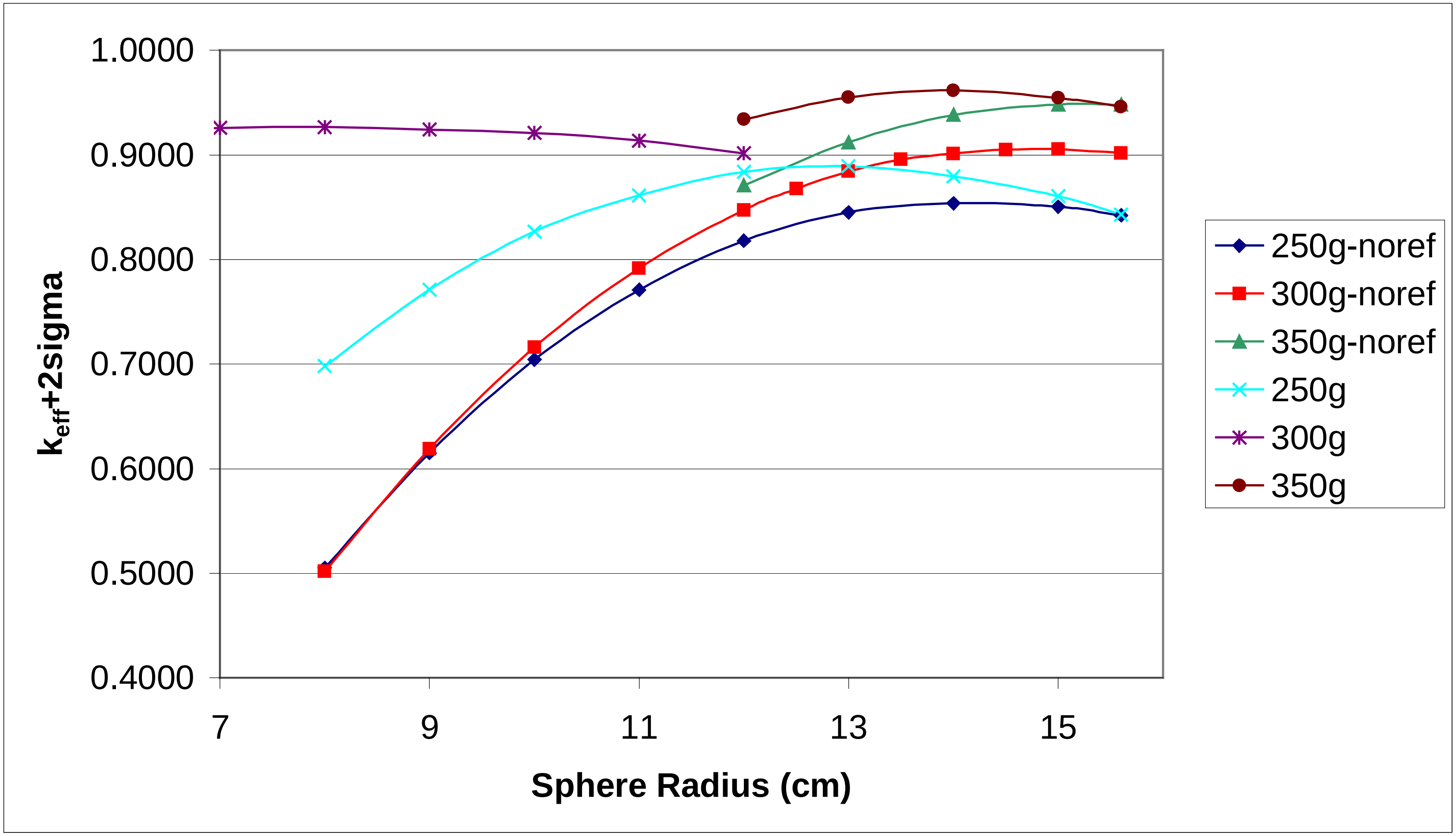


Fig. A.18. Comparison of reflector material effects inside 12-in. pipe component.

A.4. 55-GALLON DRUMS

An infinite square array of 55-gal. drum payload containers with fissile bearing spherical mixture is analyzed. An axial view of the model is shown in Fig. A.19. The 55-gal. drum is modeled as close to the actual specifications as possible (within tolerances; insignificant structural irregularities such as protrusions are ignored). The waste matrix is modeled as composed of ^{239}Pu and moderator material. Moderator material is assumed to be 60% by volume polyethylene and 40% water. The 55-gal. drum is filled with a reflector having the same contents as the moderator material (60% polyethylene, 40% water). The results are given in Table A.12 and shown in Fig. A.20. The highest permissible k_{eff}, 0.9391, is obtained with 325 g ^{239}Pu in a sphere with 14-cm radius and H/^{239}Pu of 1039. The interpolated results for a k_{eff} of 0.95 are about 335 g ^{239}Pu in each 55-gal. drum. Higher loadings of ^{239}Pu result in higher k_{eff} values due to the large volume available to optimize the moderator.

Fig. A.21 shows the system k_{eff} as a function of ^{239}Pu mass. Similar to standard 6-in. and standard 12-in. POCs, as the amount of ^{239}Pu increases, the system k_{eff} increases almost linearly. The trend remains almost linear as long as an optimum moderation can be achieved within the available volume.

Finally, the TRUPACT-II package loaded with 14 55-gal. drums as shown in Fig. A.22 (two-tier, each with 7 close-packed 55-gal. drums) each with 325 g ^{239}Pu is analyzed. The results for this configuration are given in Table A.13 and shown in Fig. A.23. For normal conditions of transport, an infinite close-packed square-pitched array of TRUPACT-II packages results in a k_{eff} of 0.9387. This highest k_{eff} is obtained with a sphere of radius 14-cm. A single TRUPACT-II container surrounded by 30-cm water yields a k_{eff} of 0.9379. A single TRUPACT-II container with vacuum boundary conditions yields a k_{eff} of 0.9385 indicating that internal reflection is essentially infinite and therefore each container is isolated from the others. Note that the bare and water-reflected case results are statistically identical (within 2σ with σ being 0.0006 for reflected and 0.0007 for bare) and should not be viewed as the bare case is more reactive than the water-reflected case.

In the above configurations, individual 55-gal. drums are mostly isolated from each other. Therefore, infinite array results are nearly identical to single unit results. However, if the reflector material (polyethylene-water mixture) surrounding each fuel/moderator sphere is removed, the interaction between the drums is maximized and results in k_{eff} values well above the upper subcritical limit. To illustrate, the infinite array of 55-gal. drums with 325 g ^{239}Pu in a fuel/moderator sphere of 10-cm radius results in a k_{eff} of 1.4911. Similarly, the same configuration with 200 g ^{239}Pu in a fuel/moderator sphere of 12-cm radius yields a k_{eff} of 1.2734. Note that the limits established in Sect. 2.2 are based on the assumption that the reflector material does exist in the 55-gal. drums (minimum net weight of 205 kg).

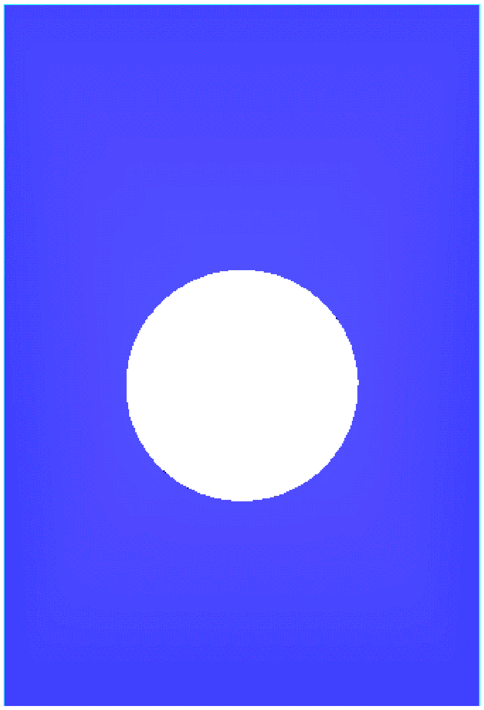


Fig. A.19. Axial view of 55-gal. drum (sphere fuel/moderator matrix).

Table A.12. Infinite array of 55-gal. drums (sphere fuel/moderator matrix)

Case name	^{239}Pu mass (g)	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
55gal-200g-r12	200	12	0.8317	0.0007	0.8331	1064
55gal-200g-r13	200	13	0.828	0.0006	0.8292	1353
55gal-200g-r14	200	14	0.8114	0.0005	0.8124	1690
55gal-200g-r15	200	15	0.7864	0.0004	0.7872	2079
55gal-200g-r16	200	16	0.7549	0.0005	0.7559	2523
55gal-250g-r10	250	10	0.8221	0.0007	0.8235	492
55gal-250g-r11	250	11	0.8554	0.0006	0.8566	655
55gal-250g-r12	250	12	0.8773	0.0006	0.8785	851
55gal-250g-r13	250	13	0.8797	0.0007	0.8811	1082
55gal-250g-r14	250	14	0.8741	0.0006	0.8753	1352
55gal-250g-r15	250	15	0.8555	0.0006	0.8567	1663
55gal-250g-r16	250	16	0.8294	0.0006	0.8306	2018
55gal-300g-r10	300	10	0.8356	0.0006	0.8368	409
55gal-300g-r11	300	11	0.8785	0.0007	0.8799	545
55gal-300g-r12	300	12	0.9058	0.0006	0.9070	709
55gal-300g-r13	300	13	0.9187	0.0006	0.9199	901
55gal-300g-r14	300	14	0.9186	0.0006	0.9198	1126
55gal-300g-r15	300	15	0.9081	0.0005	0.9091	1385
55gal-300g-r16	300	16	0.8881	0.0006	0.8893	1682
55gal-325g-r10	325	10	0.8382	0.0007	0.8396	378
55gal-325g-r11	325	11	0.8857	0.0007	0.8871	503
55gal-325g-r12	325	12	0.9161	0.0006	0.9173	654
55gal-325g-r13	325	13	0.9338	0.0007	0.9352	832
55gal-325g-r14	**325**	**14**	**0.9379**	**0.0006**	**0.9391**	**1039**
55gal-325g-r14-vac	325	14	0.9363	0.0006	0.9375	1039
55gal-325g-r14-water	325	14	0.9367	0.0006	0.9379	1039
55gal-325g-r15	325	15	0.9291	0.0006	0.9303	1279
55gal-325g-r16	325	16	0.9133	0.0006	0.9145	1552
55gal-350g-r12	350	12	0.9273	0.0008	0.9289	607
55gal-350g-r13	350	13	0.9473	0.0006	0.9485	772
55gal-350g-r14	350	14	0.9527	0.0007	0.9541	965
55gal-350g-r15	350	15	0.9480	0.0006	0.9492	1187
55gal-350g-r16	350	16	0.9337	0.0005	0.9347	1441

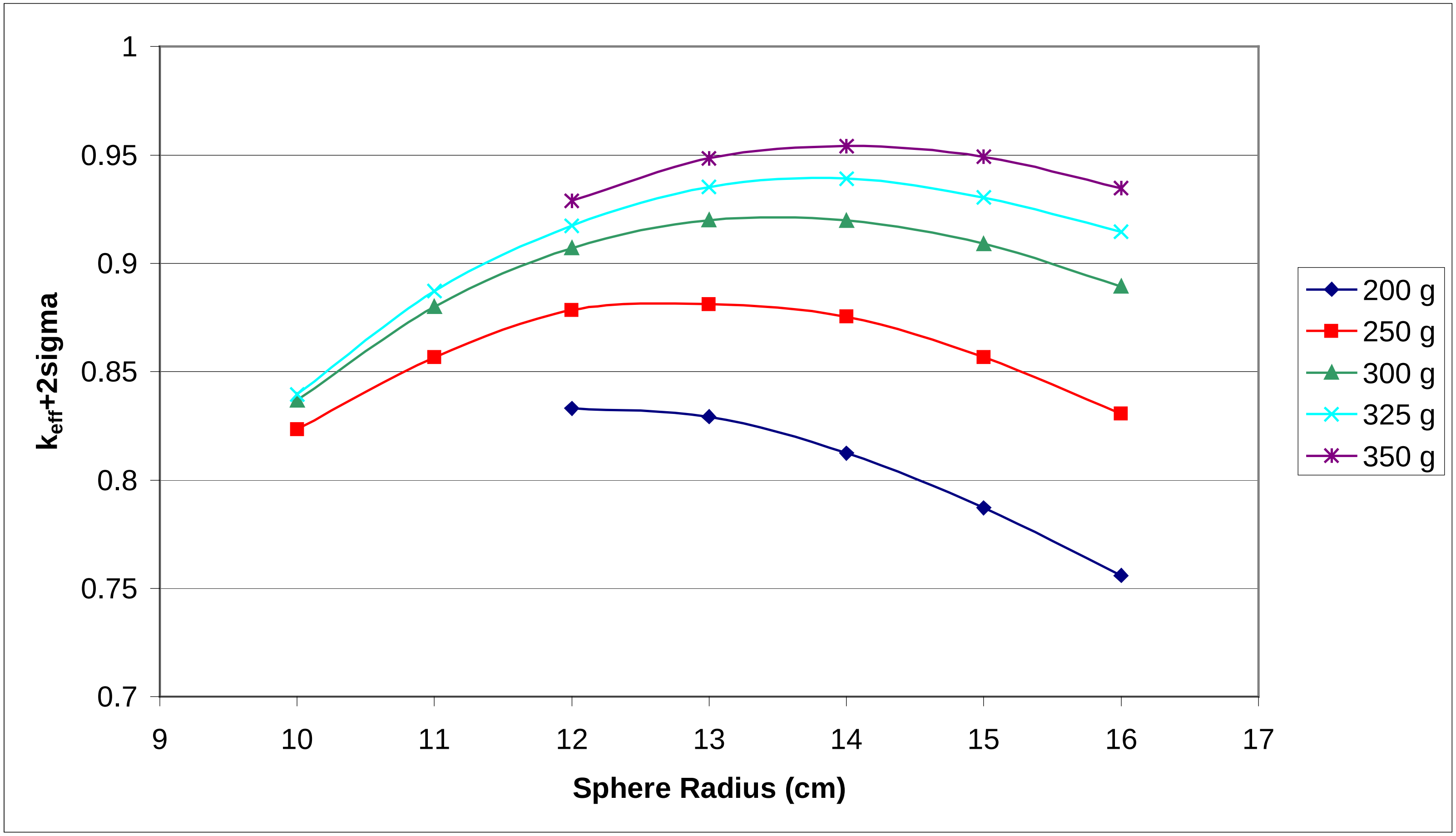


Fig. A.20. k_{eff} vs. sphere radius for an infinite array of 55-gal. drums.

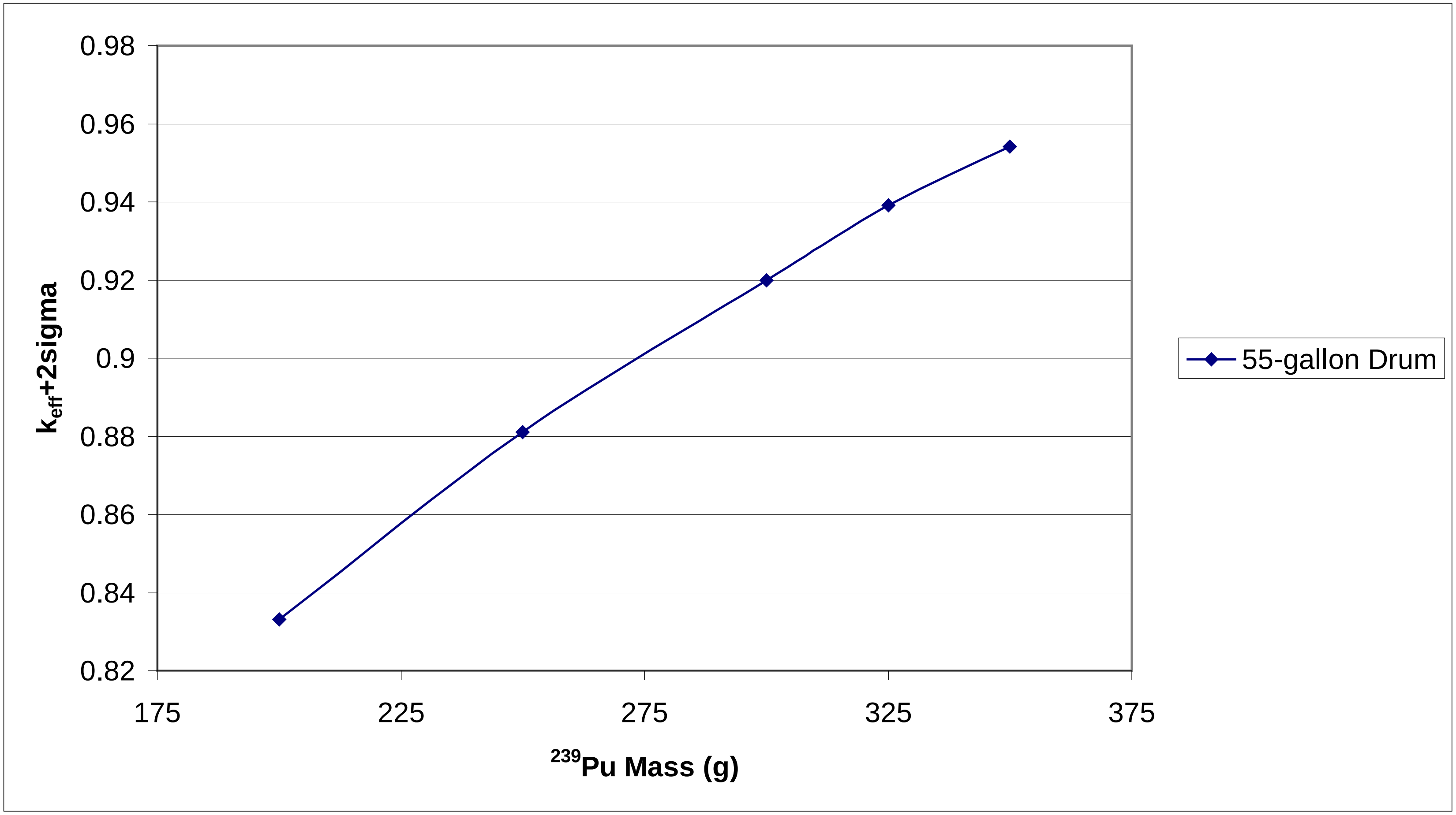
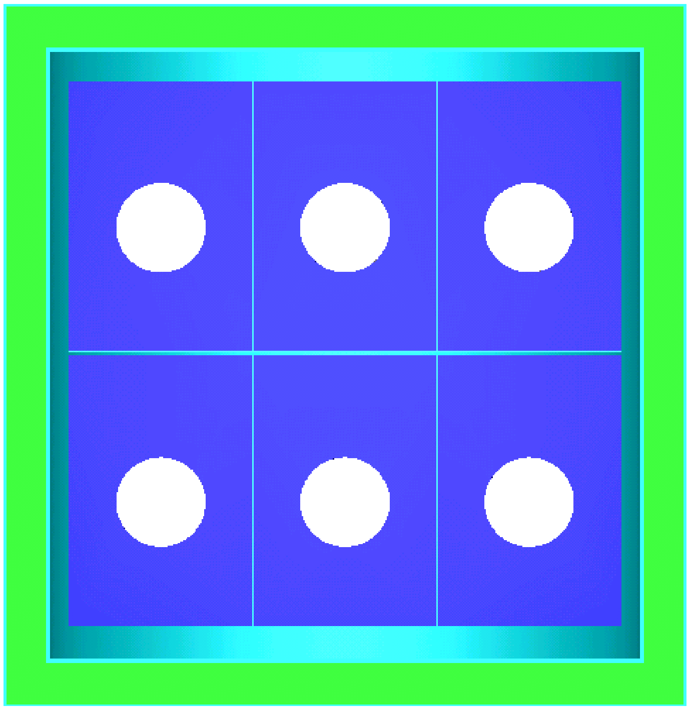
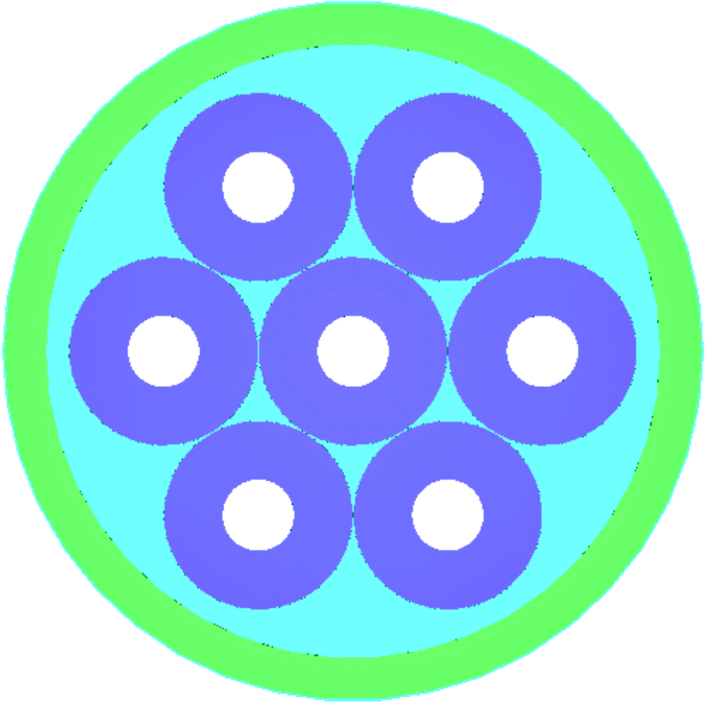


Fig. A.21. k_{eff} **vs.** ^{239}**Pu mass for an infinite array of 55-gal. drums (sphere fuel/moderator matrix).**



side view



top view

Fig. A.22. Single TRUPACT-II package with 14 55-gal. containers.

Table A.13. TRUPACT-II filled with 14 55-gal. drums

Case name	Sphere radius (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	H/^{239}Pu
tp2-55gal-325g-r12	12	0.9173	0.0006	0.9185	654
tp2-55gal-325g-r13	13	0.9338	0.0007	0.9352	832
tp2-55gal-325g-r14	**14**	**0.9375**	**0.0006**	**0.9387**	**1039**
tp2-55gal-325g-r14-1[a]	14	0.9359	0.0007	0.9373	1039
tp2-55gal-325g-r14-2[b]	14	0.9365	0.0006	0.9377	1039
tp2-55gal-325g-r14-3[c]	14	0.9370	0.0007	0.9384	1039
tp2-55gal-325g-r13-water[d]	14	0.9367	0.0006	0.9379	1039
tp2-55gal-325g-r14-vac[e]	14	0.9371	0.0007	0.9385	1039
tp2-55gal-325g-r15	15	0.9282	0.0006	0.9294	1279

[a] Water inside the TRUPACT-II containers

[b] Water inside and in between the TRUPACT-II containers

[c] Water in between the TRUPACT-II containers

[d] Single TRUPACT-II reflected by 30-cm water

[e] Single TRUPACT-II, vacuum boundary conditions

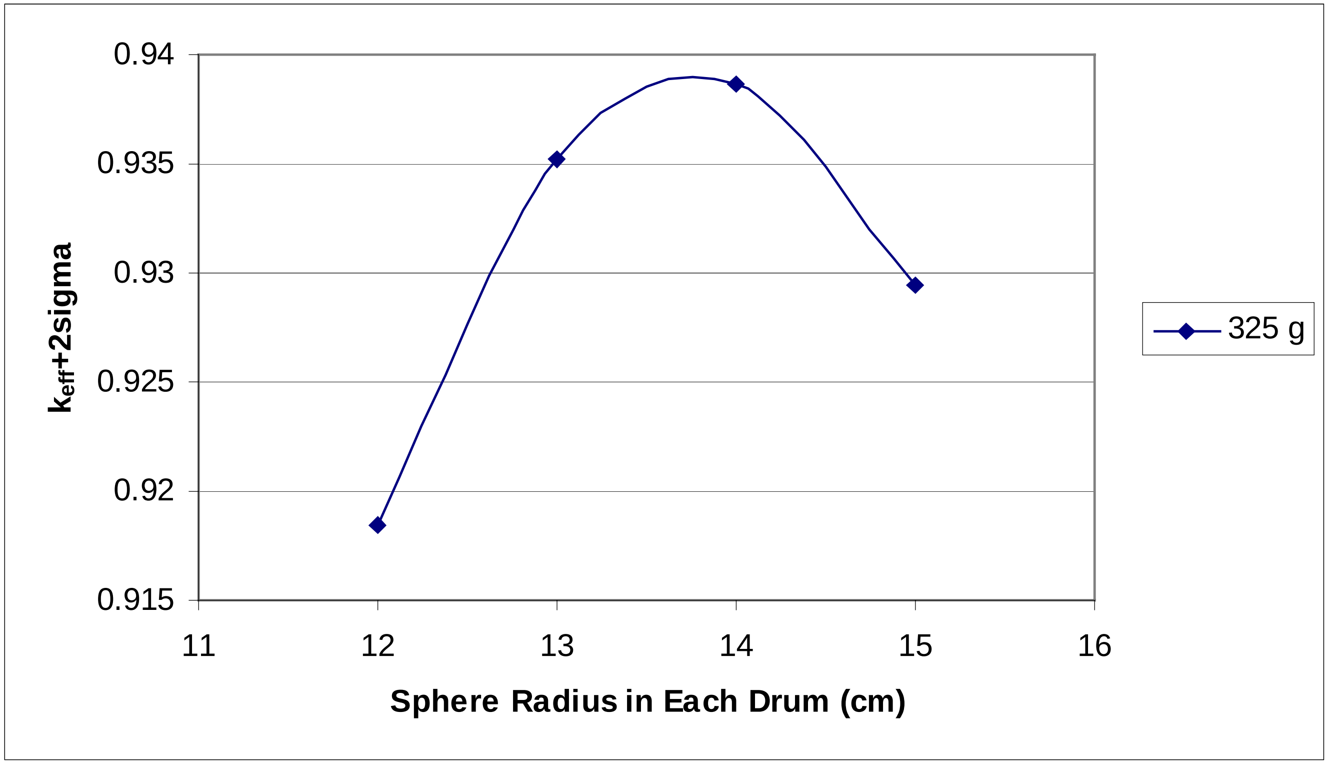


Fig. A.23. k_{eff} vs. fuel sphere radius for an infinite array of TRUPACT-II packages containing 14 55-gal. drums.

APPENDIX B

APPLIED NCSP TASKS/METHODS

APPENDIX B

APPLIED NCSP TASKS/METHODS

Various Tasks that have been supported by the U.S. DOE NCSP were used for this scoping study. The Tasks included

- Benchmarking for computational validation,
- Nuclear Data from the U.S. Evaluated Nuclear Data File B/Version V,
- Analytical Methods for performing the SCALE IV, KENO-V computational safety analyses, and
- Applicable Ranges of Bounding Curves and Data (AROBCAD) for determining the relevance of critical experiment benchmarks to the computational safety analyses and for determining the bias and uncertainties of the computational safety analyses.

Due in part to the incomplete work of the U.S. DOE NCSP AROBCAD task, only about 373 critical experiments from the about 2642 critical experiments that have been documented in the International Handbook of Evaluated Criticality Safety Benchmark Experiments were used for this scoping study of the TRUPACT-II and HalfPACT package contents. With the application of the AROBCAD sensitivity and uncertainty analysis tools, of the 373 critical experiment benchmarks, approximately

- 153 have been identified as significantly pertinent for the validation and determination of the computational biases and uncertainties for the 55-gal. drum payload containers resulting in a bias and uncertainty of calculated results of +0.018 and +0.012, respectively.
- 48 have been identified as significantly pertinent for the validation and determination of the computational biases and uncertainties for the 55-gal. drum payload containers with the concrete waste matrix resulting in a bias and uncertainty of calculated results of –0.0043 and +0.012, respectively.
- 154 have been identified as significantly pertinent for the validation and determination of the computational biases and uncertainties for the standard 6-in. POC payload containers resulting in a bias and uncertainty of calculated results of +0.016 and +0.013, respectively.
- 155 experiments have been identified as significantly pertinent for the validation and determination of the computational biases and uncertainties for the standard standard 12-in. POC payload containers resulting in a bias and uncertainty of calculated results of +0.018 and +0.012, respectively.

The above estimates of neutron cross section biases and uncertainties are based upon developing AROBCAD analytical tools.[B.1] Each safety application in the scoping study was compared with the same suite of 373 critical experiment benchmarks.[B.2]

The following provides a listing of the critical experiment benchmarks identifiers used in this scoping study:

mct001-01
mct001-02
mct001-03
mct001-04
mct004-01
mct004-02
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p3314bs3
p3314bs4
p3602bs1
p62ft231
p71f14f3
p71f14v3
p71f14v5
p71f214r
pat80ss1
pat80ss2
pat80l1
pat80l2

The experimental descriptions were taken from the following references.

Identifier	Reference
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mmf	1
mst	1
pcm	1
pmf	1
nse	3
bnwl	4
pu	2
lct	1
hmf	1
hmm	1
pci	1
p3	5
p6	5
p7	5
pat	5

1. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA Nuclear Science Committee of the Organization for Economic Co-operation and Development, NEA/NSC/DOC(95)03, September 2001 Edition.

2. S. R. Bierman and E. D. Clayton, “Critical Experiments with Low-Moderated Homogeneous Mixtures of Plutonium and Uranium Oxides Containing 8, 15, and 30 wt% Plutonium,” *Nucl. Sci. Eng*. **61**, 370–376 (1976).

3. S. R. Bierman and E. D. Clayton, “Critical Experiments to Measure the Neutron Poisoning Effect of Copper and Copper-Cadmium Plates,” *Nucl. Sci. Eng*., **55**, 58–66 (1974).

4. S. R. Bierman, B. M. Durst, and E. D. Clayton, *Critical Experiments Measuring the Reactivity Worths of Materials Commonly Encountered as Fixed Neutron Poisons*, BNWL2129, Battelle Pacific Northwest Laboratories, October 1976.

5. J. J. Lichtenwalter, S. M. Bowman, M. D. DeHart, and C. M Hopper, *Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages*, NUREG/CR-6361 (ORNL/TM-13211), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, March 1997.

The following graphics provide the results of the CANDE[B.3] and GLLSM[B.4] post processor codes for the sensitivity and uncertainty sequences (c_k represents the fraction of the variance in common between the benchmark and application systems due to cross sectional uncertainties). The CANDE code uses sensitivity data generated with SEN1 and/or SEN3 modules of a SCALE code system and the cross-section-covariance data to calculate integral parameters that give a measure of the similarity of a design system and a benchmark experiment. The linear fits of the computed benchmark k_{eff} values have been weighted by a cumulative normal distribution ranging from 1 at $c_k = 1.0$ to nearly 0.0 at $c_k = 0.0$ (assuming 5 standard deviations). The GLLSM code implements a generalized linear least squares methodology to predict the computational bias in a design system based on the difference in the computed and measured results of a suite of benchmark experiments.

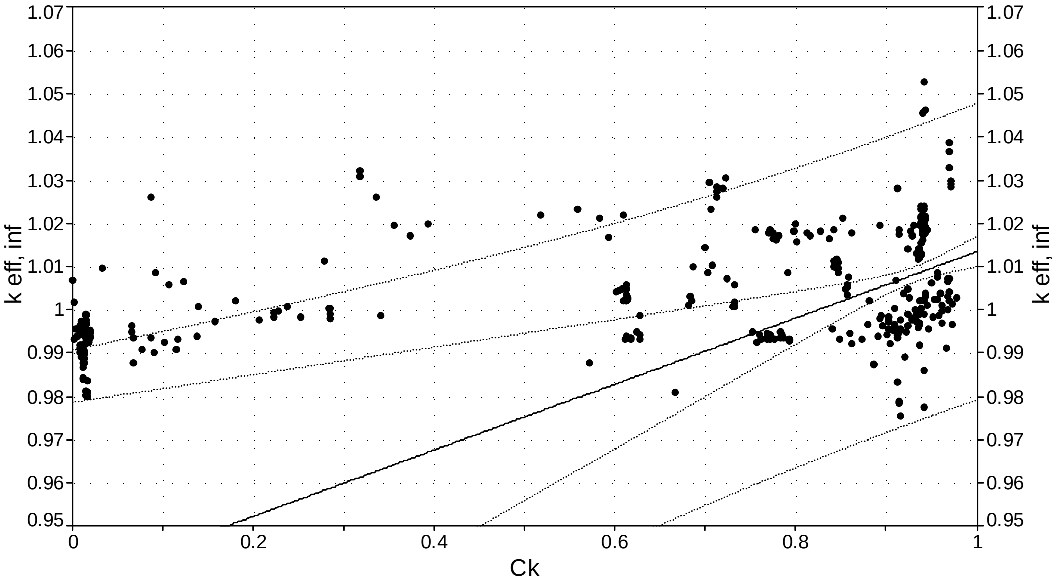

Fig. B.1. Infinite array of 55-gal. drums (Wtg 2), $k_{eff,\,inf}$ = 0.93688202 + 0.0766709107 c_k with 99% confidence intervals (GLLSM bias is +0.0184).

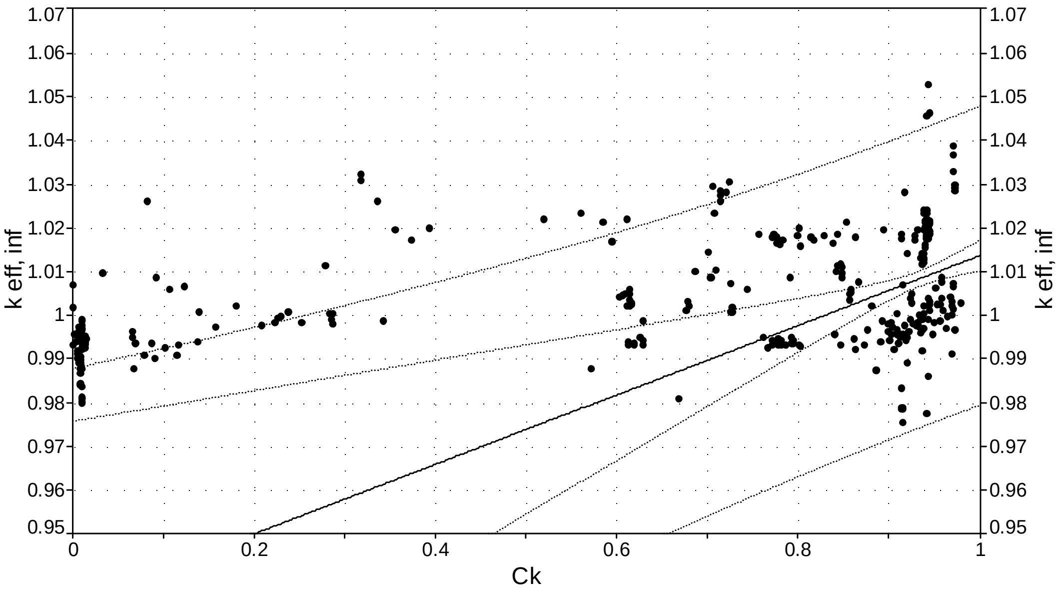

Fig. B.2. Infinite array of TRUPACT-IIs with 55-gal. drums (Wtg 2), $k_{eff,\ inf}$ = 0.93400378 + 0.079678288 c_k (GLLSM bias is +0.0181).

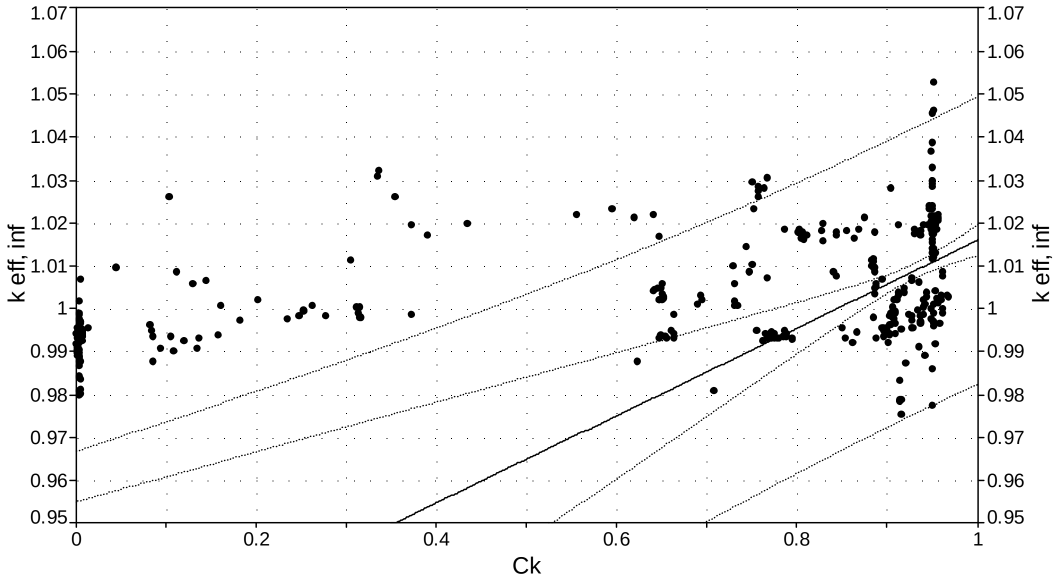

Fig. B.3. Infinite array of standard 6-in. POC (Wtg 2), $k_{eff,\ inf}$ = 0.91386737 + 0.1021443 c_k with 99% confidence intervals (GLLSM bias is +0.0159).

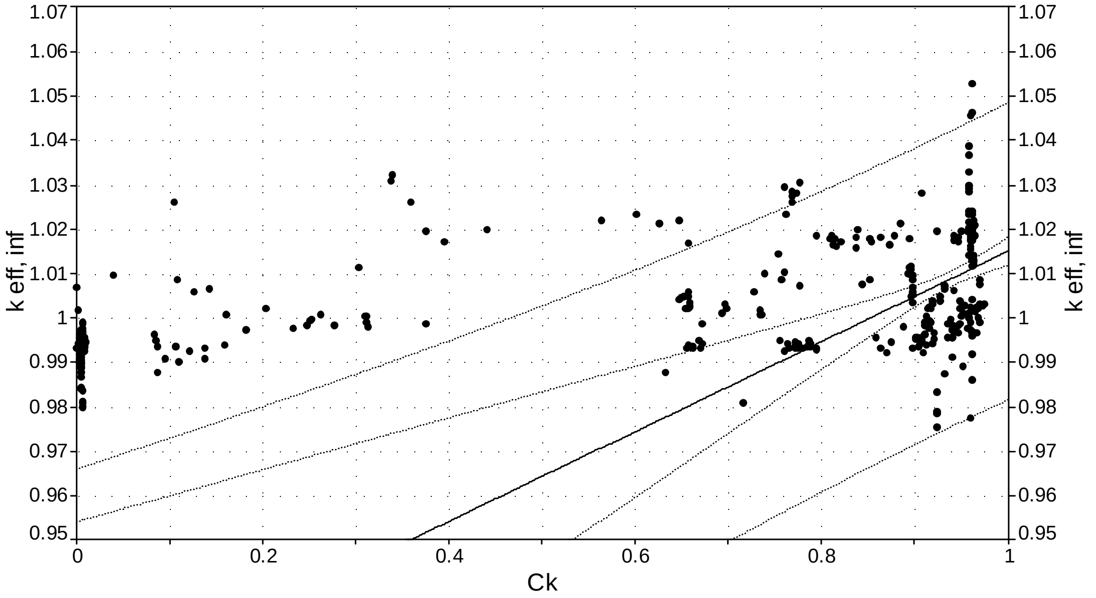

Fig. B.4. Infinite array of TRUPACT-IIs with standard 6-in. POC (Wtg 2), $k_{eff, inf}$ = 0.9134838 + 0.10164562 c_k with 99% confidence intervals (GLLSM bias is +0.0159).

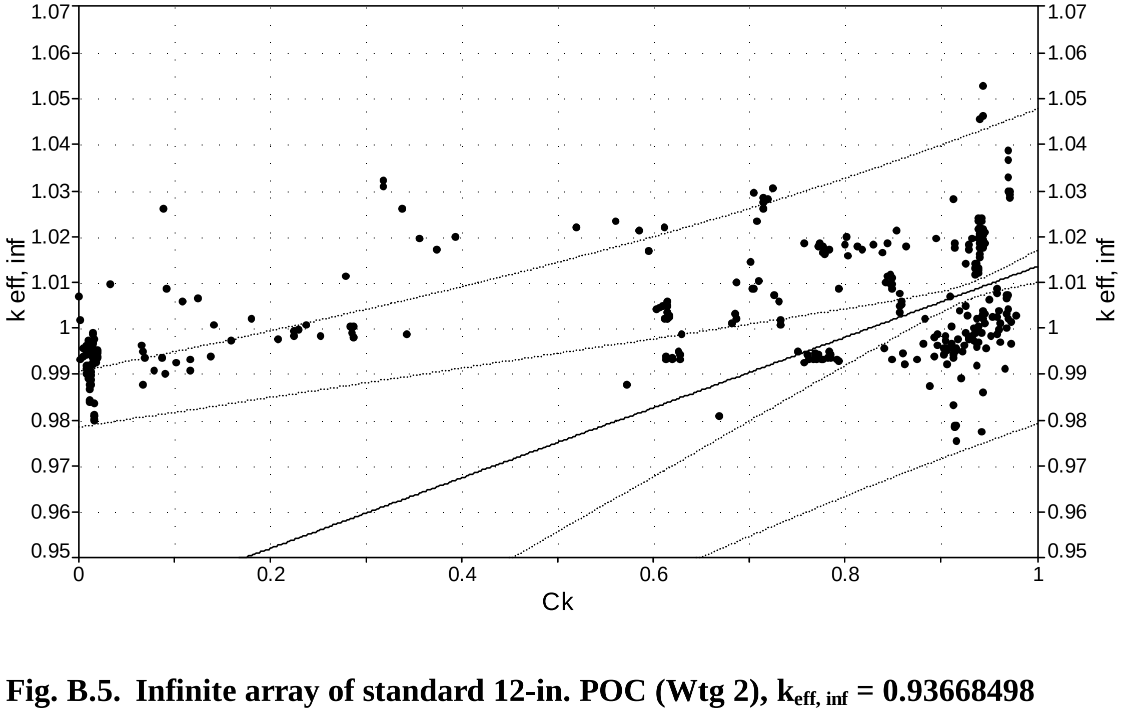

Fig. B.5. Infinite array of standard 12-in. POC (Wtg 2), $k_{eff, inf}$ = 0.93668498 +0.076873638 c_k with 99% confidence intervals (GLLSM bias is +0.0182).

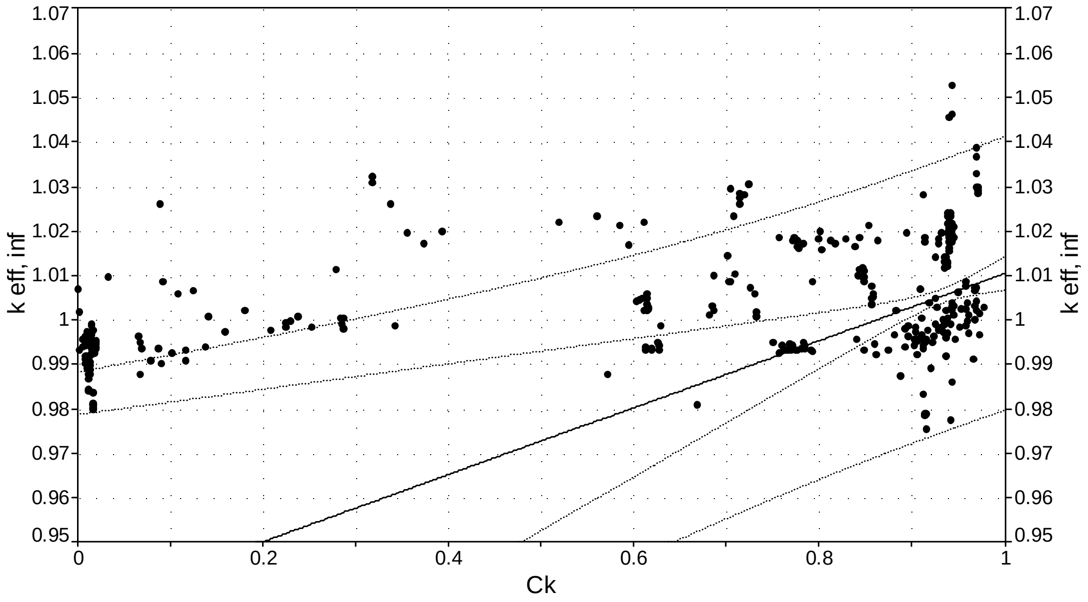

Fig. B.6. Infinite array of TRUPACT-IIs with standard 12-in. POC (Wtg 2), $k_{eff,\ inf}$ = 0.93496075 + 0.075550496 c_k with 99% confidence intervals (GLLSM bias is +0.0180).

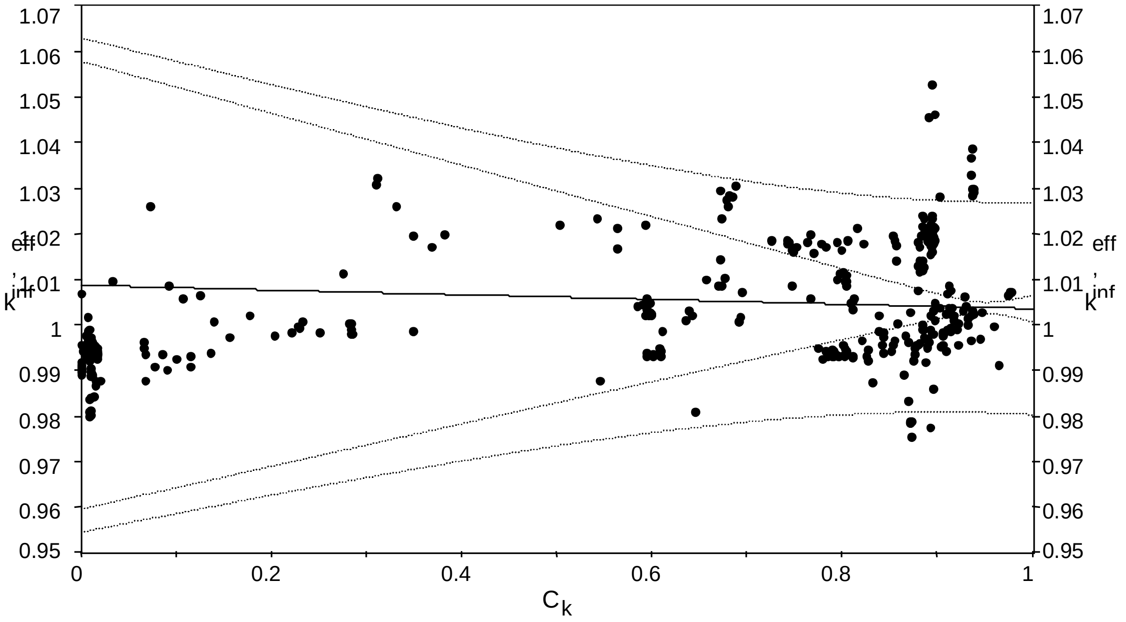

Fig. B.7. Infinite media with 0.0012 g ^{239}Pu/g Concrete waste @ 2.299 g/cc, $k_{eff,\ inf}$ = 1.0087326 – 0.0051582956 c_k with 99% confidence intervals (GLLSM bias is +0.0043).

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