ENCLOSURE 1

NEDO-33163

BWR OWNERS' GROUP: HIGH BURN UP BWR FUEL ROD GAP RELEASE FRACTIONS

GE Energy

NEDO-33163
Class I
October 2004
DRF 0000-0033-3193

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NEDC-33163
Class I
October 2004
NISYS-1145-TR002, R0
DRF 0000-0033-3193

BWR OWNERS' GROUP
HIGH BURN UP BWR FUEL ROD GAP RELEASE FRACTIONS

Developed for
BWR OWNERS' GROUP
Alternative Source Term Committee
By
KW Consulting, Inc.
for
NISYS Corporation

October 2004

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IMPORTANT NOTICE REGARDING THE CONTENTS OF THIS REPORT

Please Read Carefully

The only undertakings of the General Electric Company (GE) respecting information in this document are contained in the contract between the Boiling Water Reactor Owners' Group (BWROG) and GE, as identified in the respective utilities' BWROG Standing Purchase Order for the performance of the work described herein, and nothing in this document shall be construed as changing those individual contracts. The use of this information, except as defined by said contracts, or for any purpose other than that for which it is intended, is not authorized; and with respect to any unauthorized use, GE, nor any of the contributors to this document, makes any representation or warranty, express or implied, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

FOREWORD

To effectively utilize utility resources, the BWR Owners' Group (BWROG) sponsored the development of generic BWR fuel rod gap release fractions for high burnup fuel needed for nuclear plant alternative source term analyses.

The BWROG Alternative Source Term (AST) Committee selected NISYS Corporation as the primary contractor and KW Consulting, Inc. as the secondary contractor as they both had demonstrated extensive industry experience in the area of nuclear fuel source term analyses. This BWROG report is based on the NISYS report (NISYS-1145-TR002, Revision 0) contained herein.

The advantages for performing this work as a BWROG activity were deemed to be:

- Results can be applicable to a broad range of advanced BWR fuel & core designs[1],
- Consistency in values for all BWRs, and
- Cost leveraging (group savings) through the development of a single generic analyses for the BWR high burnup fuel gap release fractions.

1- BWR fuel, as described in this NEDO-33163NP, includes GE, Framatome and ABB BWR fuel designs.

PARTICIPATING UTILITIES

The utilities listed below contributed to the development of this report. However, while this report has been endorsed by a substantial number of the members of the BWR Owners' Group, it should not be interpreted as a commitment of any individual member to a specific course of action. Each member must formally endorse the results described in this BWROG report in order for those results to become applicable to that member.

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QUALITY ASSURANCE

Report NISYS-1145-TR002, Revision 0, was prepared by KW Consulting, Inc. but verified under the NISYS Corporation Quality Assurance (QA) program, which meets the applicable requirements of 10 CFR 50, Appendix B. The NISYS QA program was audited by General Electric Nuclear Energy on October 3, 2000 and was approved as a qualified contractor for performing this BWROG work.

NEDC-33163
Class I
October 2004
NISYS-1145-TR002, R0
DRF 0000-0033-3193

NISYS REPORT-1145-TR002, Revision 0

HIGH BURNUP BWR FUEL ROD GAP RELEASE FRACTIONS

Prepared by
KW Consulting, Inc.
for
NISYS Corporation

for

BWR OWNERS' GROUP

September 2004

(Since the NISYS Report-1145-TR002, Revision 0 has been embedded in this BWROG NEDO-33163NP report, no modifications have been made to Report 1145-TR002, including the report headers)

NISYS-1145-TR002/R0

High Burnup BWR Fuel Rod Gap Release Fractions

September 2004

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SAFETY-RELATED DOCUMENT

APPROVALS

NISYS-1145-TR002/R0

September 2004

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Revision History	
Revision Level	Summary of Change(s)
0	Original Issue

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ACROYNMS

ABB	Asea Brown Boveri
BOL	Beginning of Life
BWR	Boiling Water Reactor
EOL	End of Life
GE	General Electric
GWd/MTU	Gigawatt-day/Metric Ton Uranium
LHGR	Linear Heat Generation Rate
LOCA	Loss of Coolant Accident
NRC	Nuclear Regulatory Commission

1. INTRODUCTION

The current NRC approved gap release fractions for non-LOCA events, Table 3 of Reference [1], are contingent on a maximum linear heat generation rate below 6.3 kW/ft peak rod average power for rod burnups exceeding 54 GWd/MTU, and are not defined for rod burnups exceeding 62 GWd/MTU. Many BWR plants, however, are projecting rod power levels that will exceed these limitations in the near future. This report gives the results of gap release fraction calculations based on conservative BWR peak rod power histories that reasonably bound the currently anticipated fuel rod powers throughout life.

Consistent with Table 3 of Reference [1], gap release fraction results have been obtained for the Kr-85 and I-131 isotopes, other noble gases, other halogens and alkali metals. The gap fractions have been obtained using the FRAPCON-3 fuel rod performance code and the methodology described in Section 2.2 of Reference [2], consistent with the current gap fractions in Reference [1].

The gap release fractions have been calculated for the spectrum of fuel designs currently in use, or planned for future use, in domestic BWR plants to obtain conservative bounding BWR gap release fractions. Both full-length and part-length rods have been evaluated to obtain bundle-average gap release fractions for the following BWR fuel designs:

- GE 8x8
- GE11/13 9x9 (full- and part-length rods)
- Framatome ATRIUM-9 9x9
- GE12/14 10x10 (full- and part-length rods)
- Framatome ATRIUM-10 10x10 (full- and part-length rods)
- ABB SVEA-96/96+
- ABB SVEA-96 Optima2 (full- and part*-length rods)

Gap release fractions have been calculated from BOL through to EOL (65 GWd/MTU for full-length rods, 58 GWd/MTU for part-length rods) for all these BWR fuel designs.

* The SVEA-96 Optima2 fuel design contains part-length rods with fuel stack heights approximately two-thirds and one-third the length of the full-length rod stack heights. The part-length rods for the other fuel designs have fuel stack heights approximately two-thirds the length of the full-length rod stack heights. For the purpose of calculating the source term from the gap release fractions, the SVEA-96 Optima2 one-third length rods have been conservatively treated as if they were SVEA-96 Optima2 two-thirds length rods.

2. GEOMETRY, FABRICATION AND OPERATING CONDITIONS

The fuel rod design and operating condition inputs required for the FRAPCON-3 gap release fraction analyses are the fuel rod geometry (fuel and cladding dimensions, plenum length, etc.) and fabrication parameters (fuel density, fuel densification, as-fabricated fill gas pressure and composition, etc.), the plant operating conditions (coolant system pressure, inlet temperature and flow rate), the fast flux, and the rod power history and axial power distributions as a function of time.

2.1 FUEL ROD GEOMETRY

The fuel rod geometry and fabrication data for each of the fuel rod designs have been provided by the BWR fuel vendors, and generic bounding values have been used for the plant operating conditions.

2.2 FUEL ROD POWER HISTORIES

This evaluation has used fuel rod power histories that reasonably bound expected fuel operation to high burnups and the power histories used in the Reference [2] analyses. The power histories are given as a continuous sequence of straight line segments. Different conservative peak rod power histories have been used for each of the fuel rod designs, as follows:

- 8x8 and 9x9 full length rods: 10.3 kW/ft from 0 to 18 GWd/MTU, linearly decreasing to 6.6 kW/ft at 65 GWd/MTU
- 10x10 full length rods: 9.6 kW/ft from 0 to 22 GWd/MTU, linearly decreasing to 7.05 kW/ft at 65 GWd/MTU
- 9x9 part length rods: 11.6 kW/ft from 0 to 19.5 GWd/MTU, linearly decreasing to 7.71 kW/ft at 68 GWd/MTU
- 10x10 part length rods: 10.2 kW/ft from 0 to 19.5 GWd/MTU, linearly decreasing to 7.59 kW/ft at 68 GWd/MTU

These bounding fuel rod power histories are shown in Figures 2.1 and 2.2. These rod-average power histories were developed to bound actual BWR rod powers and exposures and consequently may exceed the vendor's licensed rod power or exposure limits.

2.3 AXIAL POWER SHAPES

The fuel rod axial power shapes used in this evaluation have been defined by using bounding limit curves for the rod local powers as a function of rod local exposure. The axial power shapes cycle from bottom-peaked at the beginning of cycle to mid-peaked in the middle of each cycle to top-peaked at the end of the cycle. Eighteen month cycles, typical of current BWR operation, have been assumed to determine the cycling from bottom- to mid- to top-peaked axial power shapes. Chopped cosine axial power shapes, with a peak-to-average ratio of 1.40, define a set of base bottom-peaked, mid-peaked and top-peaked axial power shapes for the full-length rods. Corresponding base axial power shapes for the part-length rods are defined so that the part-length rod local powers are the same as the adjacent full-length rod local powers. The axial power shapes at any time in the rod's history are then obtained by a linear transformation of these base axial power shapes such that the rod local powers are all bounded by the applicable local power limit curve, with at least one local power at the local power limit. The results for 18 month fuel

cycles will bound those for 24 month fuel cycles since an 18 month cycle would have more frequent axial power shape cycles.

The local power limit curves used in this analysis are based on bounding or actual local LHGR design limits for each fuel type. The local power limit curves are defined as a continuous sequence of straight line segments. The following local power limit curves have been used to calculate the gap release fractions:

- GE 8x8 and 9x9 fuel: 14.4 kW/ft from 0 to 15 GWd/MTU, linearly decreasing to 12.7 kW/ft at 36 GWd/MTU, linearly decreasing to 8.9 kW/ft at 70 GWd/MTU, and 8.9 kW/ft for rod local exposures above 70 GWd/MTU
- ATRIUM-9 9x9 fuel: 14.4 kW/ft from 0 to 15 GWd/MTU, linearly decreasing to 7.9 kW/ft at 64.3 GWd/MTU, and 7.9 kW/ft for rod local exposures above 64.3 GWd/MTU
- All 10x10 fuel: linearly decreasing from 14.0 kW/ft at 0 GWd/MTU to 13.7 kW/ft at 15 GWd/MTU, linearly decreasing to 9.1 kW/ft at 55 GWd/MTU, linearly decreasing to 8.0 kW/ft at 63.5 GWd/MTU, linearly decreasing to 6.985 kW/ft at 70 GWd/MTU, and 6.985 kW/ft for rod local exposures above 70 GWd/MTU

These local power limit curves are shown in Figure 2.3. These local power histories were developed to match or bound licensed LHGR limits and consequently may exceed the vendor's licensed LHGR limits.

2.4 GAMMA HEATING

The bounding rod average power histories and the local power limit curves are given in terms of linear heat generation rates, i.e., include both the energy deposited in the fuel rods and the heat generated in the coolant and core structural materials due to gamma heating. The rod power inputs used by the FRAPCON-3 code are the energy deposited in the fuel rod. A gamma heating factor of 4%, based on design data provided by the fuel vendors, has been used to convert the linear heat generation rates shown in Figure 2.1, Figure 2.2 and Figure 2.3 to the energy deposited in the fuel pellets.

2.5 ROD EXPOSURES

The peak fuel rod exposures have been increased from the 62 GWd/MTU considered in the previous analyses in Reference [2]. This evaluation extends the fuel rod burnups to 65 GWd/MTU for the full-length rods and 68 GWd/MTU for the part-length rods.

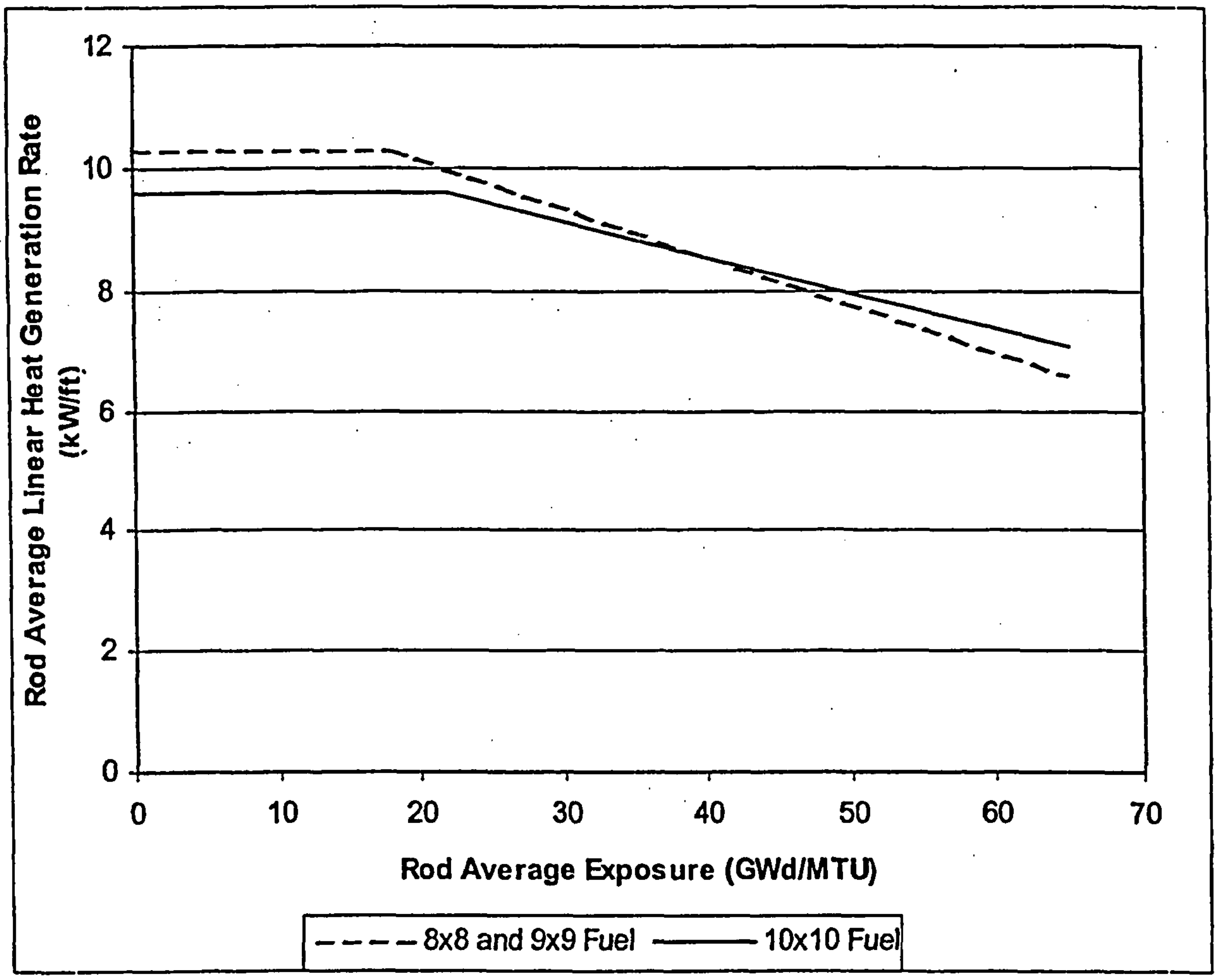

Figure 2.1 Full-length rod bounding rod power histories.

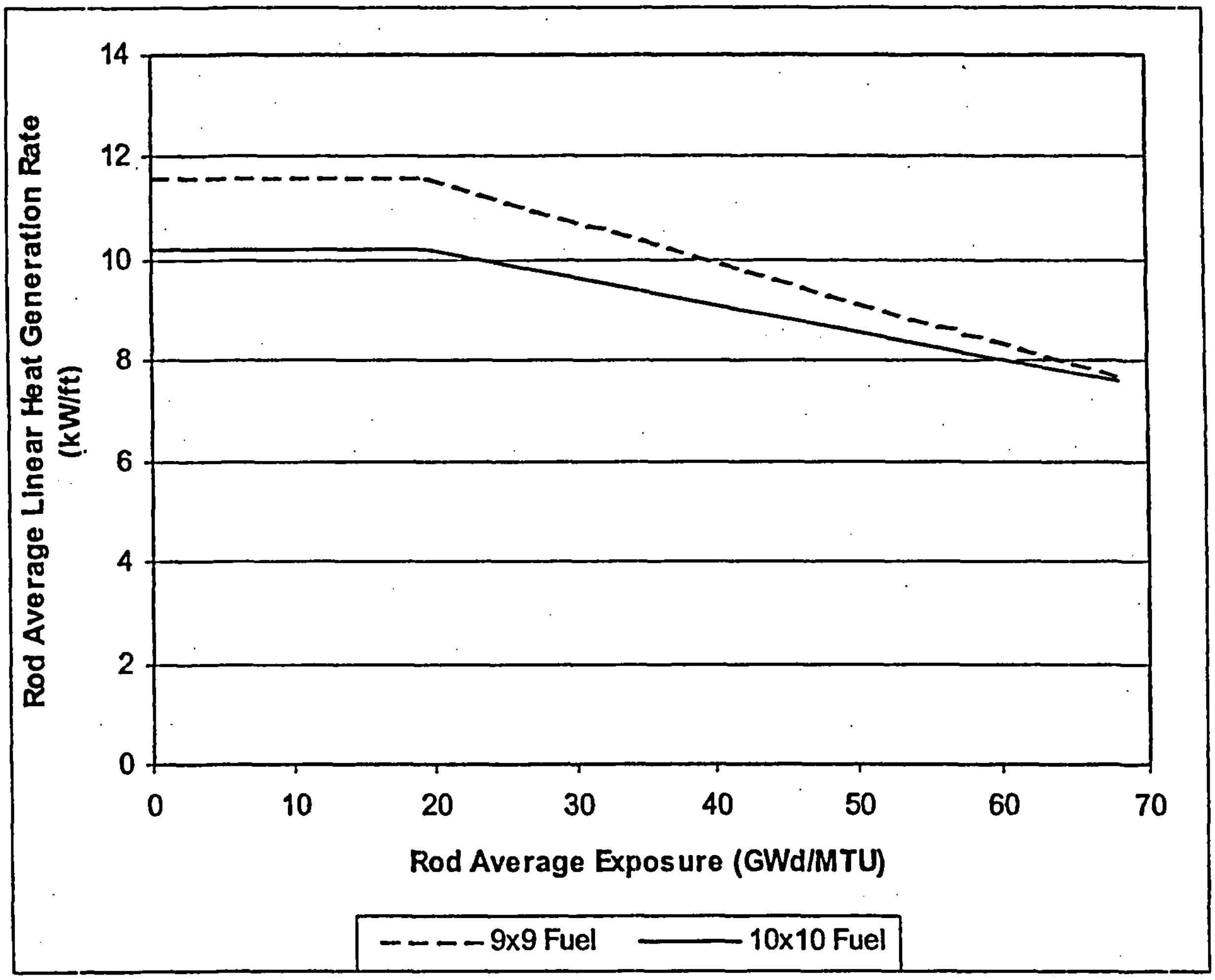

Figure 2.2 Part-length rod bounding rod power histories.

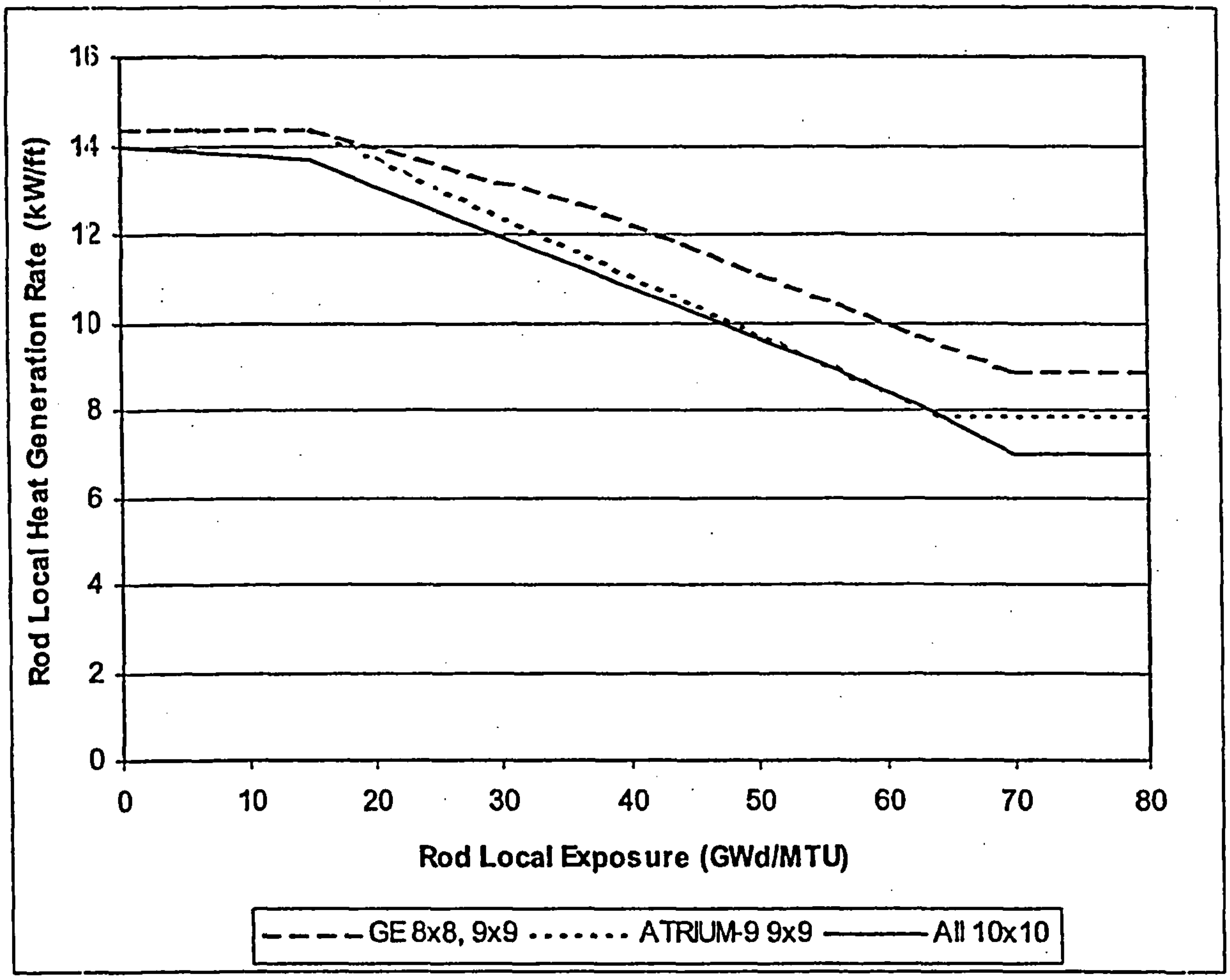

Figure 2.3 Bounding rod local power limit curves.

3. GAP RELEASE FRACTION ANALYSIS METHODOLOGY

The methodology for the calculation of the gap release fractions is the same as that described in Section 2.2 of the NRC's most recent environmental assessment of the effects of extending nuclear reactor peak rod fuel burnup above 60 GWd/MTU [2]. This methodology does not consider fuel rod fabrication variability and fuel rod performance model uncertainties.

The gap fractions have been calculated using the FRAPCON-3 fuel rod performance computer code [3,4,5], which has two fission gas release models (i) the ANS-5.4 model [6] and (ii) the Massih model [3,7]. The ANS-5.4 model calculates the fuel rod gap fractions for the stable and radioactive isotopes of the noble gases xenon and krypton, and for the radioactive isotopes of iodine and cesium. The Massih model calculates the fuel rod gap fractions only for the stable noble gases.

The ANS-5.4 model has not been verified against a large database of high burnup UO_2 fuel rod gas release data, and it tends to over-predict the gap fractions when used with the FRAPCON-3 code, in part because the constants used in the ANS-5.4 model are based on a fuel rod thermal model which did not account for the high burnup degradation of the fuel thermal conductivity. The constants used in the Massih model are based on the FRAPCON-3 fuel rod thermal model, which does account for the high burnup degradation of the fuel thermal conductivity. The Massih model has been used in the assessment of the FRAPCON-3 code against high burnup UO_2 fuel rod stable fission gas release data [5].

Due to this difference in the basis of the two FRAPCON-3 models for the calculation of the gap fractions, the Reference [2] methodology to calculate the gap fractions for the radioactive isotopes is to calculate the gap fractions for the stable noble gases with both the Massih and ANS-5.4 models, and to scale the ANS-5.4 model values for the gap fractions of the radioactive isotopes by the ratio of the Massih to the ANS-5.4 stable gas gap release fractions. This methodology eliminates some of the excess conservatism of the radioactive isotope gap release fractions obtained by using the ANS-5.4 gas release model in the FRAPCON-3 code.

The ANS-5.4 model for the gap release fractions of the radioactive isotopes is valid only for time periods of essentially constant operating conditions. The ANS-5.4 model can therefore be used to calculate the gap release fractions of the short-lived isotopes, Kr-87, Kr-88, Xe-133, Xe-135, I-131, I-133 and I-135, which all have a half-life of less than approximately 8 days. The gap release fractions for the long-lived isotopes, Kr-85, Cs-134 and Cs-137, which have a half-life of two years or more, are conservatively bounded by using the gap release fractions for the stable isotopes. For Kr-85 the gap release fraction is then given by the Massih model gap release fraction for the stable noble gases. Since the ANS-5.4 model diffusion constant for the Cesium isotopes is double that for the stable noble gases, the Cs-134 and Cs-137 gap release fractions have been calculated by modifying the FRAPCON-3 Massih model to use a diffusion constant twice that used for the stable gas release calculations.

In addition, Reference [6] specifies that precursor effects should be accounted for in the calculation of the Xe-133 and Xe-135 gap fractions. This has been done by calculating the gap release fractions for the I-133 and I-135 isotopes, and using these gap release fractions to implement the Reference [6] Section 3.3 equations for the Xe-133 and Xe-135 gap release fractions.

The FRAPCON-3 code version used in the gap release fraction analyses is the FRAPCON-3KW Version 1.2 code. This code version is based on the FRAPCON-3 Version 1.3 code released by Pacific Northwest National Laboratories, with the addition of modifications that implement user convenience features, facilitate code software maintenance and provide simplified quality assurance traceability capabilities. In

addition the FRAPCON-3KW Version 1.2 code incorporates modifications, developed by KW Consulting, of the FRAPCON-3 Version 1.3 subroutine for the calculation of the ANS-5.4 gap fraction results. These modifications eliminate excessive conservatism in the FRAPCON-3 calculation of the radioactive isotope gap release fractions and revise the output format for the gap release fractions to one that is better suited for the specific isotopes of interest for this evaluation. The FRAPCON-3KW Version 1.2 code modifications to the gap release fraction calculations have been discussed with and evaluated by the Pacific Northwest National Laboratory personnel responsible for the FRAPCON-3 code development and maintenance.

4. GAP RELEASE FRACTION RESULTS

The gap release fractions have been obtained as a function of rod average exposure from BOL to EOL for the thirteen fuel rod designs. These gap release fraction results are given in Appendix A. Bundle average gap release fractions have been calculated from the Appendix A gap release fractions for the radioactive isotope categories given in Table 3 of Reference [1]. The bundle average gap fractions have been obtained by assuming that all rods in the bundle are at the same burnup and, for those bundle designs with part-length rods, weighting the contribution of the part-length rods by the relative fuel mass in the part-length rods compared with the full-length rods. In addition, for the bundle designs with part-length rods the gap release fractions are also given for a maximum bundle exposure obtained by assuming that the full-length rods are at a burnup of 65 GWd/MTU and the part-length rods are at a burnup of 68 GWd/MTU. The bundle average gap release fractions as a function of bundle average exposure are shown in Figure 4.1 through Figure 4.15. The maximum values of the gap release fractions at any time in life are summarized in Table 4.1 for each of the fuel bundle designs.

Also shown in Figure 4.1 through Figure 4.15 are bounding curves for the gap release fractions as a function of bundle average exposure. These bounding curves are a sequence of continuous straight line segments. The parameters characterizing these bounding gap release fraction curves for each of the fuel rod designs are given in Table 4.2.

These results show that at all burnups the gap release fraction values for the GE12/14 fuel design are significantly less than those for the ATRIUM-10 and SVEA-96 fuel designs, even though the gap release fraction analyses for these 10x10 fuel designs have used the same bounding power histories and the fuel geometry for these designs are very similar. The source of this difference has been identified as the vendor values for the fuel and cladding surface roughness, which are approximately twice as large for the ATRIUM-10 and SVEA-96 fuel as for the GE12/14 fuel. This difference in the surface roughness results in larger effective fuel-cladding gaps, and therefore higher fuel temperatures, for the ATRIUM-10 and SVEA-96 fuel, compared with the GE12/14 fuel. The fuel temperature differences due to the differences in the surface roughness values are responsible for the differences between the gap release fractions for these fuel designs.

The behavior of the gap release fractions as a function of exposure is consistent with the temperature and burnup dependence of the gas diffusion constant D used in the ANS-5.4 and Massih fission gas release models:

$$D \propto 100^{Bu_{local}/Bu_{const}} e^{-Q/RT}$$

where Bu_{local} is the fuel local burnup and T is the absolute fuel local temperature, and Bu_{const} and Q are material constants specific to each of the gas release models. At low exposures the fuel temperatures are relatively constant, since the bounding rod average power and local power limits are relatively constant, and the diffusion constant increases rapidly with the increase in the local burnups. This results in the trend for the gap release fractions to increase with increasing exposure at low exposures. At moderate rod exposures the rod average power and local power limits, and therefore the fuel temperatures, decrease with increasing exposure. The decrease in the fuel temperatures tends to reduce the diffusion constant, and eventually compensates for and then outweighs the burnup dependence of the diffusion constant, resulting in first a saturation of the gap release fractions and then a decrease of the gap release fractions with increasing burnup. At high exposures, roughly above 55 – 60 GWd/MTU rod average exposure, the peak local exposures exceed the maximum values for the local power limit curves, where this analysis has conservatively assumed that there is no further decrease in the local power limits with increasing local

exposure. At these high local exposures, the peak local powers are constant and hence the peak local fuel temperatures are relatively constant. The gap release fractions then begin to increase again, as the burnup dependence of the diffusion constant again dominates the gap release fraction behavior.

In addition to the gap release fractions, rod pressures after a 24 hour hold after shutdown have also been calculated. The EOL shutdown pressures for all fuel rod designs are less than 905 psig. Since the rod internal pressure increases with increasing exposure, this EOL result for the rod pressures at shutdown conditions is bounding at all times in the fuel rod's life.

4.1 COMPARISON WITH PREVIOUS GAP RELEASE FRACTION RESULTS

The Reference [2] Table 2.4 BWR peak rod gap release fractions, given in Table 4.3, were calculated for an 8x8 BWR rod design. The corresponding gap release fractions for the GE 8x8 fuel rod design, from Appendix A Table A-1, are also given in Table 4.3. The comparison of these two sets of gap release fractions results shows that this high exposure fuel gap release fraction analysis gives:

- essentially the same gap release fractions for the Kr-87, Kr-88 and I-131 isotopes;
- approximately 100 – 200% higher gap release fractions for the Xe-133 and Xe-135 isotopes; and
- approximately 50 – 100% higher gap release fractions for the Kr-85, Cs-134 and Cs-137 isotopes.

However, the precursor effects that have been included in the Xe-133 and Xe-135 gap release fractions given in Table A-1 effectively double the gap release fractions for the Xe-133 isotope and triple the gap release fractions for the Xe-135 isotope, so that, without precursor effects, the 8x8 fuel rod gap release fractions for the short-lived isotopes (Kr-87, Kr-88, Xe-133, Xe-135 and I-131) are approximately the same in this analysis and in Reference [2], while the 8x8 fuel rod gap release fractions for the long-lived isotopes (Kr-85, Cs-134 and Cs-137) are approximately 50 – 100% higher in this analysis compared with Reference [2].

Figure 4.16 compares the 8x8 fuel rod average power history and peak local powers used in this gap release fraction analysis to high fuel exposures with those used in the Reference [2] analysis. This comparison shows that the two analyses have used approximately the same rod average powers and peak local powers for rod exposures below 20 GWd/MTU, but at higher exposures this high exposure analysis has used slightly higher rod average powers and significantly higher peak local powers. The difference in the peak local powers is sufficient to explain why gap release fractions for the long-lived isotopes, which are obtained from the FRAPCON-3 Massih model stable fission gas release results, are significantly larger in this analysis than in the Reference [2] analysis. However, this difference in the power histories is not consistent with the comparisons for the short-lived isotopes, for which the gap release fractions have been calculated with the ANS-5.4 gas release model. The result that there is relatively little difference between the short-lived isotope gap release fractions obtained in this analysis and those given in Reference [2] is therefore due to the FRAPCON-3KW Version 1.2 modifications to eliminate excessive conservatism in the FRAPCON-3 implementation of the ANS-5.4 model.

The same trends are seen in a comparison of the bundle average gap fractions given in Reference [1] Table 3 with the maximum bundle average gap fractions for the GE 8x8 fuel rod design obtained in this analysis. This comparison is given in Table 4.4, which shows that the results for the bundle average gap fractions for the long-lived isotopes (Kr-85 and the alkali metals) obtained in this analysis are approximately 75% larger than those given in Reference [1], those for the other noble gases (Kr-87,

Kr-88, Xe-133 and Xe-135) are approximately 100% higher, due to the inclusion of the precursor effects for the Xenon isotopes, and the results for the other short lived isotopes (I-131 and the other halogens) are comparable to those given in Reference [1].

4.2 GADOLINIA RODS

To optimize bundle performance while maintaining shutdown margin requirements, a small number of fuel rods in each BWR bundle may contain integral gadolinia, a strong neutron absorber. Although the gadolinia can adversely affect the rod thermal properties, the gadolinia rods operate at a lower power than their non-gadolinia counterparts. In addition, gadolinia rods:

- contain lower uranium enrichments than non-gadolinia rods,
- are placed in low power locations within the fuel bundle, and
- do not reach the elevated exposures of the non-gadolinia rods.

On these bases and consistent with the Staff's previous evaluation [2], gadolinia rods were not addressed in this evaluation and are considered bounded by the gap fractions calculated for non-gadolinia rods.

This conclusion is confirmed with recent field observations. Based on measurements of the Kr-85 inventories in the plena of high burnup BWR fuel rods, the gap fractions in the gadolinia rods were less than half those in nearby non-gadolinia rods [8].

4.3 CONSERVATISMS IN THE GAP RELEASE FRACTION RESULTS

The most significant conservatism in the calculation of the BWR fuel gap release fractions to high exposures is the assumption that the lead fuel operates at the bounding rod average and local power limits at all times in life. Though it is possible for a fuel rod to operate at these limiting power levels at some times during its life, it is extremely unlikely that it will operate at these limiting powers throughout its lifetime. In addition, plants generally operate with significant margin to the local power limits used in these calculations. These local power limits are the LHGR limits required by the plant Technical Specifications, which require reporting of any violations. Consequently, cores are generally designed with margins to the LHGR limits (typically ~10%) to avoid the generation of licensee event reports in the event of unexpected small power transients or small differences between predicted and actual core performance.

The assumption that the fuel rod operates at the bounding power levels at all times in life leads to an overestimation of the gap release fractions for the stable isotopes, and, through the degradation of the fuel-clad gap heat conductance by the stable fission gas isotopes, it results in higher fuel temperatures than will occur with realistic power histories for the BWR lead fuel rods. Through the temperature dependence of the diffusion constant, the radioactive isotope gap release fractions are very sensitive to the fuel temperatures, and therefore the assumption that the limiting fuel has operated at the bounding power levels at all times in life will also lead to conservatively high values for the gap release fractions for both the short- and long-lived isotopes.

This has been confirmed by an evaluation of the impact of using a bounding peak local power limit 10% below the Technical Specification LHGR limit for the GE12/14 full length 10x10 fuel rods. This 10% reduction in the local power limits gave a 40-50% reduction in the peak gap release fractions, confirming

the conservatism of the gap release fraction results given in this report, which have been based on the assumption that the fuel operates at the Technical Specification LHGR limits.

An additional conservatism is the assumption that all the fuel in the bundle operates at the same power as the peak rod in the bundle. Figure 4.17 shows the local peaking distribution in a typical BWR fuel bundle. This figure shows that nearly half the fuel rods in a typical BWR bundle operate at powers that are more than 10% below the peak rod in the exposure range where the peak gap fraction occurs, and hence the assumption that all the fuel in the bundle is at the same power as the peak rod gives a 40-50% factor of conservatism for the gap release fractions for more than half the rods in the bundle.

In addition, at high exposures the 10x10 fuel gap release fractions have been calculated using a conservative application of the bounding rod power histories and local power limit curves. In all the 10x10 fuel rod cases it has been found that, due to the axial burnup distribution in the fuel rod, at high exposures the 10x10 fuel bounding rod average power histories are conservatively inconsistent with 10x10 local power limit curves, in the sense that the local power limit calculated at the peak local burnup axial location is less than the bounding rod average power calculated at the rod average burnup. When this situation has been encountered, the FRAPCON-3 input used to obtain the 10x10 fuel gap release fractions has used the rod average power as given by the bounding rod average power curve and a flat axial power distribution. This conservative, but highly unrealistic, combination gives an axial power distribution that minimally exceeds the limits imposed by the local power limit curves while being consistent with the rod average power limit curves.

Other conservative assumptions in the calculation of the gap release fractions are that all the rods in the bundle have been assumed to have the same bounding peak rod average and local power history, with the axial peaking varied over the eighteen month cycles to maximize the gap release as a function of axial position in the rod, and that no credit has been taken for the reduced gap release fractions in the gadolinia rods. In addition, the ANS-5.4 gap release model assumption that the iodine and cesium diffusion coefficients are factors of 7 and 2, respectively, times greater than the diffusion coefficient for the noble gases xenon and krypton is not supported by recent release data [9,10], which show that the iodine and cesium diffusion coefficients are the same as the noble gas diffusion coefficients. The conservatism of the ANS-5.4 model is confirmed by results given in Reference [10], which indicate that the ANS-5.4 model overpredicts the I-131 gap release fractions by as much as a factor of 10. Though the scaling of the ANS-5.4 gap release fractions for the radioactive isotopes by the ratio of the stable gas release fractions obtained with the FRAPCON-3 Massih model and the ANS-5.4 model partially compensates for the overpredictions of the ANS-5.4 model, this recent data indicates there is still significant additional conservatism in the gap release fractions given in Table 4.1 and Figures 4.1 through 4.15.

Table 4.1. Maximum bundle average gap release fractions

Fuel Design	Gap Release Fractions				
	I-131	Kr-85	Other Nobles	Other Halogens	Alkali Metals
GE 8x8	0.100	0.173	0.097	0.051	0.217
GE11 9x9	0.092	0.167	0.081	0.043	0.217
GE13 9x9	0.093	0.167	0.081	0.043	0.218
ATRIUM-9	0.106	0.146	0.076	0.040	0.220
GE12 10x10	0.062	0.090	0.042	0.022	0.152
GE14 10x10	0.062	0.090	0.042	0.022	0.151
ATRIUM-10	0.083	0.121	0.055	0.029	0.201
SVEA-96/96+	0.080	0.103	0.054	0.029	0.183
SVEA-96 Optima 2	0.086	0.117	0.058	0.031	0.187

Table 4.2 Parameters characterizing the bounding gap release fraction curves

GE 8x8 and 9x9 Fuel Designs

I-131	Bundle Exposure (GWd/MTU)	0	15	68		
	Gap Release Fraction	0.0	0.10	0.10		
Kr-85	Bundle Exposure (GWd/MTU)	0	25	68		
	Gap Release Fraction	0.0	0.175	0.175		
Other Noble Gases	Bundle Exposure (GWd/MTU)	0	16	35	68	
	Gap Release Fraction	0.0	0.07	0.09	0.10	
Other Halogens	Bundle Exposure (GWd/MTU)	0	15	38	68	
	Gap Release Fraction	0.0	0.035	0.050	0.052	
Alkali Metals	Bundle Exposure (GWd/MTU)	0	9	30	68	
	Gap Release Fraction	0.0	0.15	0.22	0.22	

ATRIUM-9 Fuel Design

I-131	Bundle Exposure (GWd/MTU)	0	14	17	65	
	Gap Release Fraction	0.0	0.11	0.11	0.05	
Kr-85	Bundle Exposure (GWd/MTU)	0	19	45	65	
	Gap Release Fraction	0.0	0.15	0.15	0.125	
Other Noble Gases	Bundle Exposure (GWd/MTU)	0	15	65		
	Gap Release Fraction	0.0	0.08	0.045		
Other Halogens	Bundle Exposure (GWd/MTU)	0	15	30	65	
	Gap Release Fraction	0.0	0.041	0.037	0.020	
Alkali Metals	Bundle Exposure (GWd/MTU)	0	7	24	36	65
	Gap Release Fraction	0.0	0.17	0.225	0.22	0.18

GE 10x10 Fuel Designs

I-131	Bundle Exposure (GWd/MTU)	0	18	68		
	Gap Release Fraction	0.0	0.062	0.023		
Kr-85	Bundle Exposure (GWd/MTU)	0	18	34	44	68
	Gap Release Fraction	0.0	0.075	0.09	0.09	0.07
Other Noble Gases	Bundle Exposure (GWd/MTU)	0	18	68		
	Gap Release Fraction	0.0	0.043	0.017		
Other Halogens	Bundle Exposure (GWd/MTU)	0	18	68		
	Gap Release Fraction	0.0	0.023	0.009		
Alkali Metals	Bundle Exposure (GWd/MTU)	0	14	32	68	
	Gap Release Fraction	0.0	0.13	0.16	0.12	

ATRIUM-10 and SVEA-96 Fuel Designs

I-131	Bundle Exposure (GWd/MTU)	0	12	24	68
	Gap Release Fraction	0.0	0.086	0.086	0.036
Kr-85	Bundle Exposure (GWd/MTU)	0	14	32	68
	Gap Release Fraction	0.0	0.10	0.125	0.10
Other Noble Gases	Bundle Exposure (GWd/MTU)	0	13	25	68
	Gap Release Fraction	0.0	0.06	0.06	0.023
Other Halogens	Bundle Exposure (GWd/MTU)	0	13	25	68
	Gap Release Fraction	0.0	0.031	0.031	0.012
Alkali Metals	Bundle Exposure (GWd/MTU)	0	10	33	68
	Gap Release Fraction	0.0	0.18	0.205	0.15

Table 4.3 BWR 8x8 fuel rod gap release fractions

A – From Reference [2], Table 2.4

Rod Exposure (GWd/MTU)	Gap Release Fractions Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
43	1.0E-01	5.1E-03	7.2E-03	3.6E-02	1.4E-02	1.4E-01	1.4E-01	8.7E-02
50	8.9E-02	4.4E-03	6.3E-03	3.2E-02	1.3E-02	1.3E-01	1.3E-01	7.6E-02
60	7.9E-02	4.0E-03	5.6E-03	2.8E-02	1.1E-02	1.1E-01	1.1E-01	6.8E-02
62	7.9E-02	4.0E-03	5.6E-03	2.8E-02	1.1E-02	1.1E-01	1.1E-01	6.8E-02

B – From Appendix A, Table A-1

Rod Exposure (GWd/MTU)	Gap Release Fractions Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
43	1.6E-01	4.6E-03	6.8E-03	7.8E-02	3.7E-02	2.1E-01	2.1E-01	8.7E-02
50	1.6E-01	4.1E-03	6.1E-03	7.0E-02	3.3E-02	2.1E-01	2.1E-01	7.8E-02
60	1.6E-01	3.4E-03	5.1E-03	6.1E-02	2.8E-02	2.0E-01	2.0E-01	7.1E-02
62	1.6E-01	3.9E-03	5.8E-03	6.7E-02	3.2E-02	2.0E-01	2.0E-01	7.5E-02

Table 4.4. 8x8 bundle average gap release fractions

	Ref. [1] Table 3	This Analysis (maximums)
I-131	0.08	0.10
Kr-85	0.10	0.17
Other Noble Gases	0.05	0.10
Other Halogens	0.05	0.05
Alkali Metals	0.12	0.22

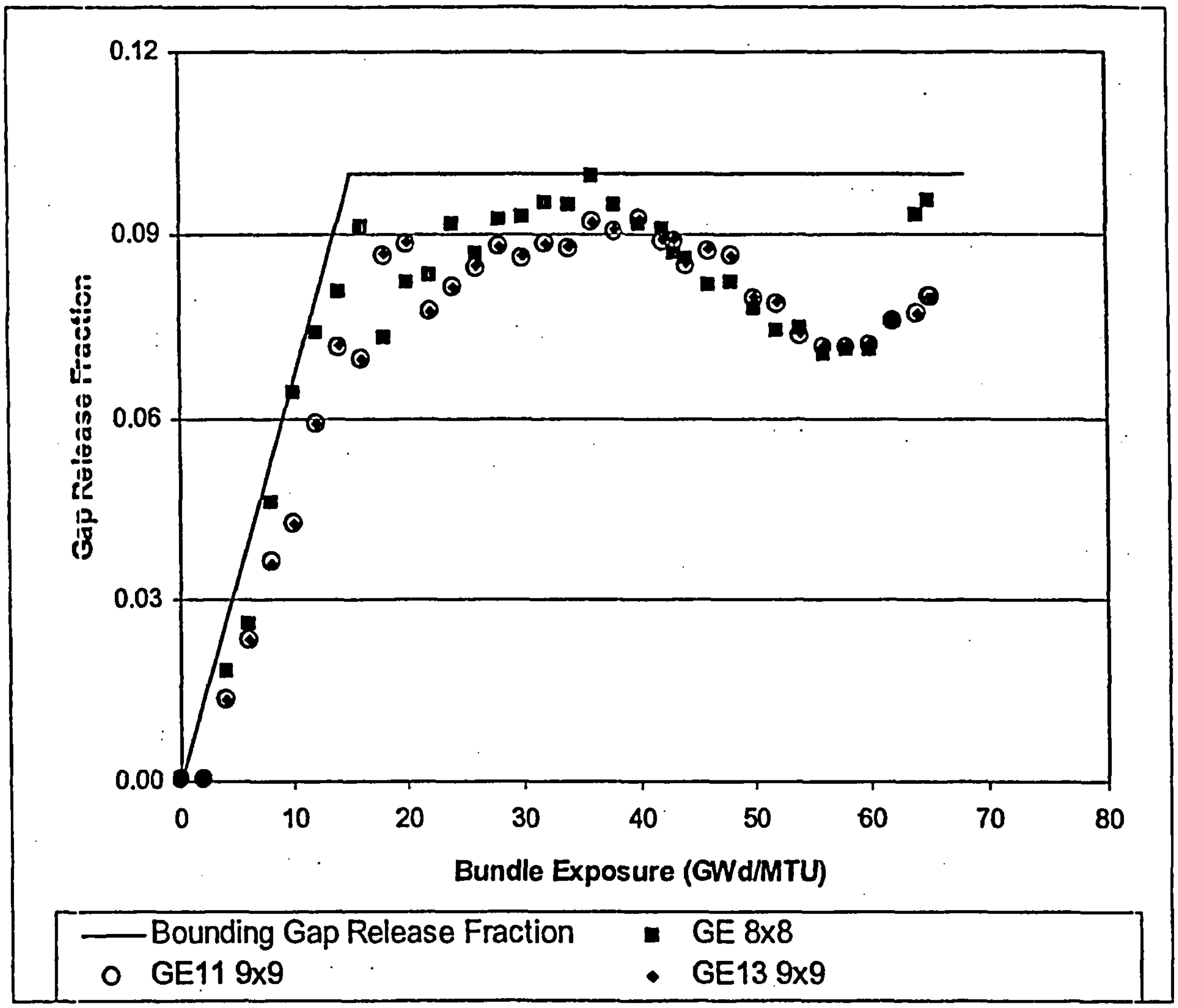

Figure 4.1 I-131 bundle average gap release fractions, GE 8x8 and 9x9 fuel designs.

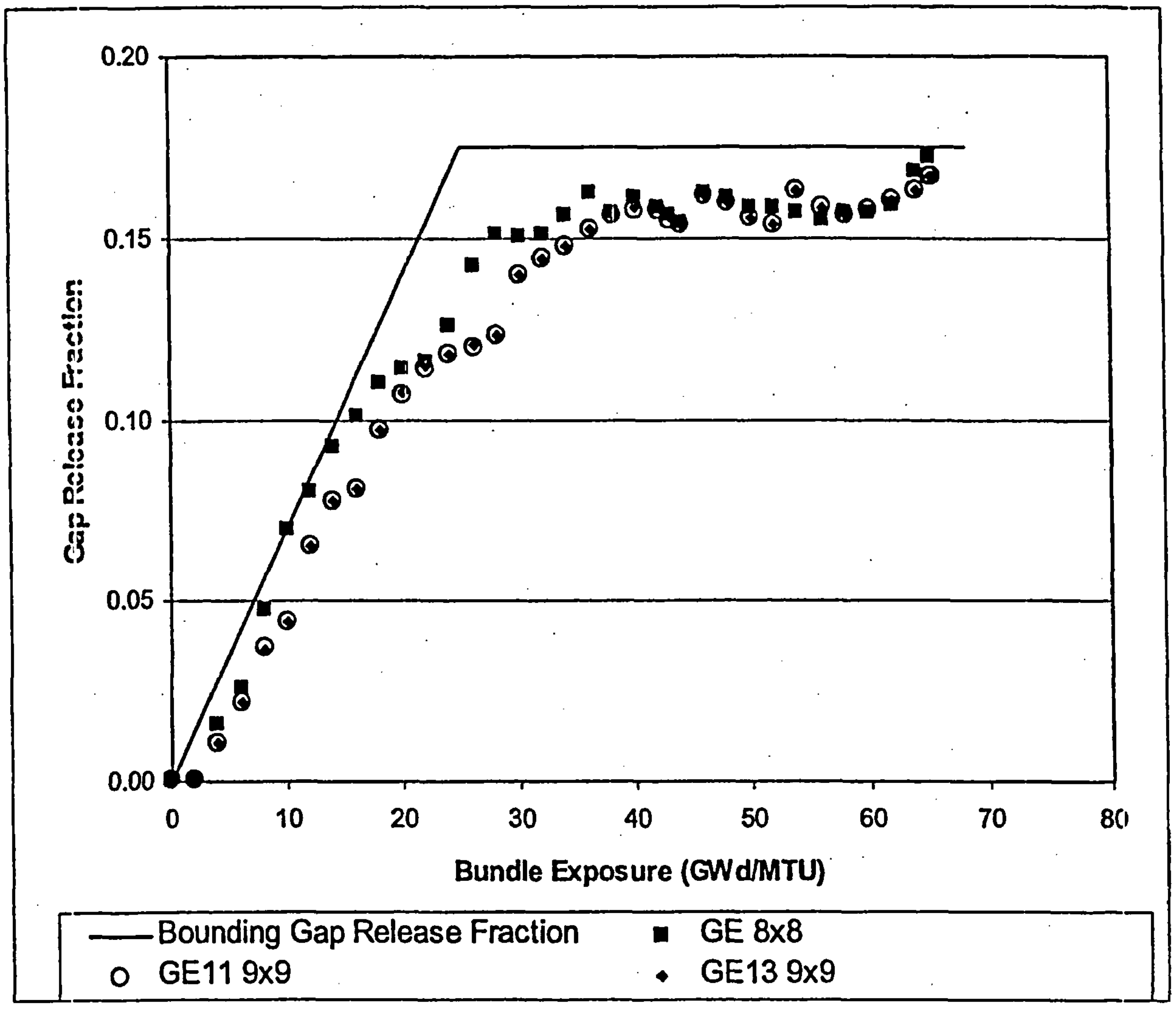

Figure 4.2 Kr-85 bundle average gap release fractions, GE 8x8 and 9x9 fuel designs.

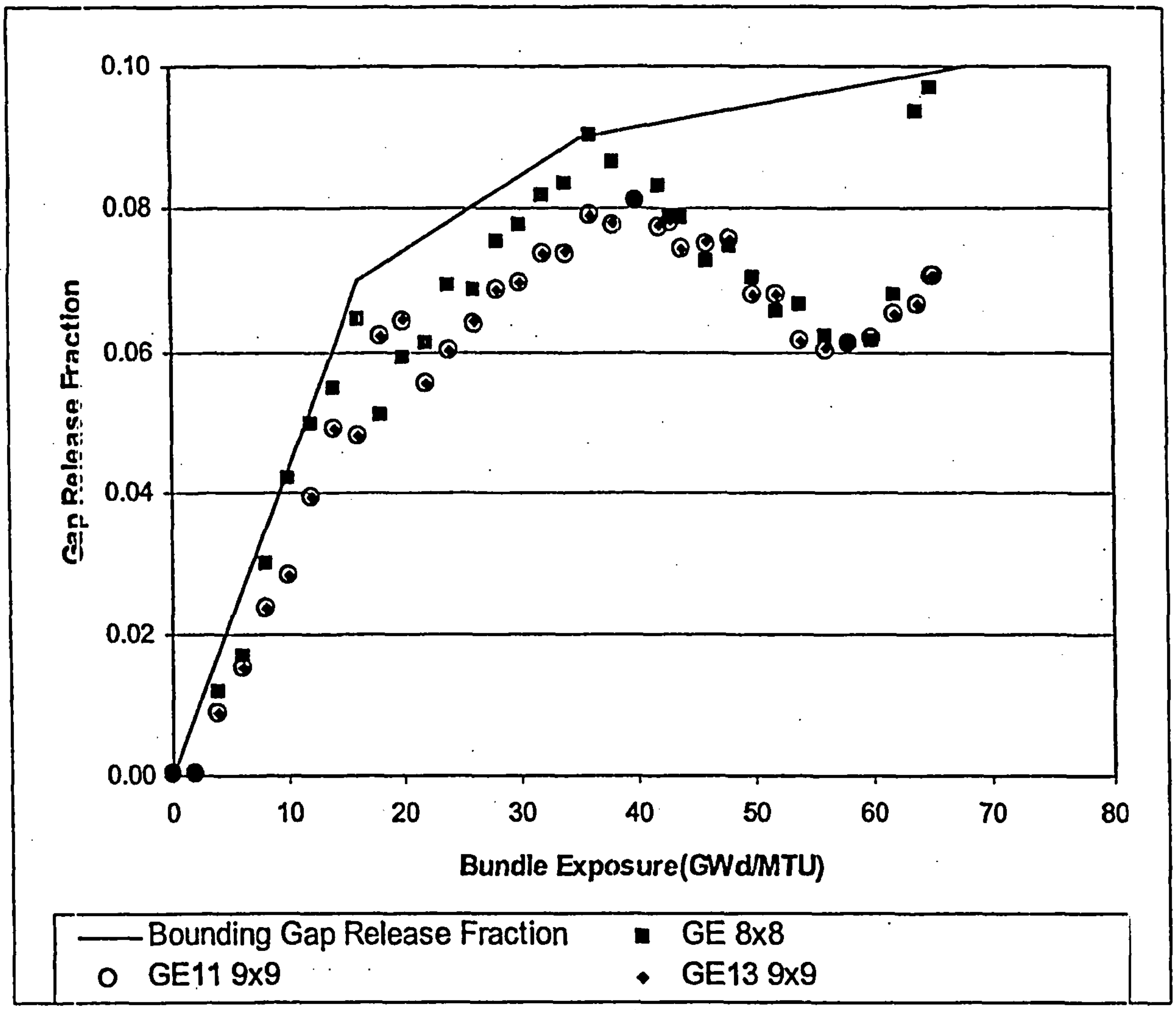

Figure 4.3 Other noble gas bundle average gap release fractions, GE 8x8 and 9x9 fuel designs.

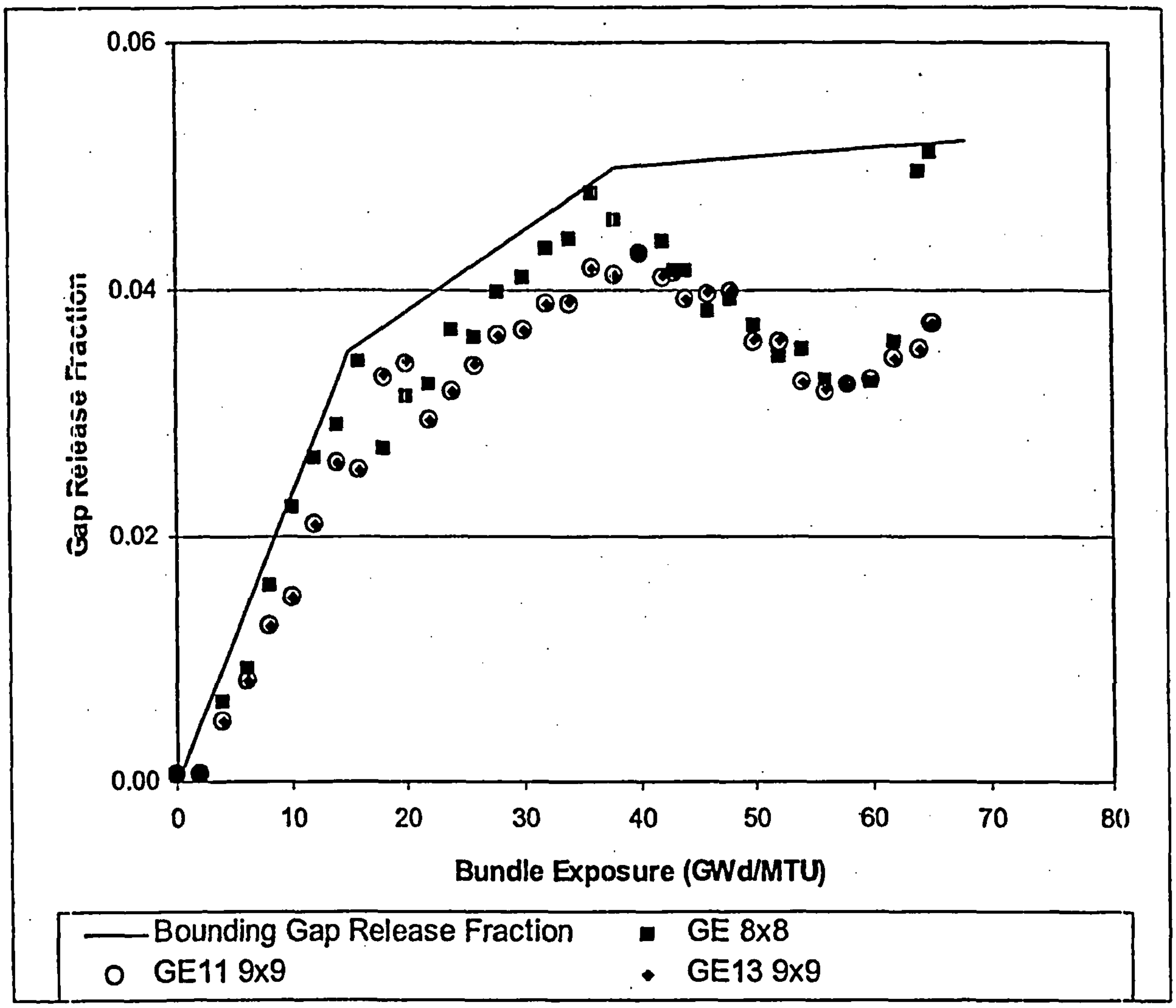

Figure 4.4 Other halogen bundle average gap release fractions, GE 8x8 and 9x9 fuel designs.

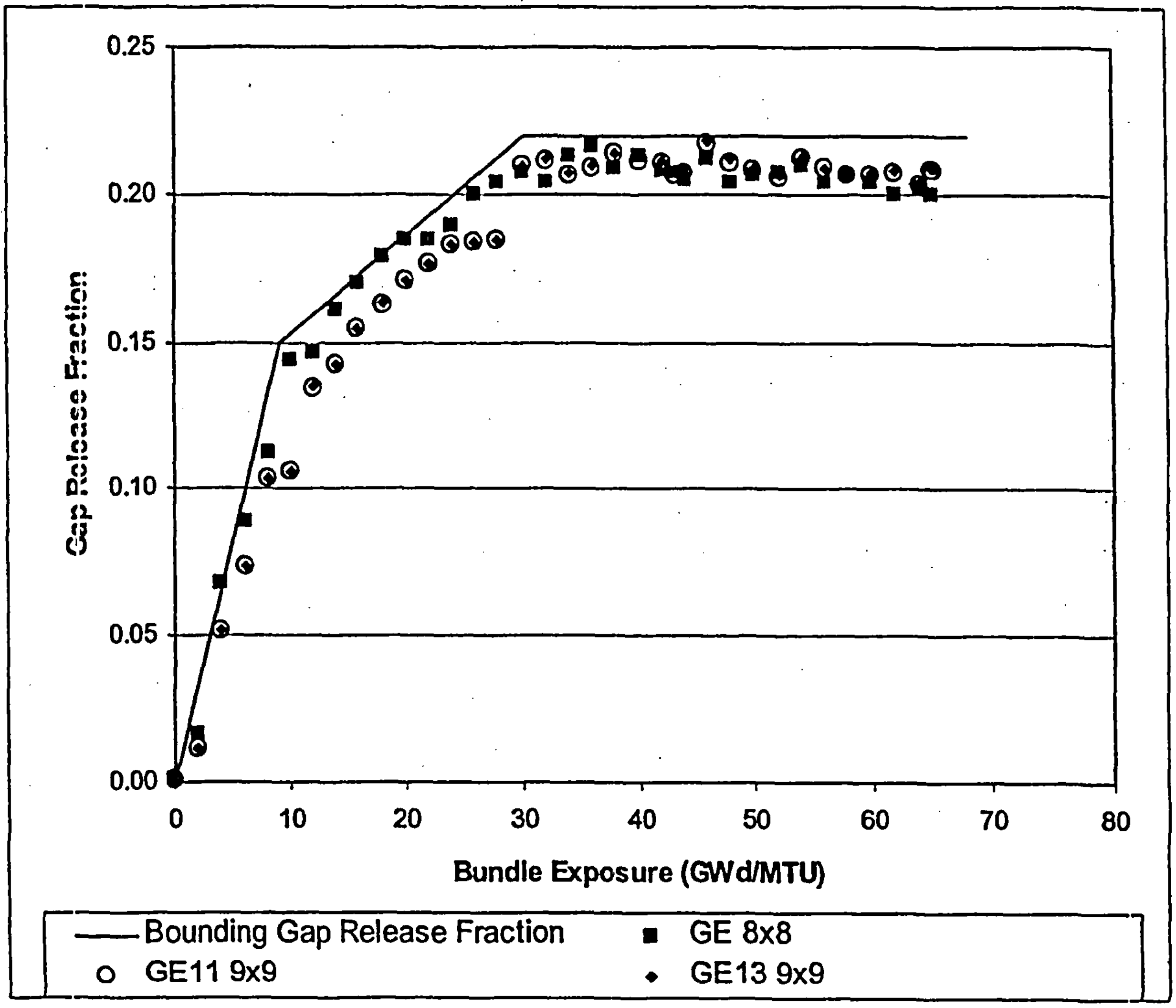

Figure 4.5 Alkali metal bundle average gap release fractions, GE 8x8 and 9x9 fuel designs.

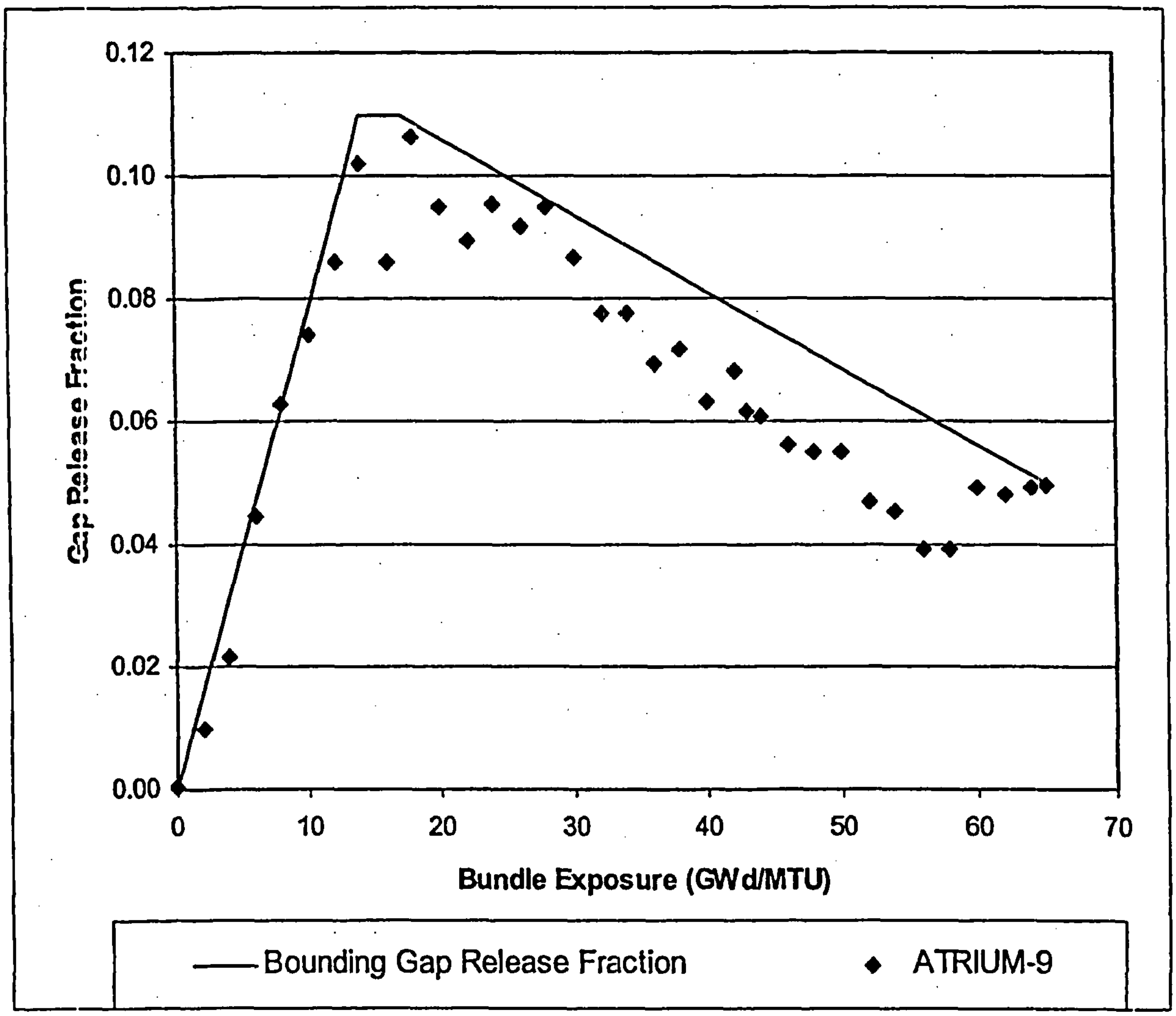

Figure 4.6 I-131 bundle average gap release fractions, ATRIUM-9 fuel design.

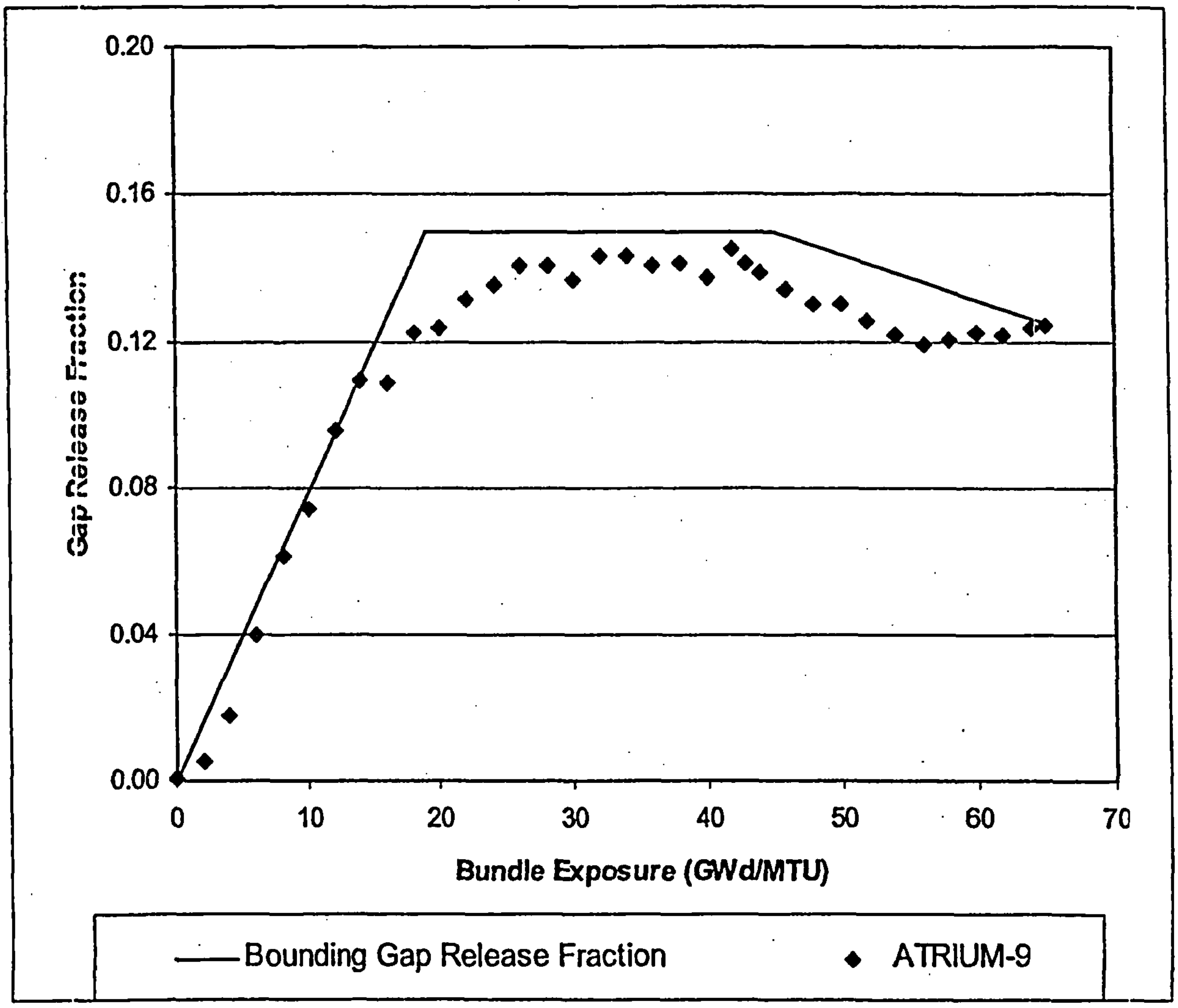

Figure 4.7 Kr-85 bundle average gap release fractions, ATRIUM-9 fuel design.

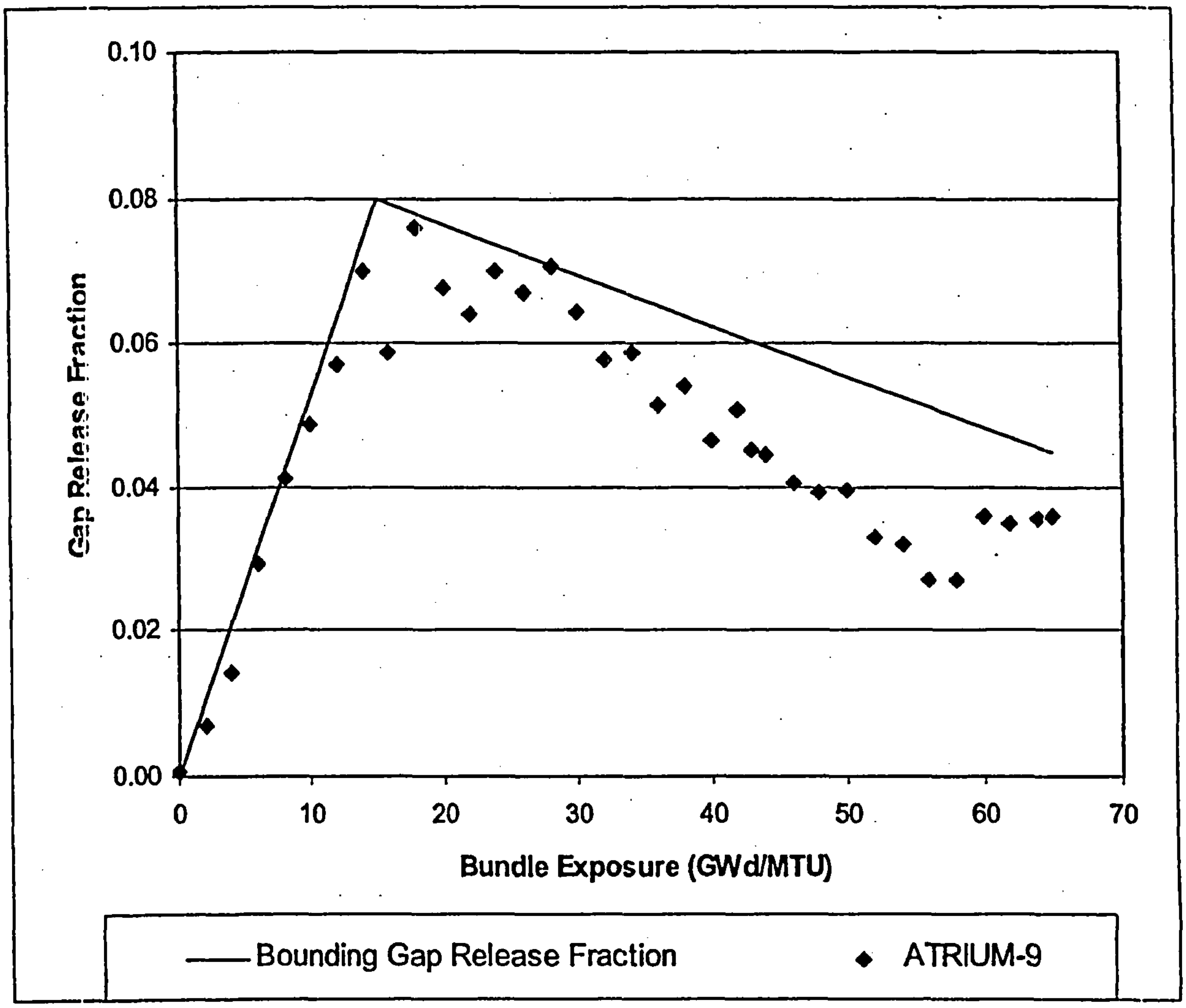

Figure 4.8 Other noble gas bundle average gap release fractions, ATRIUM-9 fuel design.

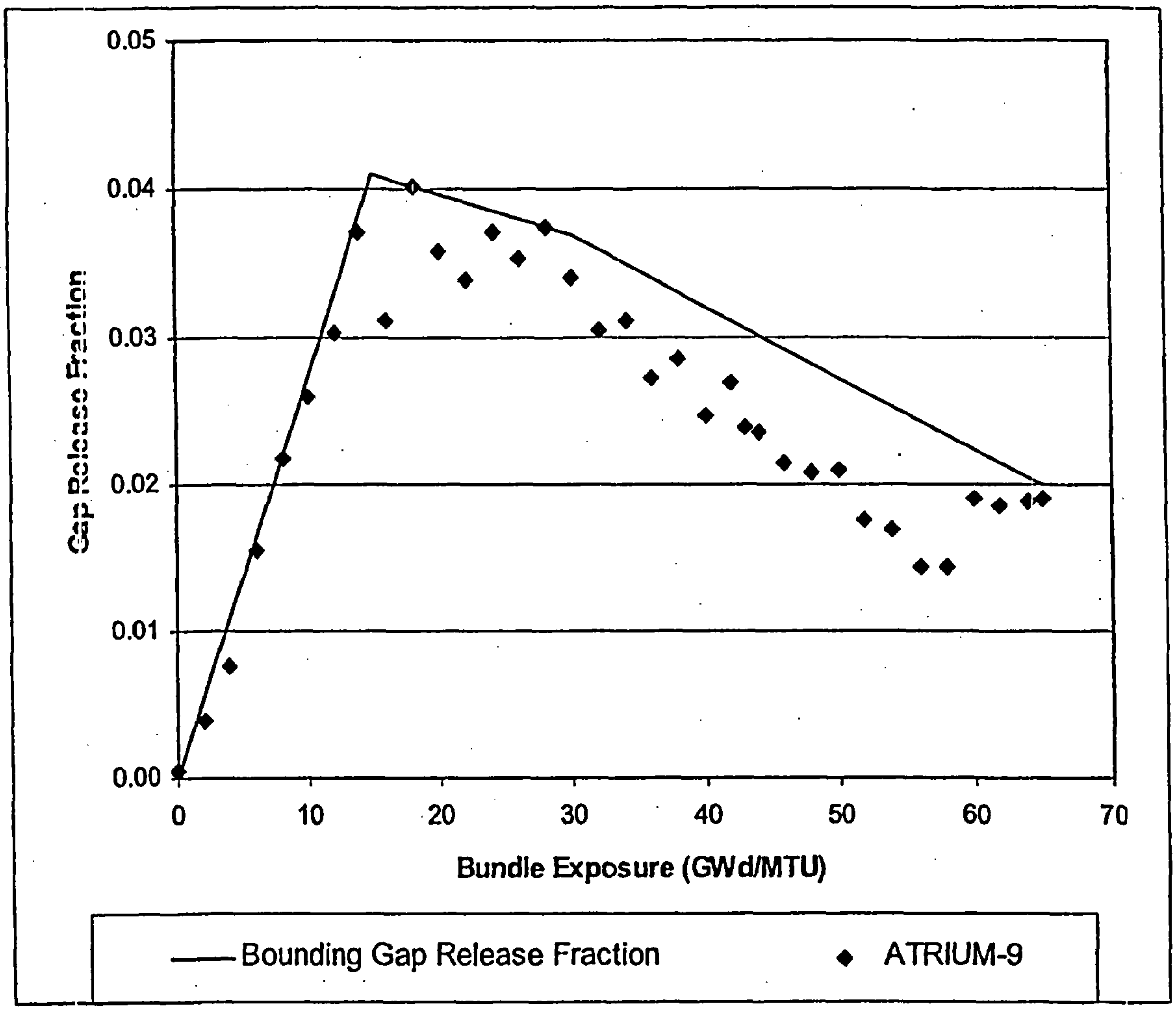

Figure 4.9 Other halogen bundle average gap release fractions, ATRIUM-9 fuel design.

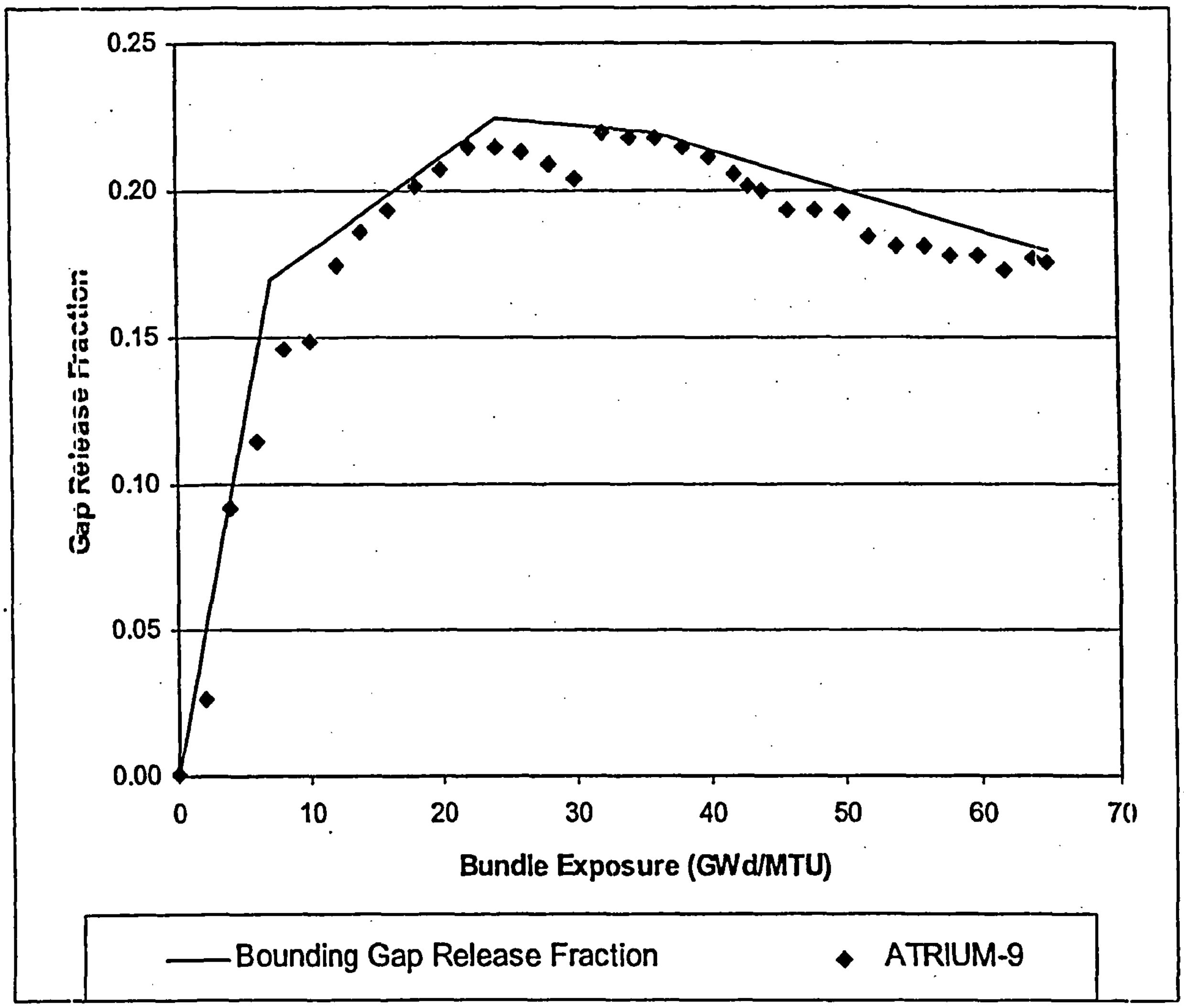

Figure 4.10 Alkali metal bundle average gap release fractions, ATRIUM-9 fuel design.

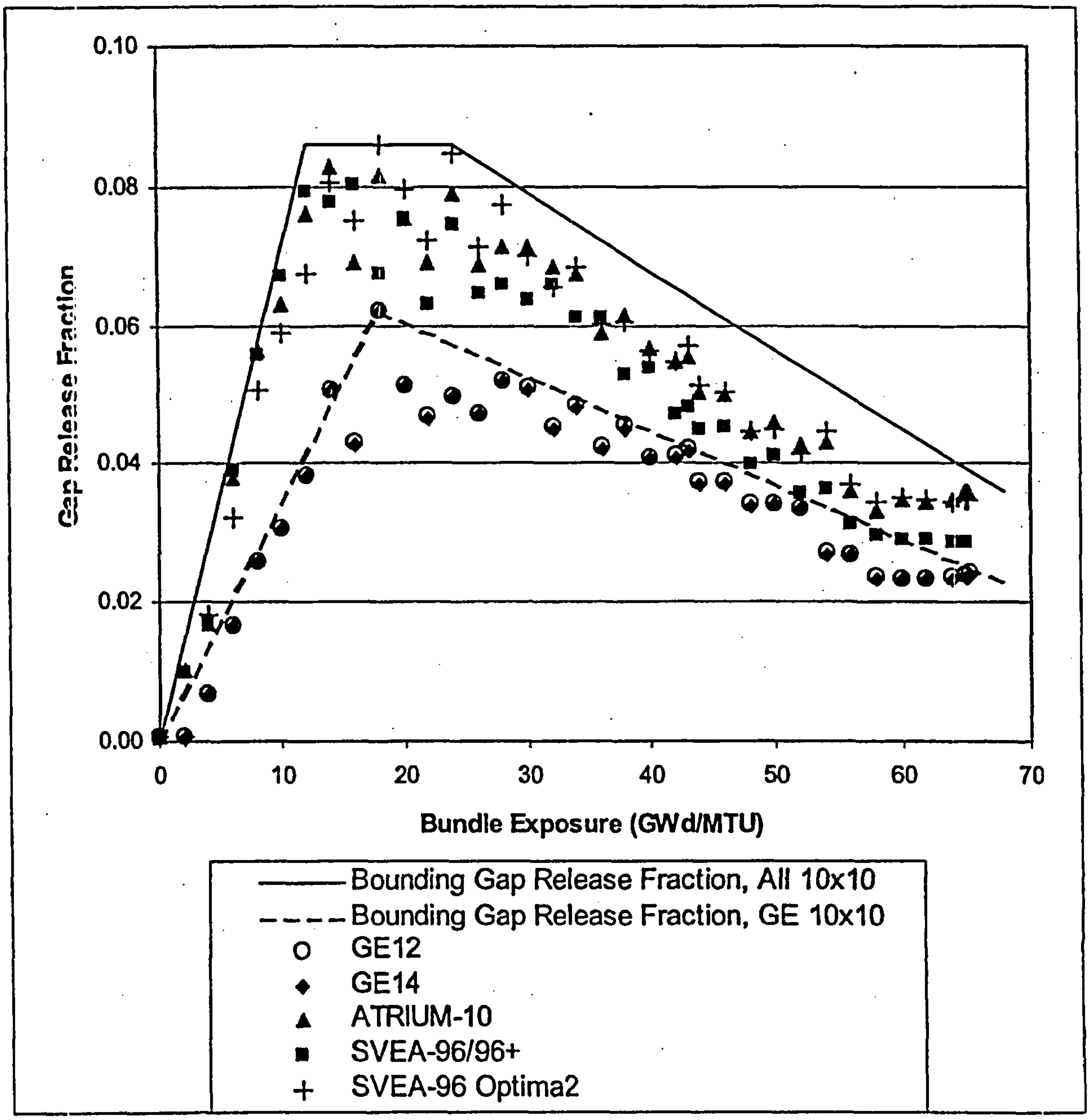

Figure 4.11 I-131 bundle average gap release fractions, 10x10 fuel designs.

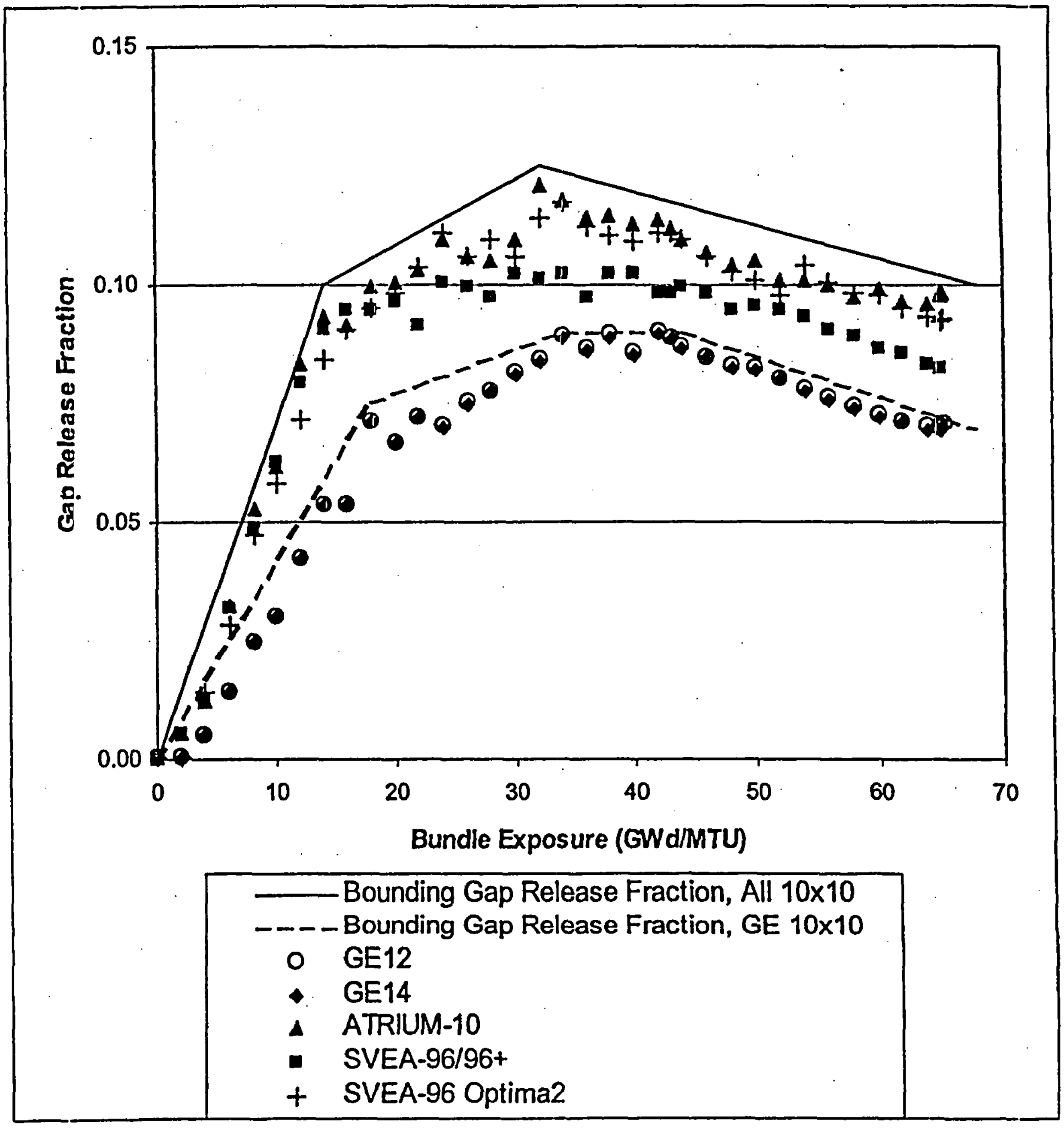

Figure 4.12 Kr-85 bundle average gap release fractions, 10x10 fuel designs.

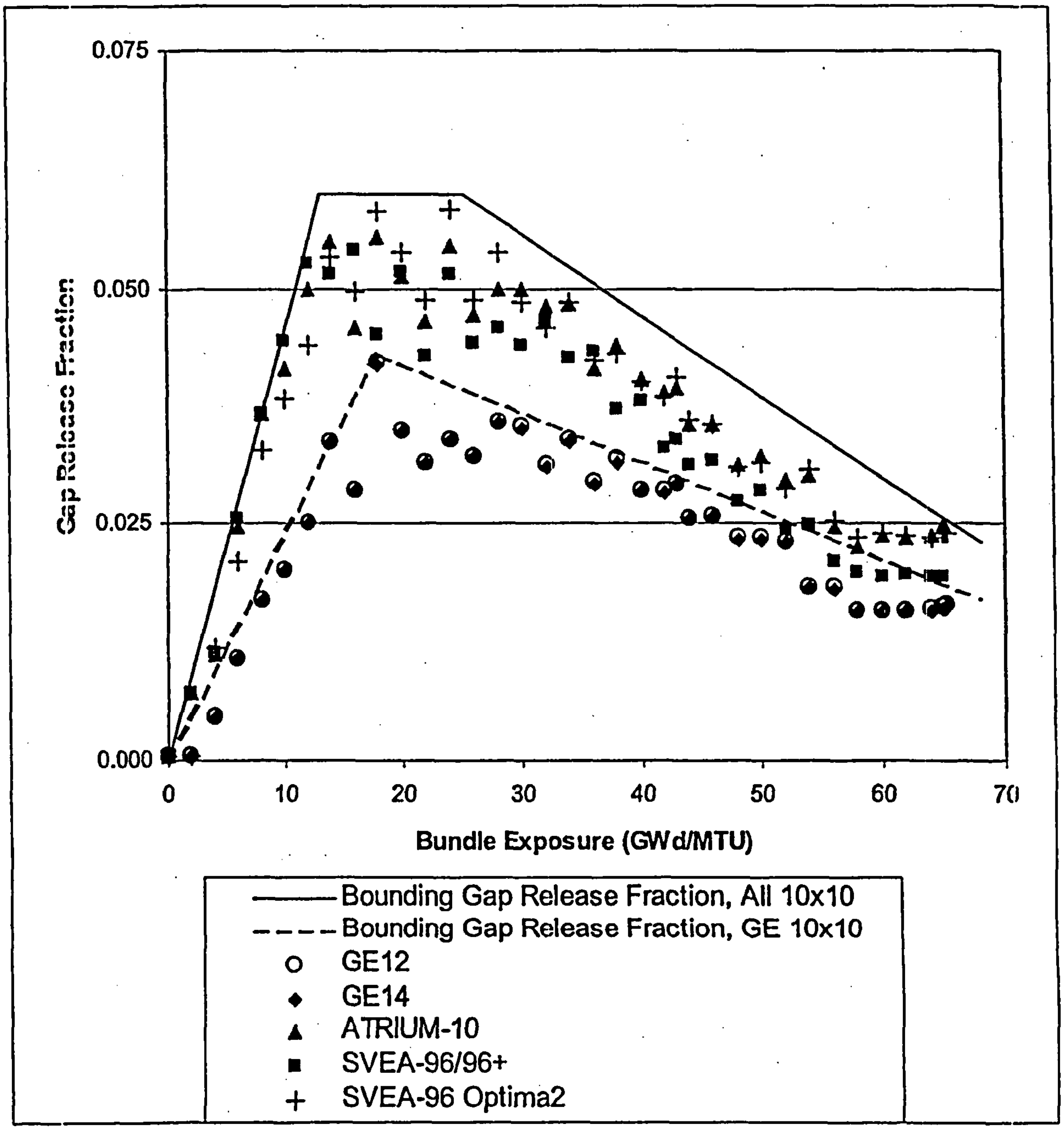

Figure 4.13 Other noble gas bundle average gap release fractions, 10x10 fuel designs.

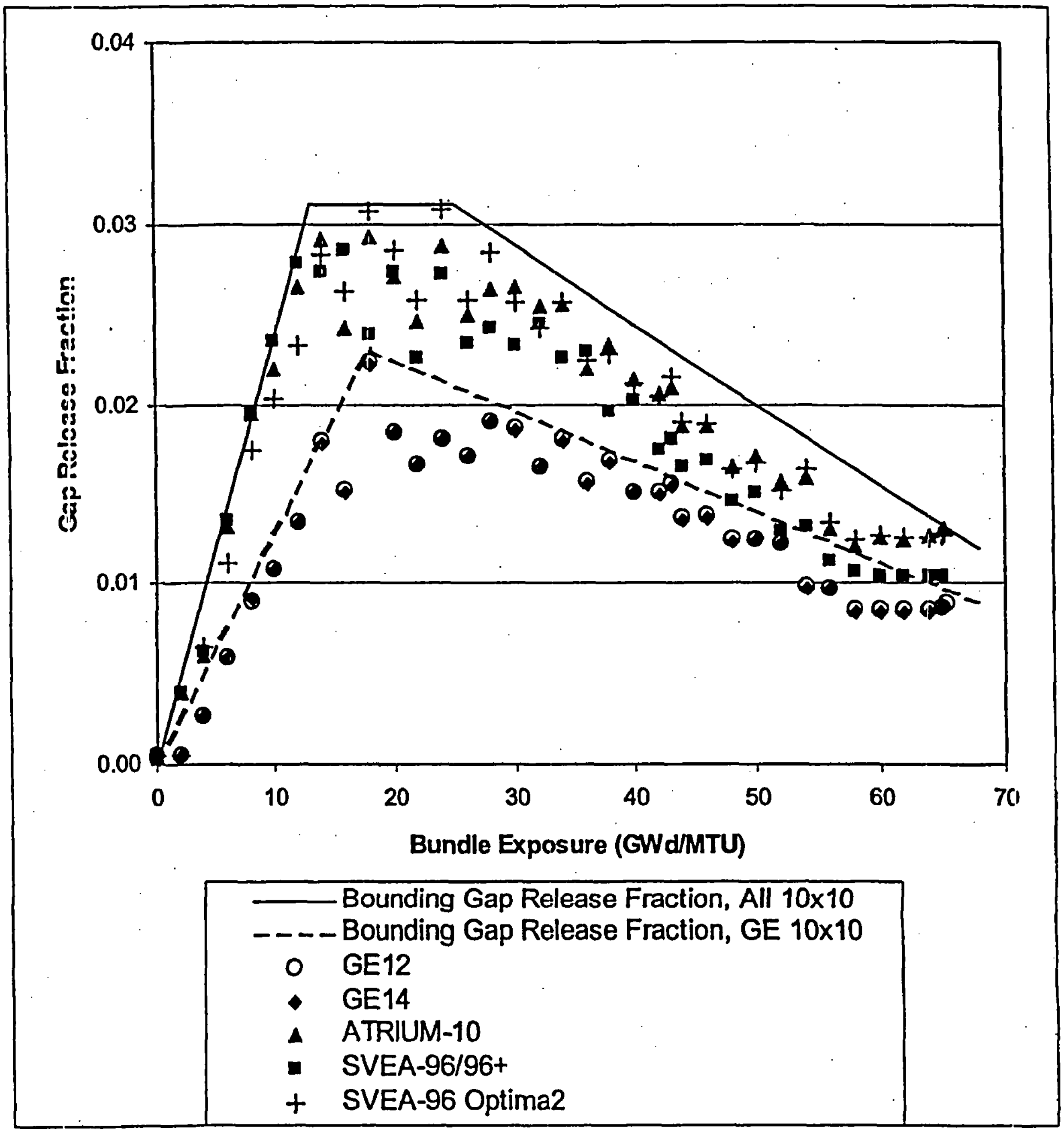

Figure 4.14 Other halogen bundle average gap release fractions, 10x10 fuel designs.

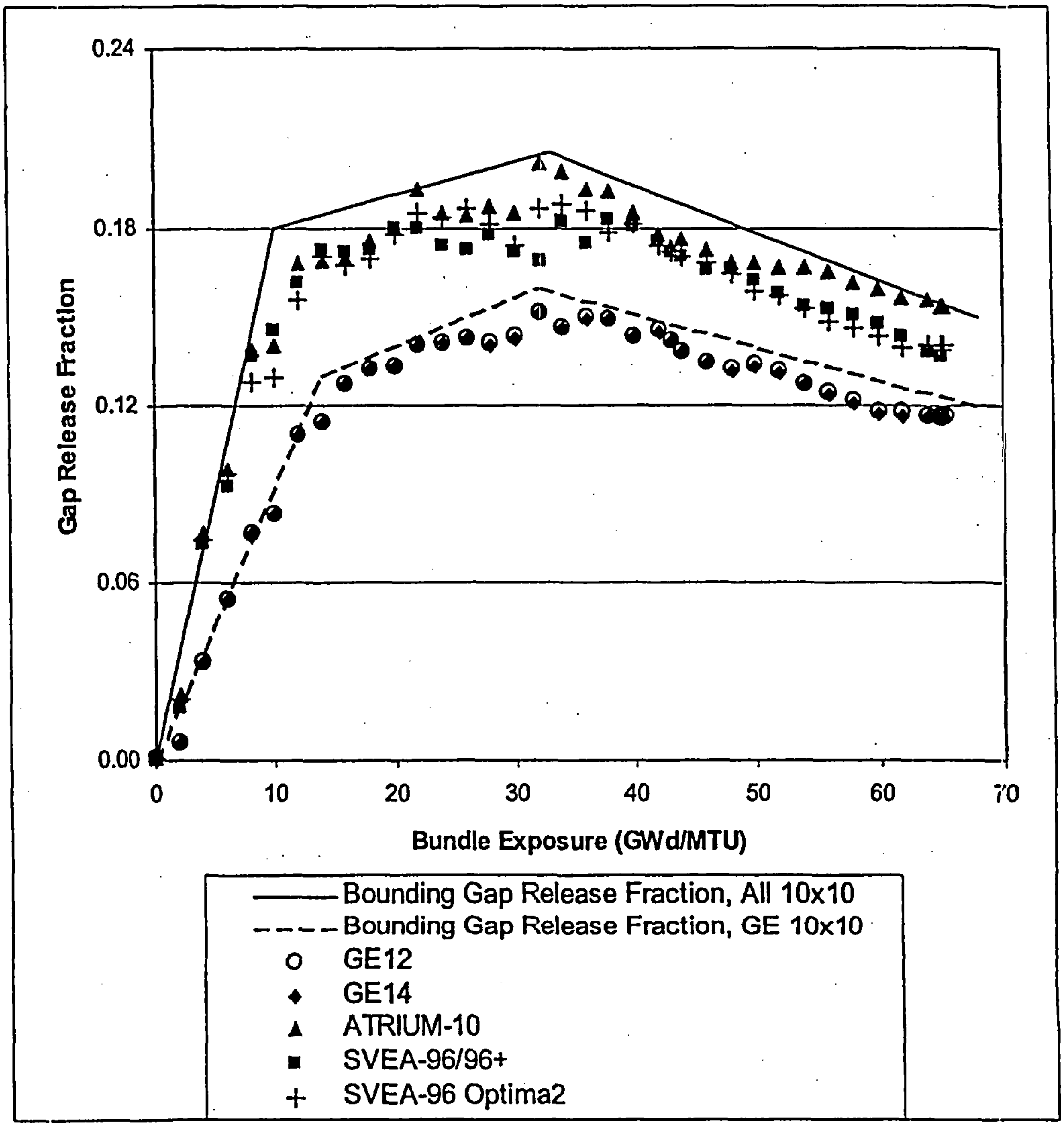

Figure 4.15 Alkali metal bundle average gap release fractions, 10x10 fuel designs.

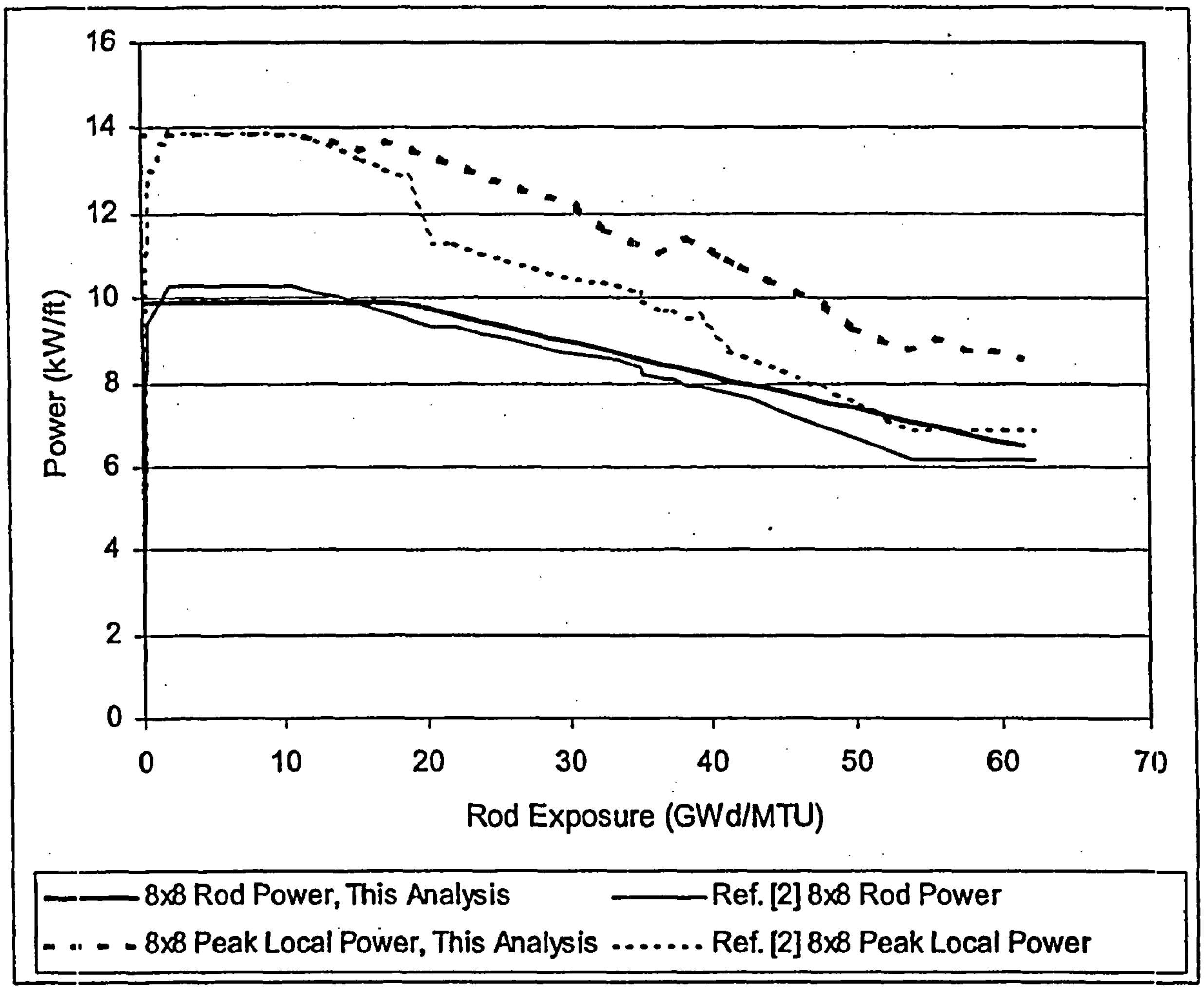

Figure 4.16 Comparison of 8x8 fuel rod power histories used to obtain gap release fractions

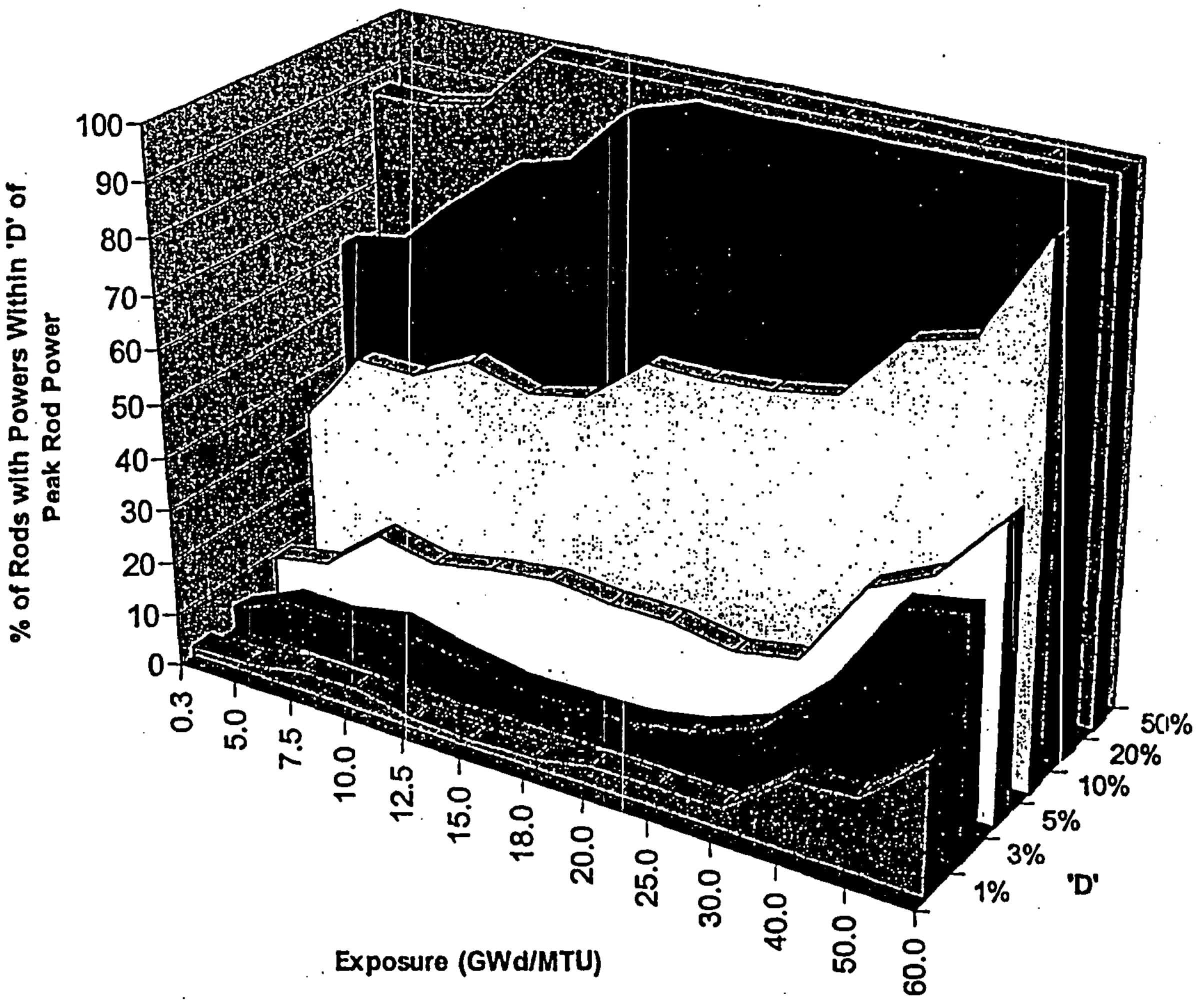

Figure 4.17 Local peaking for a typical BWR fuel bundle showing the percent of rods at powers that are within a certain percent of the peak rod for various exposures

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APPENDIX A

FUEL ROD DESIGN GAP RELEASE FRACTIONS

Table A-1

GE 8x8 Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.016	0.016	0.0000
4	0.015	0.0006	0.0008	0.0114	0.0049	0.067	0.067	0.0177
6	0.025	0.0008	0.0012	0.0165	0.0070	0.088	0.088	0.0255
8	0.047	0.0015	0.0022	0.0294	0.0125	0.112	0.112	0.0454
10	0.069	0.0021	0.0031	0.0416	0.0178	0.144	0.144	0.0636
12	0.080	0.0025	0.0037	0.0493	0.0213	0.146	0.146	0.0737
14	0.092	0.0028	0.0041	0.0544	0.0236	0.161	0.161	0.0800
16	0.101	0.0033	0.0050	0.0643	0.0281	0.170	0.170	0.0906
18	0.110	0.0026	0.0039	0.0506	0.0220	0.179	0.179	0.0729
20	0.114	0.0031	0.0045	0.0588	0.0258	0.184	0.184	0.0818
22	0.116	0.0032	0.0047	0.0608	0.0268	0.184	0.184	0.0828
24	0.126	0.0037	0.0054	0.0689	0.0306	0.189	0.189	0.0910
26	0.142	0.0037	0.0055	0.0681	0.0305	0.200	0.200	0.0856
28	0.151	0.0041	0.0061	0.0748	0.0339	0.204	0.204	0.0921
30	0.150	0.0043	0.0064	0.0771	0.0353	0.207	0.207	0.0923
32	0.151	0.0046	0.0069	0.0814	0.0378	0.204	0.204	0.0945
34	0.156	0.0048	0.0071	0.0828	0.0386	0.213	0.213	0.0945
36	0.162	0.0053	0.0079	0.0899	0.0425	0.216	0.216	0.0992
38	0.157	0.0051	0.0076	0.0860	0.0408	0.209	0.209	0.0942
40	0.161	0.0047	0.0069	0.0807	0.0378	0.213	0.213	0.0910
42	0.158	0.0049	0.0072	0.0825	0.0391	0.208	0.208	0.0904
43	0.156	0.0046	0.0068	0.0783	0.0369	0.207	0.207	0.0865
44	0.154	0.0046	0.0069	0.0782	0.0371	0.205	0.205	0.0857
46	0.162	0.0042	0.0062	0.0722	0.0338	0.212	0.212	0.0812
48	0.161	0.0044	0.0065	0.0741	0.0350	0.204	0.204	0.0816
50	0.158	0.0041	0.0061	0.0700	0.0330	0.206	0.206	0.0775
52	0.158	0.0037	0.0056	0.0653	0.0304	0.207	0.207	0.0738
54	0.157	0.0038	0.0057	0.0662	0.0309	0.210	0.210	0.0741
56	0.155	0.0035	0.0052	0.0617	0.0287	0.204	0.204	0.0700
58	0.157	0.0034	0.0051	0.0606	0.0279	0.206	0.206	0.0706
60	0.157	0.0034	0.0051	0.0610	0.0281	0.204	0.204	0.0706
62	0.159	0.0039	0.0058	0.0674	0.0316	0.200	0.200	0.0753
64	0.168	0.0061	0.0090	0.0932	0.0467	0.202	0.202	0.0929
65	0.172	0.0064	0.0094	0.0964	0.0486	0.200	0.200	0.0952

Table A-2

GE11/13 9x9 Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.011	0.011	0.0000
4	0.010	0.0004	0.0006	0.0084	0.0036	0.052	0.052	0.0129
6	0.022	0.0007	0.0011	0.0150	0.0064	0.073	0.073	0.0231
8	0.037	0.0012	0.0017	0.0237	0.0101	0.104	0.104	0.0364
10	0.044	0.0014	0.0021	0.0277	0.0118	0.106	0.106	0.0421
12	0.065	0.0019	0.0029	0.0388	0.0166	0.134	0.134	0.0583
14	0.077	0.0025	0.0037	0.0484	0.0209	0.141	0.141	0.0709
16	0.080	0.0024	0.0036	0.0468	0.0203	0.153	0.153	0.0679
18	0.096	0.0032	0.0047	0.0608	0.0266	0.161	0.161	0.0847
20	0.106	0.0033	0.0049	0.0631	0.0278	0.169	0.169	0.0865
22	0.114	0.0028	0.0042	0.0548	0.0240	0.175	0.175	0.0763
24	0.118	0.0031	0.0047	0.0596	0.0263	0.182	0.182	0.0807
26	0.120	0.0034	0.0050	0.0636	0.0282	0.183	0.183	0.0839
28	0.122	0.0036	0.0054	0.0676	0.0303	0.183	0.183	0.0867
30	0.140	0.0037	0.0056	0.0684	0.0310	0.210	0.210	0.0844
32	0.143	0.0040	0.0060	0.0720	0.0329	0.210	0.210	0.0862
34	0.146	0.0040	0.0060	0.0720	0.0330	0.205	0.205	0.0856
36	0.151	0.0044	0.0066	0.0777	0.0360	0.207	0.207	0.0902
38	0.155	0.0043	0.0064	0.0760	0.0351	0.212	0.212	0.0884
40	0.157	0.0046	0.0068	0.0798	0.0372	0.210	0.210	0.0908
42	0.156	0.0043	0.0064	0.0751	0.0348	0.209	0.209	0.0861
43	0.153	0.0043	0.0064	0.0754	0.0351	0.205	0.205	0.0856
44	0.151	0.0041	0.0061	0.0717	0.0332	0.206	0.206	0.0822
46	0.160	0.0041	0.0061	0.0725	0.0334	0.216	0.216	0.0847
48	0.158	0.0042	0.0062	0.0734	0.0341	0.209	0.209	0.0843
50	0.154	0.0037	0.0055	0.0660	0.0303	0.206	0.206	0.0774
52	0.152	0.0037	0.0055	0.0659	0.0304	0.203	0.203	0.0765
54	0.162	0.0033	0.0049	0.0593	0.0270	0.211	0.211	0.0715
56	0.157	0.0032	0.0048	0.0580	0.0265	0.207	0.207	0.0693
58	0.155	0.0033	0.0049	0.0593	0.0272	0.205	0.205	0.0695
60	0.156	0.0034	0.0050	0.0601	0.0276	0.205	0.205	0.0700
62	0.159	0.0036	0.0053	0.0639	0.0294	0.206	0.206	0.0743
64	0.162	0.0037	0.0055	0.0654	0.0302	0.202	0.202	0.0756
65	0.166	0.0040	0.0060	0.0699	0.0327	0.207	0.207	0.0788

Table A-3

GE11 9x9 Part-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.014	0.014	0.0000
4	0.009	0.0004	0.0006	0.0078	0.0033	0.039	0.039	0.0121
6	0.015	0.0005	0.0007	0.0099	0.0042	0.066	0.066	0.0154
8	0.024	0.0008	0.0012	0.0161	0.0068	0.086	0.086	0.0249
10	0.039	0.0013	0.0020	0.0265	0.0113	0.102	0.102	0.0405
12	0.060	0.0020	0.0030	0.0402	0.0172	0.136	0.136	0.0610
14	0.075	0.0026	0.0039	0.0516	0.0223	0.157	0.157	0.0769
16	0.088	0.0029	0.0044	0.0574	0.0249	0.168	0.168	0.0846
18	0.107	0.0038	0.0056	0.0730	0.0319	0.184	0.184	0.1043
20	0.119	0.0039	0.0059	0.0757	0.0332	0.190	0.190	0.1070
22	0.118	0.0030	0.0045	0.0591	0.0258	0.190	0.190	0.0846
24	0.115	0.0031	0.0046	0.0598	0.0262	0.195	0.195	0.0838
26	0.116	0.0033	0.0049	0.0625	0.0275	0.191	0.191	0.0859
28	0.136	0.0040	0.0059	0.0751	0.0333	0.197	0.197	0.1011
30	0.138	0.0042	0.0062	0.0783	0.0349	0.201	0.201	0.1029
32	0.162	0.0049	0.0073	0.0889	0.0403	0.225	0.225	0.1113
34	0.164	0.0051	0.0075	0.0908	0.0415	0.224	0.224	0.1102
36	0.165	0.0050	0.0075	0.0901	0.0413	0.227	0.227	0.1084
38	0.169	0.0054	0.0081	0.0956	0.0442	0.231	0.231	0.1124
40	0.167	0.0053	0.0078	0.0923	0.0428	0.228	0.228	0.1080
42	0.178	0.0059	0.0088	0.1030	0.0480	0.228	0.228	0.1189
43	0.183	0.0063	0.0093	0.1084	0.0508	0.226	0.226	0.1232
44	0.182	0.0059	0.0087	0.1024	0.0477	0.224	0.224	0.1176
46	0.182	0.0060	0.0090	0.1039	0.0487	0.229	0.229	0.1175
48	0.175	0.0056	0.0084	0.0972	0.0455	0.232	0.232	0.1101
50	0.172	0.0050	0.0074	0.0868	0.0403	0.231	0.231	0.1001
52	0.173	0.0051	0.0076	0.0891	0.0416	0.234	0.234	0.1015
54	0.171	0.0048	0.0071	0.0839	0.0388	0.229	0.229	0.0969
56	0.170	0.0048	0.0071	0.0841	0.0391	0.227	0.227	0.0965
58	0.173	0.0044	0.0066	0.0788	0.0362	0.230	0.230	0.0931
60	0.173	0.0044	0.0066	0.0785	0.0361	0.230	0.230	0.0921
62	0.177	0.0044	0.0065	0.0781	0.0358	0.227	0.227	0.0926
64	0.174	0.0043	0.0064	0.0766	0.0351	0.222	0.222	0.0906
65	0.174	0.0041	0.0061	0.0736	0.0336	0.221	0.221	0.0877
66	0.173	0.0041	0.0061	0.0732	0.0334	0.220	0.220	0.0873
68	0.172	0.0042	0.0062	0.0748	0.0343	0.222	0.222	0.0879

Table A-4

GE13 9x9 Part-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.014	0.014	0.0000
4	0.009	0.0004	0.0006	0.0078	0.0033	0.039	0.039	0.0121
6	0.015	0.0005	0.0007	0.0099	0.0042	0.066	0.066	0.0153
8	0.024	0.0008	0.0012	0.0161	0.0068	0.086	0.086	0.0248
10	0.039	0.0013	0.0020	0.0265	0.0113	0.102	0.102	0.0405
12	0.060	0.0020	0.0030	0.0402	0.0172	0.140	0.140	0.0610
14	0.075	0.0026	0.0039	0.0516	0.0223	0.156	0.156	0.0769
16	0.088	0.0029	0.0044	0.0574	0.0249	0.170	0.170	0.0845
18	0.110	0.0039	0.0058	0.0749	0.0328	0.184	0.184	0.1071
20	0.123	0.0041	0.0060	0.0781	0.0343	0.189	0.189	0.1104
22	0.118	0.0030	0.0045	0.0590	0.0257	0.195	0.195	0.0844
24	0.117	0.0031	0.0047	0.0607	0.0265	0.193	0.193	0.0851
26	0.123	0.0034	0.0051	0.0660	0.0291	0.193	0.193	0.0908
28	0.134	0.0039	0.0058	0.0738	0.0327	0.200	0.200	0.0993
30	0.139	0.0042	0.0062	0.0785	0.0350	0.210	0.210	0.1033
32	0.160	0.0048	0.0071	0.0876	0.0397	0.235	0.235	0.1097
34	0.164	0.0050	0.0075	0.0905	0.0414	0.232	0.232	0.1100
36	0.165	0.0050	0.0075	0.0898	0.0412	0.237	0.237	0.1082
38	0.169	0.0054	0.0080	0.0953	0.0441	0.237	0.237	0.1122
40	0.167	0.0053	0.0078	0.0925	0.0428	0.242	0.242	0.1086
42	0.181	0.0060	0.0089	0.1048	0.0488	0.241	0.241	0.1210
43	0.185	0.0063	0.0094	0.1090	0.0510	0.239	0.239	0.1242
44	0.181	0.0058	0.0087	0.1017	0.0474	0.237	0.237	0.1170
46	0.181	0.0060	0.0089	0.1028	0.0482	0.241	0.241	0.1164
48	0.174	0.0056	0.0082	0.0961	0.0449	0.247	0.247	0.1090
50	0.174	0.0050	0.0074	0.0873	0.0405	0.245	0.245	0.1009
52	0.173	0.0051	0.0076	0.0887	0.0413	0.241	0.241	0.1011
54	0.172	0.0048	0.0071	0.0839	0.0388	0.236	0.236	0.0971
56	0.171	0.0048	0.0072	0.0845	0.0392	0.233	0.233	0.0971
58	0.173	0.0044	0.0065	0.0785	0.0361	0.236	0.236	0.0928
60	0.174	0.0044	0.0066	0.0790	0.0364	0.237	0.237	0.0929
62	0.176	0.0043	0.0064	0.0772	0.0353	0.234	0.234	0.0918
64	0.173	0.0042	0.0063	0.0761	0.0348	0.230	0.230	0.0902
65	0.174	0.0041	0.0061	0.0735	0.0335	0.229	0.229	0.0878
66	0.172	0.0040	0.0060	0.0723	0.0330	0.227	0.227	0.0864
68	0.171	0.0041	0.0062	0.0740	0.0339	0.228	0.228	0.0871

Table A-5

Framatome ATRIUM-9 Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.005	0.0003	0.0005	0.0064	0.0027	0.026	0.026	0.0094
4	0.017	0.0007	0.0010	0.0137	0.0058	0.091	0.091	0.0210
6	0.039	0.0014	0.0021	0.0287	0.0122	0.114	0.114	0.0442
8	0.061	0.0020	0.0030	0.0408	0.0174	0.146	0.146	0.0626
10	0.074	0.0024	0.0036	0.0484	0.0208	0.148	0.148	0.0737
12	0.095	0.0029	0.0043	0.0567	0.0244	0.174	0.174	0.0853
14	0.109	0.0036	0.0053	0.0694	0.0302	0.186	0.186	0.1014
16	0.108	0.0030	0.0044	0.0583	0.0253	0.193	0.193	0.0853
18	0.122	0.0039	0.0058	0.0753	0.0331	0.201	0.201	0.1060
20	0.123	0.0035	0.0052	0.0671	0.0294	0.207	0.207	0.0944
22	0.131	0.0033	0.0049	0.0634	0.0277	0.214	0.214	0.0892
24	0.135	0.0036	0.0054	0.0695	0.0307	0.214	0.214	0.0950
26	0.140	0.0035	0.0052	0.0663	0.0292	0.213	0.213	0.0914
28	0.140	0.0037	0.0055	0.0701	0.0310	0.209	0.209	0.0945
30	0.136	0.0034	0.0050	0.0639	0.0282	0.204	0.204	0.0854
32	0.143	0.0030	0.0045	0.0573	0.0253	0.219	0.219	0.0774
34	0.143	0.0031	0.0046	0.0583	0.0258	0.218	0.218	0.0772
36	0.140	0.0027	0.0040	0.0511	0.0225	0.218	0.218	0.0691
38	0.141	0.0028	0.0042	0.0537	0.0237	0.214	0.214	0.0715
40	0.137	0.0024	0.0036	0.0461	0.0202	0.211	0.211	0.0628
42	0.145	0.0026	0.0039	0.0505	0.0222	0.205	0.205	0.0681
43	0.141	0.0023	0.0035	0.0447	0.0196	0.201	0.201	0.0614
44	0.138	0.0023	0.0034	0.0442	0.0194	0.200	0.200	0.0605
46	0.134	0.0021	0.0031	0.0401	0.0175	0.193	0.193	0.0556
48	0.130	0.0020	0.0030	0.0389	0.0170	0.193	0.193	0.0545
50	0.130	0.0020	0.0030	0.0392	0.0171	0.192	0.192	0.0546
52	0.125	0.0017	0.0025	0.0326	0.0142	0.184	0.184	0.0465
54	0.121	0.0016	0.0024	0.0315	0.0137	0.181	0.181	0.0449
56	0.119	0.0013	0.0020	0.0266	0.0115	0.181	0.181	0.0386
58	0.120	0.0013	0.0020	0.0267	0.0115	0.178	0.178	0.0387
60	0.122	0.0018	0.0027	0.0354	0.0155	0.178	0.178	0.0487
62	0.121	0.0018	0.0027	0.0345	0.0151	0.173	0.173	0.0475
64	0.123	0.0018	0.0027	0.0353	0.0154	0.177	0.177	0.0488
65	0.124	0.0018	0.0027	0.0355	0.0155	0.175	0.175	0.0490

Table A-6

GE12/14 10x10 Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.005	0.005	0.0000
4	0.005	0.0002	0.0003	0.0045	0.0019	0.032	0.032	0.0069
6	0.014	0.0005	0.0008	0.0106	0.0045	0.054	0.054	0.0164
8	0.024	0.0008	0.0012	0.0165	0.0070	0.076	0.076	0.0255
10	0.029	0.0009	0.0014	0.0191	0.0081	0.083	0.083	0.0293
12	0.041	0.0012	0.0018	0.0241	0.0103	0.109	0.109	0.0358
14	0.052	0.0016	0.0024	0.0324	0.0139	0.112	0.112	0.0487
16	0.051	0.0013	0.0020	0.0264	0.0113	0.126	0.126	0.0399
18	0.069	0.0020	0.0030	0.0402	0.0173	0.130	0.130	0.0595
20	0.064	0.0017	0.0025	0.0329	0.0141	0.131	0.131	0.0486
22	0.070	0.0015	0.0023	0.0303	0.0130	0.139	0.139	0.0452
24	0.068	0.0017	0.0025	0.0331	0.0143	0.139	0.139	0.0483
26	0.072	0.0015	0.0023	0.0307	0.0132	0.140	0.140	0.0451
28	0.075	0.0017	0.0026	0.0345	0.0149	0.138	0.138	0.0500
30	0.079	0.0017	0.0026	0.0338	0.0146	0.140	0.140	0.0491
32	0.081	0.0015	0.0022	0.0293	0.0126	0.148	0.148	0.0425
34	0.086	0.0016	0.0024	0.0320	0.0139	0.142	0.142	0.0459
36	0.083	0.0014	0.0021	0.0275	0.0119	0.145	0.145	0.0399
38	0.086	0.0015	0.0023	0.0298	0.0129	0.145	0.145	0.0427
40	0.082	0.0013	0.0020	0.0266	0.0115	0.139	0.139	0.0384
42	0.087	0.0013	0.0020	0.0266	0.0115	0.141	0.141	0.0385
43	0.086	0.0014	0.0021	0.0274	0.0119	0.138	0.138	0.0395
44	0.084	0.0012	0.0018	0.0240	0.0103	0.134	0.134	0.0350
46	0.082	0.0012	0.0018	0.0241	0.0104	0.131	0.131	0.0349
48	0.080	0.0011	0.0016	0.0218	0.0094	0.128	0.128	0.0318
50	0.079	0.0011	0.0016	0.0216	0.0093	0.130	0.130	0.0318
52	0.077	0.0011	0.0016	0.0217	0.0093	0.128	0.128	0.0317
54	0.074	0.0008	0.0012	0.0162	0.0069	0.123	0.123	0.0243
56	0.072	0.0008	0.0012	0.0163	0.0070	0.120	0.120	0.0243
58	0.070	0.0007	0.0010	0.0135	0.0058	0.117	0.117	0.0204
60	0.068	0.0007	0.0010	0.0134	0.0057	0.113	0.113	0.0202
62	0.067	0.0007	0.0010	0.0135	0.0058	0.113	0.113	0.0203
64	0.065	0.0007	0.0010	0.0133	0.0057	0.111	0.111	0.0200
65	0.065	0.0007	0.0010	0.0135	0.0058	0.110	0.110	0.0203

Table A-7

GE12 10x10 Part-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.005	0.005	0.0000
4	0.000	0.0000	0.0000	0.0000	0.0000	0.032	0.032	0.0000
6	0.010	0.0004	0.0005	0.0072	0.0031	0.044	0.044	0.0112
8	0.022	0.0007	0.0011	0.0153	0.0065	0.077	0.077	0.0238
10	0.034	0.0012	0.0018	0.0245	0.0104	0.074	0.074	0.0378
12	0.046	0.0015	0.0022	0.0297	0.0127	0.113	0.113	0.0456
14	0.061	0.0021	0.0031	0.0419	0.0180	0.129	0.129	0.0635
16	0.073	0.0022	0.0032	0.0431	0.0185	0.135	0.135	0.0654
18	0.085	0.0028	0.0041	0.0550	0.0237	0.152	0.152	0.0819
20	0.086	0.0024	0.0036	0.0480	0.0207	0.150	0.150	0.0716
22	0.086	0.0018	0.0027	0.0363	0.0156	0.151	0.151	0.0547
24	0.084	0.0019	0.0029	0.0380	0.0164	0.159	0.159	0.0566
26	0.098	0.0021	0.0031	0.0415	0.0179	0.160	0.160	0.0620
28	0.095	0.0022	0.0033	0.0435	0.0188	0.167	0.167	0.0641
30	0.100	0.0022	0.0033	0.0437	0.0188	0.165	0.165	0.0643
32	0.110	0.0023	0.0034	0.0444	0.0192	0.180	0.180	0.0648
34	0.114	0.0024	0.0036	0.0474	0.0206	0.177	0.177	0.0681
36	0.114	0.0022	0.0032	0.0424	0.0184	0.187	0.187	0.0615
38	0.117	0.0023	0.0035	0.0456	0.0198	0.184	0.184	0.0652
40	0.114	0.0021	0.0031	0.0412	0.0178	0.180	0.180	0.0593
42	0.114	0.0021	0.0031	0.0406	0.0176	0.178	0.178	0.0588
43	0.112	0.0021	0.0031	0.0413	0.0179	0.174	0.174	0.0593
44	0.109	0.0018	0.0027	0.0360	0.0155	0.171	0.171	0.0523
46	0.107	0.0019	0.0028	0.0367	0.0159	0.165	0.165	0.0529
48	0.107	0.0017	0.0025	0.0330	0.0142	0.167	0.167	0.0482
50	0.109	0.0018	0.0027	0.0353	0.0153	0.166	0.166	0.0512
52	0.107	0.0015	0.0023	0.0303	0.0130	0.162	0.162	0.0446
54	0.111	0.0016	0.0025	0.0327	0.0141	0.163	0.163	0.0479
56	0.108	0.0015	0.0023	0.0306	0.0132	0.160	0.160	0.0449
58	0.110	0.0016	0.0024	0.0322	0.0139	0.160	0.160	0.0471
60	0.108	0.0016	0.0024	0.0323	0.0140	0.156	0.156	0.0471
62	0.106	0.0016	0.0025	0.0324	0.0140	0.156	0.156	0.0470
64	0.112	0.0018	0.0027	0.0350	0.0151	0.161	0.161	0.0505
65	0.112	0.0018	0.0027	0.0356	0.0154	0.160	0.160	0.0512
66	0.110	0.0018	0.0027	0.0351	0.0152	0.173	0.173	0.0503
68	0.119	0.0020	0.0029	0.0383	0.0166	0.171	0.171	0.0548

Table A-8

GE14 10x10 Part-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.005	0.005	0.0000
4	0.000	0.0000	0.0000	0.0000	0.0000	0.032	0.032	0.0000
6	0.010	0.0004	0.0005	0.0072	0.0031	0.044	0.044	0.0112
8	0.022	0.0008	0.0011	0.0153	0.0065	0.077	0.077	0.0238
10	0.034	0.0012	0.0018	0.0245	0.0104	0.074	0.074	0.0378
12	0.046	0.0015	0.0022	0.0297	0.0127	0.113	0.113	0.0457
14	0.061	0.0021	0.0031	0.0419	0.0180	0.128	0.128	0.0635
16	0.073	0.0022	0.0032	0.0431	0.0185	0.136	0.136	0.0654
18	0.085	0.0028	0.0041	0.0550	0.0237	0.151	0.151	0.0820
20	0.086	0.0024	0.0036	0.0481	0.0207	0.148	0.148	0.0717
22	0.086	0.0018	0.0027	0.0364	0.0156	0.151	0.151	0.0548
24	0.084	0.0019	0.0029	0.0381	0.0164	0.157	0.157	0.0567
26	0.098	0.0021	0.0031	0.0416	0.0179	0.161	0.161	0.0621
28	0.095	0.0022	0.0033	0.0436	0.0188	0.159	0.159	0.0643
30	0.095	0.0021	0.0031	0.0416	0.0179	0.161	0.161	0.0613
32	0.107	0.0022	0.0033	0.0433	0.0187	0.178	0.178	0.0632
34	0.110	0.0023	0.0035	0.0459	0.0199	0.180	0.180	0.0659
36	0.110	0.0021	0.0031	0.0411	0.0178	0.181	0.181	0.0595
38	0.110	0.0022	0.0033	0.0431	0.0187	0.186	0.186	0.0615
40	0.112	0.0021	0.0031	0.0406	0.0176	0.183	0.183	0.0585
42	0.111	0.0020	0.0030	0.0393	0.0170	0.180	0.180	0.0569
43	0.109	0.0021	0.0031	0.0404	0.0175	0.176	0.176	0.0580
44	0.107	0.0018	0.0027	0.0355	0.0153	0.173	0.173	0.0516
46	0.105	0.0018	0.0027	0.0362	0.0157	0.167	0.167	0.0522
48	0.104	0.0016	0.0024	0.0323	0.0139	0.164	0.164	0.0470
50	0.107	0.0018	0.0026	0.0349	0.0151	0.161	0.161	0.0505
52	0.105	0.0015	0.0022	0.0296	0.0128	0.158	0.158	0.0436
54	0.106	0.0016	0.0024	0.0314	0.0135	0.161	0.161	0.0459
56	0.105	0.0015	0.0022	0.0299	0.0129	0.155	0.155	0.0439
58	0.106	0.0016	0.0023	0.0312	0.0134	0.154	0.154	0.0456
60	0.107	0.0016	0.0024	0.0322	0.0139	0.151	0.151	0.0469
62	0.105	0.0016	0.0024	0.0323	0.0140	0.148	0.148	0.0468
64	0.108	0.0017	0.0026	0.0340	0.0147	0.168	0.168	0.0489
65	0.110	0.0018	0.0027	0.0349	0.0151	0.166	0.166	0.0502
66	0.109	0.0018	0.0027	0.0350	0.0152	0.166	0.166	0.0501
68	0.113	0.0019	0.0028	0.0364	0.0158	0.168	0.168	0.0519

Table A-9

Framatome ATRIUM-10 10x10 Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.005	0.0003	0.0005	0.0066	0.0028	0.021	0.021	0.0096
4	0.012	0.0005	0.0008	0.0106	0.0045	0.077	0.077	0.0163
6	0.032	0.0012	0.0018	0.0244	0.0104	0.099	0.099	0.0375
8	0.053	0.0018	0.0027	0.0370	0.0158	0.140	0.140	0.0568
10	0.062	0.0021	0.0031	0.0417	0.0178	0.141	0.141	0.0636
12	0.084	0.0025	0.0037	0.0500	0.0214	0.169	0.169	0.0762
14	0.093	0.0027	0.0041	0.0547	0.0235	0.168	0.168	0.0826
16	0.091	0.0022	0.0033	0.0445	0.0191	0.168	0.168	0.0673
18	0.099	0.0028	0.0042	0.0550	0.0238	0.174	0.174	0.0813
20	0.099	0.0025	0.0037	0.0496	0.0214	0.178	0.178	0.0733
22	0.102	0.0023	0.0034	0.0453	0.0195	0.192	0.192	0.0674
24	0.109	0.0027	0.0041	0.0534	0.0232	0.184	0.184	0.0777
26	0.105	0.0024	0.0035	0.0466	0.0202	0.183	0.183	0.0680
28	0.104	0.0025	0.0038	0.0492	0.0214	0.186	0.186	0.0704
30	0.109	0.0025	0.0038	0.0495	0.0215	0.184	0.184	0.0708
32	0.120	0.0024	0.0036	0.0469	0.0204	0.201	0.201	0.0668
34	0.117	0.0024	0.0036	0.0473	0.0207	0.198	0.198	0.0661
36	0.112	0.0021	0.0031	0.0401	0.0174	0.191	0.191	0.0569
38	0.113	0.0022	0.0033	0.0427	0.0186	0.190	0.190	0.0597
40	0.111	0.0020	0.0030	0.0393	0.0171	0.183	0.183	0.0554
42	0.112	0.0019	0.0029	0.0376	0.0163	0.175	0.175	0.0532
43	0.110	0.0020	0.0029	0.0384	0.0167	0.171	0.171	0.0540
44	0.108	0.0017	0.0026	0.0342	0.0148	0.174	0.174	0.0488
46	0.105	0.0017	0.0026	0.0342	0.0149	0.170	0.170	0.0485
48	0.102	0.0015	0.0022	0.0295	0.0128	0.166	0.166	0.0426
50	0.103	0.0016	0.0024	0.0310	0.0134	0.166	0.166	0.0445
52	0.099	0.0014	0.0021	0.0281	0.0121	0.164	0.164	0.0409
54	0.099	0.0015	0.0022	0.0289	0.0125	0.165	0.165	0.0418
56	0.098	0.0012	0.0017	0.0231	0.0099	0.163	0.163	0.0341
58	0.095	0.0010	0.0016	0.0209	0.0090	0.159	0.159	0.0311
60	0.097	0.0011	0.0016	0.0219	0.0094	0.157	0.157	0.0325
62	0.094	0.0011	0.0016	0.0217	0.0093	0.154	0.154	0.0322
64	0.094	0.0011	0.0016	0.0220	0.0094	0.153	0.153	0.0326
65	0.096	0.0011	0.0017	0.0228	0.0098	0.151	0.151	0.0337

Table A-10

Framatome ATRIUM-10 10x10 Part-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.005	0.0003	0.0005	0.0063	0.0027	0.024	0.024	0.0090
4	0.011	0.0005	0.0007	0.0100	0.0042	0.057	0.057	0.0153
6	0.029	0.0011	0.0016	0.0215	0.0091	0.080	0.080	0.0333
8	0.037	0.0012	0.0018	0.0243	0.0103	0.109	0.109	0.0376
10	0.045	0.0014	0.0022	0.0292	0.0125	0.116	0.116	0.0451
12	0.064	0.0021	0.0031	0.0414	0.0177	0.145	0.145	0.0633
14	0.088	0.0025	0.0038	0.0510	0.0219	0.176	0.176	0.0782
16	0.094	0.0030	0.0045	0.0595	0.0257	0.180	0.180	0.0895
18	0.099	0.0026	0.0039	0.0526	0.0226	0.183	0.183	0.0794
20	0.115	0.0036	0.0053	0.0700	0.0304	0.195	0.195	0.1035
22	0.113	0.0030	0.0045	0.0590	0.0255	0.193	0.193	0.0876
24	0.115	0.0032	0.0048	0.0625	0.0272	0.191	0.191	0.0914
26	0.115	0.0024	0.0036	0.0484	0.0209	0.193	0.193	0.0717
28	0.113	0.0026	0.0039	0.0519	0.0225	0.196	0.196	0.0757
30	0.116	0.0025	0.0038	0.0499	0.0216	0.193	0.193	0.0730
32	0.131	0.0031	0.0046	0.0599	0.0261	0.198	0.198	0.0864
34	0.127	0.0029	0.0043	0.0560	0.0243	0.201	0.201	0.0806
36	0.141	0.0029	0.0044	0.0568	0.0248	0.211	0.211	0.0812
38	0.136	0.0030	0.0044	0.0575	0.0251	0.211	0.211	0.0805
40	0.134	0.0026	0.0038	0.0499	0.0217	0.211	0.211	0.0710
42	0.135	0.0027	0.0041	0.0532	0.0233	0.204	0.204	0.0746
43	0.133	0.0025	0.0037	0.0483	0.0210	0.203	0.203	0.0687
44	0.131	0.0025	0.0038	0.0491	0.0214	0.198	0.198	0.0694
46	0.132	0.0024	0.0036	0.0477	0.0208	0.198	0.198	0.0679
48	0.134	0.0026	0.0039	0.0507	0.0222	0.195	0.195	0.0713
50	0.131	0.0022	0.0034	0.0440	0.0191	0.195	0.195	0.0630
52	0.130	0.0023	0.0035	0.0454	0.0198	0.195	0.195	0.0643
54	0.127	0.0020	0.0030	0.0396	0.0172	0.189	0.189	0.0572
56	0.127	0.0021	0.0031	0.0413	0.0179	0.187	0.187	0.0593
58	0.127	0.0022	0.0032	0.0425	0.0185	0.191	0.191	0.0505
60	0.130	0.0023	0.0034	0.0446	0.0194	0.192	0.192	0.0631
62	0.129	0.0023	0.0035	0.0455	0.0198	0.188	0.188	0.0638
64	0.126	0.0023	0.0035	0.0452	0.0198	0.187	0.187	0.0630
65	0.125	0.0024	0.0036	0.0462	0.0202	0.186	0.186	0.0640
66	0.127	0.0025	0.0037	0.0473	0.0207	0.187	0.187	0.0653
68	0.127	0.0024	0.0036	0.0471	0.0207	0.185	0.185	0.0646

Table A-11

ABB SVEA-96, SVEA-96+ Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.005	0.0003	0.0005	0.0065	0.0028	0.017	0.017	0.0093
4	0.012	0.0005	0.0008	0.0109	0.0046	0.072	0.072	0.0166
6	0.031	0.0012	0.0018	0.0250	0.0106	0.092	0.092	0.0382
8	0.048	0.0018	0.0027	0.0362	0.0155	0.136	0.136	0.0553
10	0.062	0.0022	0.0033	0.0439	0.0188	0.145	0.145	0.0666
12	0.079	0.0026	0.0039	0.0522	0.0224	0.161	0.161	0.0788
14	0.090	0.0026	0.0038	0.0511	0.0220	0.172	0.172	0.0771
16	0.094	0.0027	0.0040	0.0535	0.0231	0.171	0.171	0.0799
18	0.094	0.0022	0.0033	0.0446	0.0192	0.172	0.172	0.0671
20	0.096	0.0026	0.0039	0.0511	0.0221	0.179	0.179	0.0750
22	0.091	0.0021	0.0032	0.0423	0.0182	0.179	0.179	0.0625
24	0.100	0.0026	0.0039	0.0510	0.0221	0.173	0.173	0.0739
26	0.099	0.0022	0.0033	0.0437	0.0189	0.172	0.172	0.0641
28	0.097	0.0023	0.0034	0.0453	0.0196	0.177	0.177	0.0653
30	0.102	0.0022	0.0033	0.0436	0.0189	0.171	0.171	0.0632
32	0.101	0.0024	0.0035	0.0459	0.0200	0.168	0.168	0.0653
34	0.102	0.0022	0.0032	0.0422	0.0183	0.181	0.181	0.0607
36	0.097	0.0022	0.0033	0.0429	0.0187	0.174	0.174	0.0605
38	0.102	0.0019	0.0028	0.0366	0.0159	0.182	0.182	0.0523
40	0.102	0.0019	0.0029	0.0377	0.0164	0.180	0.180	0.0532
42	0.098	0.0017	0.0025	0.0325	0.0141	0.175	0.175	0.0466
43	0.098	0.0017	0.0026	0.0335	0.0146	0.171	0.171	0.0477
44	0.099	0.0016	0.0023	0.0306	0.0132	0.170	0.170	0.0442
46	0.098	0.0016	0.0024	0.0312	0.0135	0.165	0.165	0.0448
48	0.094	0.0014	0.0020	0.0269	0.0116	0.165	0.165	0.0392
50	0.095	0.0014	0.0021	0.0280	0.0121	0.162	0.162	0.0405
52	0.094	0.0012	0.0018	0.0238	0.0102	0.157	0.157	0.0352
54	0.093	0.0012	0.0018	0.0243	0.0104	0.153	0.153	0.0357
56	0.090	0.0010	0.0015	0.0205	0.0088	0.152	0.152	0.0306
58	0.089	0.0010	0.0014	0.0194	0.0083	0.150	0.150	0.0291
60	0.086	0.0009	0.0014	0.0190	0.0081	0.147	0.147	0.0284
62	0.085	0.0010	0.0014	0.0191	0.0082	0.143	0.143	0.0285
64	0.083	0.0009	0.0014	0.0189	0.0081	0.138	0.138	0.0282
65	0.082	0.0009	0.0014	0.0189	0.0081	0.136	0.136	0.0282

Table A-12

ABB SVEA-96 Optima2 Full-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.020	0.020	0.0000
4	0.014	0.0006	0.0009	0.0118	0.0050	0.075	0.075	0.0182
6	0.028	0.0010	0.0015	0.0208	0.0088	0.099	0.099	0.0322
8	0.048	0.0016	0.0025	0.0333	0.0142	0.130	0.130	0.0516
10	0.059	0.0019	0.0029	0.0387	0.0165	0.131	0.131	0.0597
12	0.072	0.0022	0.0032	0.0437	0.0187	0.157	0.157	0.0672
14	0.084	0.0027	0.0040	0.0532	0.0229	0.170	0.170	0.0805
16	0.090	0.0024	0.0036	0.0480	0.0206	0.166	0.166	0.0729
18	0.095	0.0029	0.0044	0.0581	0.0251	0.168	0.168	0.0862
20	0.097	0.0026	0.0039	0.0521	0.0225	0.175	0.175	0.0772
22	0.103	0.0024	0.0036	0.0473	0.0204	0.184	0.184	0.0705
24	0.110	0.0029	0.0044	0.0572	0.0248	0.182	0.182	0.0833
26	0.105	0.0024	0.0036	0.0481	0.0208	0.186	0.186	0.0705
28	0.109	0.0027	0.0041	0.0532	0.0231	0.181	0.181	0.0767
30	0.105	0.0024	0.0037	0.0480	0.0208	0.173	0.173	0.0692
32	0.114	0.0023	0.0034	0.0446	0.0193	0.186	0.186	0.0641
34	0.116	0.0024	0.0036	0.0473	0.0206	0.188	0.188	0.0668
36	0.111	0.0021	0.0031	0.0404	0.0176	0.186	0.186	0.0578
38	0.108	0.0021	0.0032	0.0415	0.0181	0.177	0.177	0.0584
40	0.107	0.0020	0.0029	0.0381	0.0166	0.180	0.180	0.0540
42	0.109	0.0019	0.0028	0.0369	0.0160	0.172	0.172	0.0526
43	0.108	0.0020	0.0029	0.0386	0.0168	0.169	0.169	0.0543
44	0.107	0.0017	0.0026	0.0342	0.0148	0.168	0.168	0.0489
46	0.103	0.0017	0.0026	0.0337	0.0146	0.166	0.166	0.0478
48	0.100	0.0015	0.0022	0.0290	0.0125	0.162	0.162	0.0419
50	0.098	0.0015	0.0022	0.0295	0.0128	0.156	0.156	0.0423
52	0.095	0.0013	0.0020	0.0267	0.0115	0.155	0.155	0.0389
54	0.102	0.0015	0.0022	0.0295	0.0127	0.150	0.150	0.0428
56	0.098	0.0012	0.0017	0.0233	0.0100	0.146	0.146	0.0345
58	0.096	0.0011	0.0016	0.0213	0.0091	0.143	0.143	0.0318
60	0.095	0.0011	0.0016	0.0216	0.0092	0.140	0.140	0.0321
62	0.092	0.0011	0.0016	0.0213	0.0091	0.137	0.137	0.0317
64	0.090	0.0011	0.0016	0.0211	0.0090	0.137	0.137	0.0313
65	0.089	0.0011	0.0016	0.0213	0.0091	0.136	0.136	0.0315

Table A-13

ABB SVEA-96 Optima2 Part-Length Rods

Rod Exposure (GWd/MTU)	Gap Release Fractions							
	Kr-85	Kr-87	Kr-88	Xe-133	Xe-135	Cs-134	Cs-137	I-131
0	0.000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.0000
2	0.000	0.0000	0.0000	0.0000	0.0000	0.019	0.019	0.0000
4	0.009	0.0004	0.0006	0.0078	0.0033	0.057	0.057	0.0120
6	0.023	0.0008	0.0012	0.0171	0.0072	0.071	0.071	0.0266
8	0.032	0.0011	0.0016	0.0219	0.0093	0.103	0.103	0.0341
10	0.041	0.0014	0.0021	0.0288	0.0122	0.111	0.111	0.0444
12	0.061	0.0021	0.0031	0.0419	0.0179	0.138	0.138	0.0641
14	0.082	0.0025	0.0037	0.0498	0.0213	0.166	0.166	0.0764
16	0.092	0.0031	0.0047	0.0619	0.0267	0.174	0.174	0.0933
18	0.093	0.0026	0.0039	0.0518	0.0223	0.176	0.176	0.0784
20	0.109	0.0034	0.0051	0.0669	0.0290	0.194	0.194	0.0995
22	0.107	0.0029	0.0043	0.0575	0.0248	0.186	0.186	0.0857
24	0.114	0.0033	0.0049	0.0643	0.0279	0.187	0.187	0.0943
26	0.112	0.0025	0.0037	0.0493	0.0213	0.183	0.183	0.0732
28	0.113	0.0028	0.0041	0.0543	0.0235	0.178	0.178	0.0794
30	0.112	0.0026	0.0038	0.0503	0.0218	0.180	0.180	0.0736
32	0.111	0.0027	0.0041	0.0534	0.0232	0.179	0.179	0.0769
34	0.125	0.0029	0.0043	0.0562	0.0244	0.176	0.176	0.0812
36	0.121	0.0030	0.0044	0.0573	0.0250	0.178	0.178	0.0814
38	0.130	0.0027	0.0041	0.0532	0.0232	0.185	0.185	0.0758
40	0.129	0.0028	0.0042	0.0550	0.0241	0.188	0.188	0.0768
42	0.129	0.0026	0.0038	0.0501	0.0219	0.184	0.184	0.0708
43	0.138	0.0029	0.0043	0.0558	0.0244	0.191	0.191	0.0780
44	0.134	0.0025	0.0038	0.0493	0.0215	0.190	0.190	0.0701
46	0.134	0.0026	0.0039	0.0505	0.0220	0.184	0.184	0.0711
48	0.129	0.0024	0.0035	0.0462	0.0201	0.182	0.182	0.0656
50	0.127	0.0025	0.0037	0.0476	0.0208	0.182	0.182	0.0669
52	0.125	0.0022	0.0033	0.0430	0.0187	0.176	0.176	0.0611
54	0.124	0.0020	0.0030	0.0397	0.0172	0.174	0.174	0.0571
56	0.121	0.0020	0.0030	0.0399	0.0173	0.170	0.170	0.0571
58	0.119	0.0021	0.0031	0.0405	0.0176	0.171	0.171	0.0575
60	0.121	0.0022	0.0032	0.0421	0.0183	0.169	0.169	0.0593
62	0.121	0.0022	0.0033	0.0429	0.0187	0.165	0.165	0.0602
64	0.122	0.0023	0.0034	0.0439	0.0192	0.167	0.167	0.0610
65	0.123	0.0024	0.0035	0.0459	0.0201	0.166	0.166	0.0634
66	0.125	0.0024	0.0036	0.0468	0.0205	0.177	0.177	0.0644
68	0.126	0.0024	0.0036	0.0465	0.0204	0.177	0.177	0.0638

General Electric Company

AFFIDAVIT

I, Jason S. Post, state as follows:

(1) I am Manager, Engineering Quality & Safety Evaluations, General Electric Company ("GE") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in Enclosures 2 and 3 to BWROG-06009 letter J. E. Conen to NRC, *BWR Owners' Group Alternate Source Term High Burn Up BWR Fuel Rod Gap Release Fractions,* dated March 30, 2006. The proprietary information in Enclosure 2 is delineated by a double underline inside double square brackets. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation[3] refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination. The proprietary information in Enclosure 3, *Evaluation of the Impact of Fast Transients on the GAP Release Fractions,* is the entire report, *NISYS-1145-TR003/R0.* Paragraph (3) of this affidavit, provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, <u>Critical Mass Energy Project v. Nuclear Regulatory Commission</u>, 975F2d871 (DC Cir. 1992), and <u>Public Citizen Health Research Group v. FDA</u>, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a., (4)b., and (4)c., above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed GE fuel data and evaluation interpretative results of the impact of fast transients on gap release functions as they relate to the present and future BWR fuels for the Boiling Water Reactor ("BWR"). Besides the inherent value of the GE fuel data, substantial resources have been expended by GE to develop this information in support of the BWR Owners' Group.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 31 day of March 2006.

Jason S. Post

Jason S. Post
General Electric Company