JNC TN9400 99-049

Analysis of measurements for a Uranium-free core experiment at the BFS-2 critical assembly

April 1999

O-arai Engineering Center
Japan Nuclear Cycle Development Institute

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Abstract

This document describes a series of calculations that were carried out to model various measurements from the BFS-58-1-I1 experiment. BFS-58-1-I1 was a mock-up of a uranium-free, Pu burning core at BFS-2, a Russian critical assembly operated by IPPE. The experiment measured values of Keff, Na void reactivity worth, material sample reactivity worths and reaction rate ratios.

The experiments were modelled using a number of different methods. Basic nuclear data was taken from JENDL-3.2, in either 70 or 18 groups. Cross-section data for the various material regions of the assembly were calculated by either SLAROM or CASUP; the heterogeneous structure of the core regions was modelled in these calculations, with 3 different options considered for representing the (essentially 2D) geometry of the assembly components in a 1D cell model. Whole reactor calculations of flux and Keff were done using both a diffusion model (CITATION) and a transport model (TWOTRAN2), both using an RZ geometry. Reactivity worths were calculated both directly from differences in Keff values and by using the exact perturbation calculations of PERKY and SN-PERT (for CITATION and TWOTRAN2, respectively).

Initial calculations included a number of inaccuracies in the assembly representation, a result of communication difficulties between JNC and IPPE; these errors were removed for the final calculations that are presented. Calculations for the experiments have also been carried out in Russia (IPPE) and France (CEA) as part of an international comparison exercise, some of those results are also presented here.

The calculated value of Keff was 1.1%Δk/k higher than the measured value, Na void worth C/E values were ~1.06; these results were considered to be reasonable. (Discrepancies in certain Na void values were probably due to experimental causes, though the efect should be investigated in any future experiments.) Several sample worth values were small compared with calculational uncertainties, for other cases C/E values of 1.1 to 1.3 were typical, values that are rather high. Reaction rate ratio C/E values were beyond the bounds of what was considered reasonable.

The data describing the BFS-58-1-I1 assembly and experiments, as supplied by IPPE, is given in full in Appendix I. Those modifications to the data necessary to produce a practicable calculational model are described in Appendix II. Appendix III shows datafiles created to represent the assembly.

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BFS-2におけるウラン無し炉心臨界実験の解析結果

(研究報告書)

スチュアート・ハンター*

要 旨

本報告書は、ロシア・オブニンスク物理エネルギー研究所(IPPE)の臨界実験施設BFS-2において実施されたBFS-58-1-I1実験の測定値に対する解析結果を記載したものである。同実験体系は、Pu燃焼炉としてUが存在しない炉心を構成したものである。測定量は、実効増倍係数、Naボイド反応度価値、物質サンプル反応度価値及び反応率比である。

解析における基本核データライブラリは、JENDL-3.2を用いた。種々の物質構成を持つ実験体系各部の実効断面積はSLAROM及びCASUPにより求めた。この際、2次元的な物質配置を1次元非均質モデルで処理するために、3種類のオプションを用いて検討を行った。中性子束分布及び実効増倍係数は、2次元r-z体系で、拡散理論(CITATION)及び輸送理論(TWOTRAN2)を用いて求めた。反応度価値は、直接計算及び厳密摂動計算(拡散計算の場合PERKYを、輸送計算の場合SN-PERTを使用)によって求めた。

実験体系仕様及び実験結果の詳細は、ロシアへの委託研究ISTC-220の報告書をベースに、不明点をIPPE技術者から追加入手した。解析結果については、ISTC報告会でIPPE及び仏CEAの結果を入手した。参考のため、本実験値に対するIPPE及び仏CEAによる解析値も記載した。

実効増倍係数は、解析値が実験値に対して1.1%δk/kk'大きかった。Naボイド反応度価値のC/E値は約1.06だった。これらは実験解析上の誤差を考慮すれば整合性に問題ない結果と考えられる。物質サンプル反応度価値のC/E値は概ね1.1～1.3の範囲であり、各種反応率比のC/E値は1.0からのずれが大きかった。これらについては、実験解析上の誤差からは合理的な説明ができず、IPPE提示の実験誤差や今回使用した解析モデルの改善等についてさらなる検討が必要である。

本実験解析の実施により、Uが存在しない炉心体系における解析精度に関する情報が初めて得られたことに加え、今後推進されるロシアとの研究協力を通じて解析対象とすべきBFS-2臨界実験体系のモデル化に関する知見を蓄積できた。

なお、今後の検討に資するため、BFS-58-1-I1実験体系に関するIPPEの提示情報、計算モデル構築上修正する必要性が生じた情報、及び解析用データセットをそれぞれ付録にまとめた。

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1 Introduction

There have been many studies undertaken to examine the possible adaptation of LMFBR designs so that they burn, rather than breed, plutonium[1-1 to 1-3]. This work is of particular relevance to the former Soviet Union, where there are large stockpiles of military grade plutonium, and the economic situation strongly supports the exploitation of this material as a fuel resource, rather than incurring the cost burdens associated with storage and disposal.

Characteristic of plutonium burning MOX cores[1-4] is a reduced uranium fraction in the plutonium-uranium fuel mix, with the limit of a uranium free core delivering the best performance in terms of plutonium burning rates. With this increased plutonium enrichment, a smaller fuel inventory is required to produce a critical core. In adapting a breeder core to plutonium burning, the reduction in fuel inventory is typically achieved by replacing some of the fuel pellets by an inert diluent material.

The increased plutonium fraction and the presence of diluent material have a number of effects on the characteristics of a plutonium burner core, when compared with a traditional breeder design. The reduction (or elimination) of the uranium fraction greatly reduces the Doppler effect, because of the large contribution from ^{238}U. Similarly, the loss of reactivity with burn-up is increased, because of the lack of in-core Pu breeding from ^{238}U. There are significant changes in the flux spectrum; in particular, the moderating effect of diluent and the removal of the breeder zones (which have a buffering effect) cause a softening of the spectrum in the core. Because of the differences in core characteristics, calculational methods developed and validated for traditional breeder reactor designs do not necessarily remain equally valid for use with plutonium burning designs. Likewise, in conjunction with the comparatively coarse group structure condensations used in reactor physics calculations, the changes in spectrum have the potential to modify basic nuclear data.

Critical assembly experiments are used in order to evaluate the validity of nuclear data and reactor physics calculation methods, and where necessary they provide a basis for data adjustments and correction factors. A first critical assembly which included a mock-up of the uranium free configuration of an efficient plutonium burning core was assembled at the Russian BFS-2 experimental facility[1-5]; the analysis of this critical assembly experiment, BFS-58-1-I1, is the subject of the current report.

The experiment measured a number of parameters - Na void worth, reactivity worths of material samples, reaction rate ratios. Various calculational methods adopted as standard at PNC have been used to model the BFS-58-1-I1 assembly and calculate values for the experimental measurements. This

analysis was in the framework of an international collaboration, with the experiment also being modelled in Russia (IPPE) and in France (CEA).

2 The BFS-58-1-I1 Assembly

This section gives a description of the BFS-58-1-I1 assembly and experiments, and of those simplifications of the assembly geometry that were made to facilitate the effective modelling of the experiments. Full details of the data are given in the various appendices.

2.1 BFS-58-1-I1 Configuration

The BFS-2 facility allows the collection of an assembly, consisting of a number of S/As spaced on a hexagonal array and located on a steel support structure. Each S/A comprises a cylindrical steel wrapper tube, inside of which is a stack of cylindrical blocks of various materials used in the construction of a fast reactor core and associated structures. The choice of the cylindrical blocks used defines the design of different S/As within a BFS-2 assembly.

The BFS-58-1-I1 experimental assembly was constructed with the aim of representing a Pu burning core with uranium-free fuel and a fraction of Al_2O_3 diluent in the core. The amount of Pu available for the BFS-2 facility was insufficient to create a complete assembly with just U-free fuel. For the BFS-58-1-I1 experiment, U-free fuel was represented in the S/As of the central region of the assembly, but the outer S/As represented MOX fuel. The MOX fuel S/As used were those remaining in the assembly from a previous experiment, they had been designed to represent a core for the BN-800 fast reactor.

In the BFS-58-1-I1 assembly there are just 6 different designs of S/As, defined by the configuration of cylindrical blocks stacked in the wrapper tube. Generally, the stacks consist of several regions each with a single block type; but in those regions representing the reactor core there is a complex repeating cell structure comprising blocks of a number of different materials. The 6 S/A designs represent different reactor S/As as follows:

- Pu fuel with Al_2O_3 diluent
- LEZ (low enrichment zone) fuel, with type 'green' Na [Pu & depleted UO_2]
- LEZ fuel, with type 'laser' Na [otherwise identical to the other LEZ fuel]
- MEZ (medium enrichment zone) fuel [enriched U-235 & depleted UO_2]
- Control rod [rod follower, absorber is withdrawn]
- Radial blanket

The LEZ and MEZ S/As and nomenclature come from the preceeding BN-800 experimental assembly.

The configuration of each of the 6 S/A types as a series of axial zones of different compositions is shown in Appendix I. The appendix also includes a plan of each of the layout of the 6 S/A types in the assembly, as well as other data.

2.2 Experimental Measurements

The measurements carried out on BFS-58-1-I1were of 3 kinds: the reactivity worth of Na voiding in the central region of the core; the reactivity worth of introducing samples of different materials in the core centre; the ratios of various reaction rates. A value for the k-effective of the assembly was also measured.

The Na void worths were obtained from measurements of the reactivity (k-effective) of the assembly in different configurations. The Na voiding was achieved by temporarily removing S/As from the assembly and replacing certain of the Na blocks in the stack with equivalent 'empty' boxes (i.e. blocks with no Na inside). Na was only removed from the central fifth of the core axial region. Only central Pu fuel S/As were voided, with measurements for 19 S/As (rings 1 to 3), 37 S/As (rings 1 to 4) and 18 S/As (ring 4 only) voided. All 3 measurements were made with all other S/As unvoided. A fourth measurement was made: voiding 18 S/As (ring 4) with rings 1 to 3 voided throughout the measurement.

Reaction rates were measured using a variety of different detectors. All detectors were placed axially near the core centre plane; some were placed in the gaps between wrapper tubes, others replaced the central Pu fuel S/A. Relative reaction rates were measured for a number of different pairs of reactions.

The samples were in the form of rods, up to 7.1 mm in diameter and from 100 to 141 mm in length. Each was inserted in the gaps between wrapper tubes, at the centre of the assembly and axially to the centre of the core region. The reactivity worth of inserting a sample was measured using the oscillation method. The experiment measured a total of 34 different samples, comprising 16 different materials.

Appendix I gives further details of the experimental measurements, including their results.

2.3 Modelling Assumptions.

In order to produce a workable computer model of the BFS-58-1-I1 experimental assembly, a number of simplifying assumptions were applied to the geometry of the assembly. Where details of the BFS-58-1-I1 assembly are referred to, more information can be obtained from Appendix I.

The reactor S/A layout, other than the central Pu fuel zone, is not quite symmetric However, the hexagonal S/A array was represented in the simpler geometry of a 2D (RZ) reactor model. This greatly reduces the computing resources required, and since all the experimental

measurements took place at the centre of the assembly the effect of the assumption should be minimal.

Nuclear data was calculated to represent each of the different axial zones of the 6 S/A types. Where a zone has axial structure (in the core zones) this was modelled, but the radial structure of the block and wrapper tube in a hexagonal cell was not modelled. For non-fuel zones an homogeneous cell model of blocks, wrapper and surrounding air was used; for core zones various cell models were examined, sub-section 3.2 gives details.

There are minor variations in the height of the core zones in the 4 designs of fuel S/A. They were too small to sensibly represent them as different axial meshes within the reactor model, so the core region was adjusted to be the same height in all 4 fuel S/As, taking the innermost type, the Pu without U fuel, as the definitive core height. Material number densities were adjusted, to maintain the core material mass unaltered.

Similar to the core zones, the 4 designs of fuel S/A contain Na plenum and B_4C/Na shield zones that are not all of the same height. The differences are caused by minor discrepancies in the heights of the 'laser' Na and 'green' Na blocks (though they have the identical masses of isotopes, see appendices I & II). In the reactor model, 'laser' Na was used throughout to give a uniform height. The 'green' Na blocks contain one isotope, Hydrogen, which is not present in the 'laser' Na: the model was adjusted to correct for this in the Na plenum zones (though not in the B_4C/Na shield zones).

Not all the 6 rod types have exactly the same height of block stack. The reactor model would display numerical instability if it included regions where there were no material blocks. To overcome this, the shorter S/As (MEZ fuel and Control Rods) were assumed to have an added region of Al shield, to bring them up to the same height as the LEZ and Pu without U fuel S/As. Since only a relatively small amount of material is involved, at the edge of the assembly, adding this material had very little effect on the results of the calculations.

The available axial layout data for the control rod is not completely consistent: the height of the Na region is specified as a number of blocks (but there are 2 possible types of blocks, of different heights), its top is also specified relative to the core region (in other S/As). The latter definition has been assumed. The possible difference is small, there are few control rods and they are not near the central (experimental) region of the assembly, so the effect should be negligible.

The radial blanket S/As have a stack of blocks ~75 cm taller than any of the other S/As; this corresponds to the height of the steel support structure, it was uncertain whether these blocks are in place of the steel support.

The steel support was not included in the model of these S/As; they were taken to be just the stack of blocks (with wrapper tube) to the whole height of the model. Since the edge of the assembly is involved, the effect of any variation will be minimal.

The materials introduced in the sample worth experiments are represented in the calculations by modifying the nuclear data over the volume of a single central S/A and an axial height of 13.2 cm, with the sample material mixed with the wrapper tube in the cell model. The actual samples consisted of rods of a few millimetre diameter and various lengths in the region of 13 cm.

2.4 Initial Data Variants

The data for the BFS-58-1-I1 experimental assembly was provided by IPPE of Russia, with contact being generally by e-mail rather than face-to-face. As a result of communication difficulties, the earlier calculations carried out by JNC incorporated some erroneous data. The data has since been corrected, but it was not considered necessary to repeat early scoping calculations, their conclusions remained valid. The errors were as follows.

The wrapper thickness was at first taken to be 0.1 mm, whereas the actual value is 1.0 mm. When corrected, this increased the smeared number density of the steel isotopes by 50 - 100% in core zones, and even more in some non-core zones.

The wrapper tube was originally believed to be hexagonal, not circular. This resulted in a small error in wrapper mass, but the effect was subsumed in that of the wrapper thickness error.

There was at first no data available on which S/A positions corresponded to which of the two types of LEZ fuel S/A. So a single LEZ fuel S/A was modelled, corresponding to a mix of both 'laser' Na and 'green' Na versions of the LEZ fuel.

In all the calculations that used a single averaged LEZ fuel S/A, as well as some in which the 'laser' Na and 'green' Na versions of the LEZ were modelled explicitly, the wrong proportions of the 2 LEZ fuel types were used: 170 'laser' Na and 288 'green' Na S/As, rather than 224 'laser' Na and 234 'green' Na.

The nuclear data file used with the CASUP calculations didn't include all the isotopes present in the BFS-58-1-I1 experiment. The missing isotopes were: Pu^{238}, Ti, Ga, Li^{6}, Li^{7}, N^{14} and N^{15}. A new nuclear data file was created for later CASUP calculations, including all isotopes.

3 Modelling Methods

The following sub-sections describe the various computer programs (sub-section 3.1) used to model the BFS-58-1-I1 experiments, and the main characteristics of the model they are used to create. For detailed information on the model, refer to the three appendices. Appendix I gives the data that describes the BFS-58-1-I1 assembly and experiments, whilst appendix II details how that data was modified to produce a practical model; appendix III presents computer data files for the model.

3.1 Computer Programs

A number of different computer programs are used to carry out the various stages of the calculations to represent the BFS-58-1-I1 experiments. Furthermore, alternative methods were available for each of the stages and the study has included some comparison of different methods.

There are 3 basic stages to the calculation route, the later stages require data produced in the preceeding stage(s). First are cell model calculations, to calculate nuclear data appropriate to each of the regions of the assembly with different isotopic compositions. Second are whole reactor calculations of reactivity and flux distribution. Finally are perturbation calculations of the reactivity differences caused by the small changes to the assembly configuration by the various experiments. There are a few other calculations (e.g. nuclear data condensation, β-eff calculations), but all are based on the above 3 calculation types.

Two different programs were used for the cell calculations: SLAROM[3-1] and CASUP. These both use the collision probability method to solve the transport equations. The main difference are in the methods used to represent the flux reduction across an array of fissile material. SLAROM uses Dancoff factors, which implicitly assumes that such an array is completely regular. CASUP uses a more general method, that due to Tone[3-2], which is in principle applicable to any distribution of fissile material.

The reactor calculations were carried out using either a diffusion model, CITATION[3-3], or a transport model, TWOTRAN2[3-4]. Both were used in 2D (RZ) geometry, with an identical representation of the experimental assembly configuration. S_4 order calculations were used in the transport model. (An attempt was made to also use a 3D (hex-Z) model, MOSES, but problems were encountered, caused by the large size of the model.)

The two perturbation programs used, PERKY[3-5] and SN-PERT[3-6], performed exact perturbation calculations, based on the results of CITATION and TWOTRAN2 calculations, respectively. An alternatve, simpler method of calculating

reactivity differences was to use the difference in Keff values from whole reactor calculations.

3.2 Fuel Region Cell Models

For most material regions the calculations of nuclear data just used a homogeneous model, with a smeared average number density. However, for the core fuel regions a 1D heterogeneous model representing the structure of the stack of blocks was used. Each model consists of a series of regions, each representing a single block (with an averaged number density within the block).

The blocks are not the only material in the core regions: there is also the wrapper tube and the surrounding air and making up the hexagonal cell of the S/A; in the MEZ fuel there are also some steel rods. Three possible methods of incorporating this radial structure in the 1D (axial) cell model were examined:

Increase the cell model height by adding sections consisting of wrapper tube and air to the stack of blocks.

Increase the cell model height by mixing the wrapper tube and air into each of the material blocks (excluding those with fissile material).

Ignore the wrapper tube and air, just model the stack of material blocks.

Figure 3.1 shows, in a representative manner, the actual 2D geometry and the three 1D cell models used.

Nuclear data for that part of the core where the sample is inserted during sample reactivity worth measurements is calculated by including the sample material in the same section of the cell model as the wrapper tube and air. For the option that did not include the wrapper tube and air, the sample material was added to all non-fissile materials in the block stack.

3.3 Modelling Details

Nuclear data used in the calculations was taken from JENDL-3.2[3-7], primarily in 70 energy groups, though some calculations were done for 18 energy groups.

For a brief examination of the effect of mesh size, a core flux mesh was used in which both axial and radial meshes were essentially of a uniform ~3 cm size; this was then repeated with the mesh size halved to ~1.5 cm. The core flux meshes used in the main calculations are as shown in appendix II: approximately 4.4 cm axially and 3 cm radially, but reduced to ~2.2 cm and ~2.3 cm respectively in the region of the material samples/Na void.

The reactivity worths of the material samples were small, from 2.4×10^{-4} to as low as 1.1×10^{-6} $\Delta k/k$, so it was

necessary to set tight convergence criteria on the reactor Keff calculations. Having regard for the CITATION and TWOTRAN2 programs using only single precision arithmetic, the convergence criteria used were 10^{-6}.

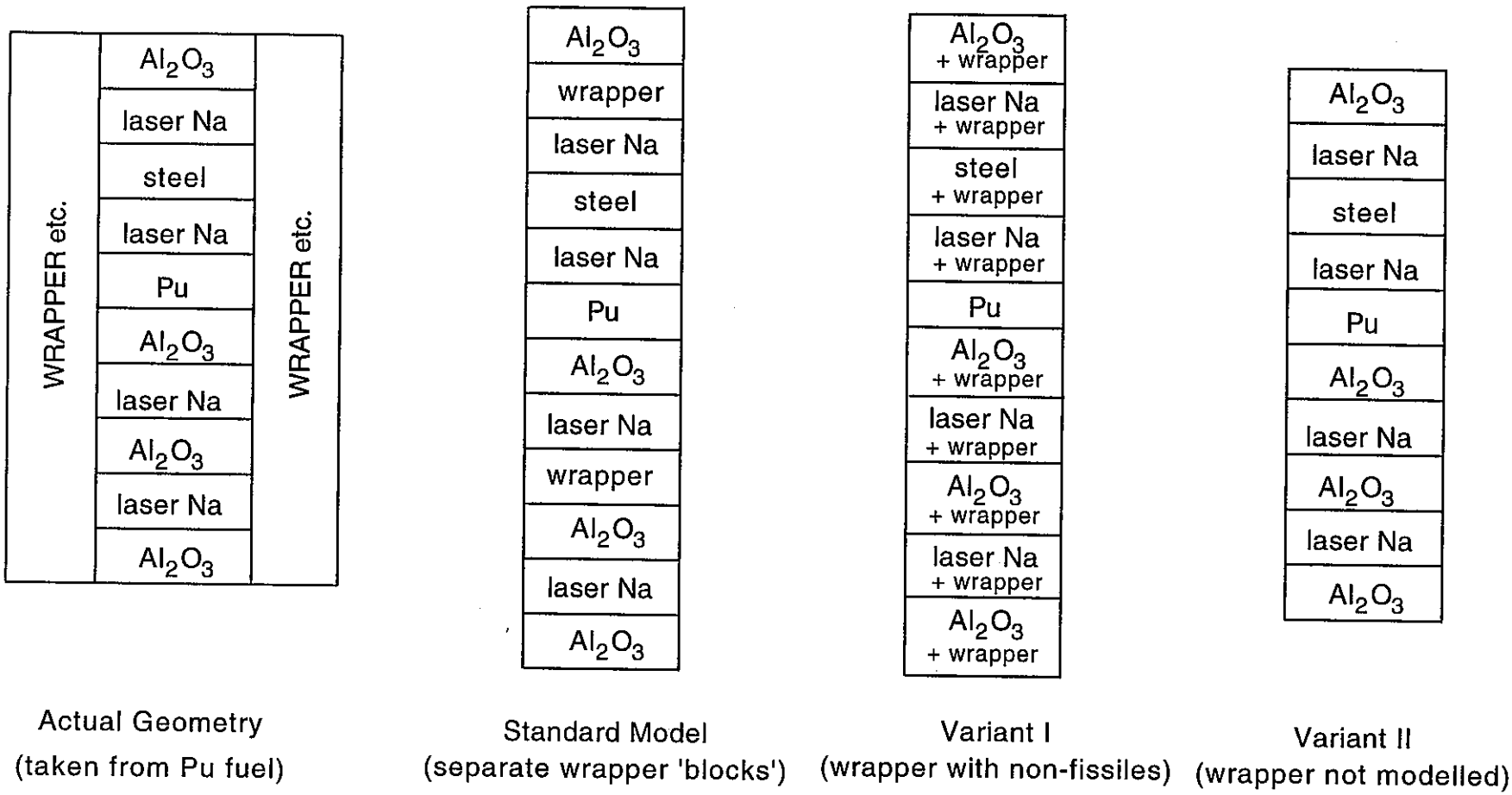


Figure 3.1 The 3 fuel region cell model options

4 Calculational Results

Initial calculations, done whilst the calculational model was still undergoing development, are presented in sub-section 4.1; these scoping calculations were such that the results will not be significantly affected by the inaccuracies of the initial model. In sub-section 4.2 results are presented for calculations with the finalized version of the model, including an assessment of errors. Sub-section 4.3 presents the results of some independant calculations for the BFS-58-1-I1 experiment.

4.1 Initial Scoping Calculations

Initially the model used for the calculations included various inaccuracies as described in sub-section 2.4. Calculations were done that examined the effects of correcting these factors. Calculations also examined the effects of using the different models and calculational methods of section 3. Despite the inaccuracies in the model, the calculations allow a number of conclusions to be drawn.

4.1.1 K-effective Results

Table 4.1 shows the calculated values of Keff for various combinations of modelling assumptions and methods. Of the modelling inaccuracies: those involving the LEZ fuel have a negligible effect; the use of an incomplete isotope set increased Keff by 0.1%; using a wrapper thickness of 1/10'th the actual value reduced Keff by as much as 2.5%. Examining the different modelling assumptions: the standard mesh was essentially no different from the uniform mesh of ~3cm, but halving the latter to ~1.5cm reduced Keff by ~0.2%; the 3 fuel cell models were responsible for Keff variations of more than 0.5%; changing from 70 to 18 groups had a negligible effect using CITATION, but when using TWOTRAN2 the Keff value reduced by more than 0.3%. The CASUP and SLAROM cell model program produced differences in Keff of less than 0.1%, whilst changing from the diffusion (CITATION) to the transport (TWOTRAN2) program increased Keff by more than 3%.

The error in wrapper thickness was the only modelling inaccuracy that had a significant effect. At first sight it seemed anomalous that increasing the amount of steel wrapper in the core caused an increase in reactivity, though the result was consistent with the effect of completely removing the wrapper from the fuel cell model. A SAGEP sensitivity analysis of the reactivity[4-1] confirmed the result and showed that the main contributions to the reactivity increase came from elastic scattering in Fe, Ni and Cr. This was judged to be related to the softened spectrum and significant fission at low energies that are typical of a Pu burning core with diluent.

4.1.2 Na Void Results

The results of calculations modelling the Na void experiments are shown in Table 4.2. All reactivity worth values are given as a percentage of the delayed neutron fraction (βeff); a value was calculated for βeff, 3.5725×10^{-3}. The results of Table 4.2 can clearly be divided into two sets, for two of the experiments all calculations give reasonable agreement (within -10% to +15%), but for the two other experiments there are much larger discrepancies. The problem cases both involve the state with 19 S/As voided as either the start or end point of the experiment: the most likely cause of the discrepancies would appear to be some fault in the experimental measurement of this state, though the available information has been checked by IPPE and no irregularities have been uncovered. For this study, the Na void measurements involving the 19 S/As voided state have been excluded from further consideration.

The choice of fuel cell model was seen to have a significant effect; the version with the wrapper etc. modelled as separate regions gave the most accurate results, the other options giving void worths ~11% higher. Reducing the number of energy groups from 70 to 18 reduced the void reactivity by ~13%: it is known[1-4] that the coarser spectrum can cause inaccuracies in Na void values for a Pu burning core. The CASUP and SLAROM based values differ by ~3%, but the difference is at least in part due to the CASUP calculations using the reduced set of isotopes. The TWOTRAN2 transport calculations produced void worths ~3% higher than the CITATION diffusion calculations. The PERKY perturbation calculations differed from the direct calculations from Keff differences by only ~1%.

4.1.3 Sample Worth Results

Table 4.3 shows the results of calculations of the material sample worth experiments. The results are given both as absolute values (a percentage of βeff) and relative to the measured values (C/E ratios). The calculational accuracy is limited by the convergence criteria used in calculating Keff values, the difference in Keff values has an uncertainty of 0.06% βeff from this source alone. Most of the sample worth values are small; for half of the cases the above uncertainty is significant, from 10% to as much as 200% of the measured value.

Some of the material samples - C, Na, Al, Al_2O_3 and $Pu^{240}O_2$ - have such a low reactivity worth that the calculational uncertainty dominates and little if any reliance can be placed on those results. The results for $(CH_2)_n$ show C/E values that are rather larger than other cases, these C/E values also increase with the mass of the $(CH_2)_n$ specimen: it was concluded that there is a significant shielding

effect within the $(CH_2)_n$ sample, which is beyond the scope of the fuel cell models used.

Ignoring the above sample materials,a number of general conclusions were drawn. Since alterations in the modelling of LEZ S/As had a negligible effect (sub-section 4.1.1), the differences between the sample worths with different LEZ representations are indicative of the effects of the calculational uncertainty. Of the 3 different fuel cell models used, that modelling the wrapper as separate regions tended to produce the better (less extreme) results. TWOTRAN2 tends to produce higher values than CITATION; there seems to be no definite trend as to differences between SLAROM and CASUP (the latter with only a partial set of isotopes); the use of a perturbation calculation, rather than a direct difference of Keff values, tended to produce higher C/E values, the difference was more noticeable with SN-PERT (used with TWOTRAN2) than for PERKY (used with CITATION).

There is a general tendency for C/E values to increase with sample mass, indicative of the existence of sample shielding effects not included in the model. This effect is to some extent masked by the large uncertainties, but for sample materials with a large worth (Li^6, B^{10}) the effect is clear; B^{10} was the only sample material (other than $(CH_2)_n$) for which the size of the effect was clearly significant (>5%).

For the final calculations of sub-section 4.2, a small number of sample worth experiments were selected. These were chosen to as far as possible span the range of materials, but limited to just cases where the absolute sample worth was high relative to the uncertainty. The 10 cases chosen were: 1 (U^{235}); 2 (U^{238}); 4 (B^{10}); 9 ((CH2)n); 13 (Pu^{239}); 19 (AmO_2); 23 (NpO_2); 26 (Li^6); 31 ($Pu^{240}O_2$) and 34 ($Pu^{239}O_2$).

4.1.4 Reaction Rate Results

The ratios of specific nuclear reaction rates, at the core centre, were calculated based on a 70 group CITATION calculation using nuclear data prepared using SLAROM with the wrapper represented as separate regions in the fuel cell model. The model included the initial inaccuracies of using the wrong proportions of the two LEZ fuel types, and of using the wrong wrapper thickness.

Table 4.4 shows the ratios of various fission reaction rates, both measured and calculated values. The C/E ratios show a much greater variation from unity than was expected for the relatively well-known major fission reactions.

4.2 Final Corrected Calculations

Final sets of calculations were done, with all the modelling inaccuracies of sub-section 2.4 corrected. The

fuel cell model adopted was that in which the wrapper was modelled as a separate region. 70 group nuclear data was used. The sample worth calculations were limited to 10 cases in which uncertainties did not dominate (see sub-section 4.1.3).

Table 4.5 shows the results, both as a percentage of βeff and as C/E ratios, using various combinations of the computer programs. The effects of changing a single calculation method - CASUP for SLAROM, TWOTRAN2 for CITATION, perturbation calculation for Keff difference - are shown as multipliers on C/E values in Table 4.6. To calculate the effect of TWOTRAN2/CITATION, the transport-diffusion correction factor, a CITATION calculation was adjusted to use the same isotropic nuclear data as is used in the transport calculation. The effects of altering calculation methods are generally no more than ~1% change in C/E, though the transport-diffusion corrections for the Na void values are >3%, and for one sample the CASUP - SLAROM effect is >5%.

A final set of C/E values, the 'best estimate' values from the calculations, are shown in Table 4.6 ; they were produced by taking the cases calculated using CASUP, CITATION and PERKY, then applying the transport-diffusion correction factors. Whilst the C/E values for the Keff and Na void values appear reasonable at ~1.01 and ~1.06 respectively, for the sample worths the C/E values are typically in the range 1.1 to 1.3, with values as high as 1.6.

There are various errors and uncertainties in the 'best estimate' C/E values; Table 4.7 lists both the errors associated with the measurements themselves (from appendix I) and the uncertainties (i.e. correction factors) associated with each of the calculational models. How these various components are combined to give a single overall uncertainty value for each case depends on the purpose for which they will be used. The final column of Table 4.7 shows overall uncertainties calculated on the basis of a linear combination of the measurement error with half of each modelling uncertainty factor; the values are generally 1-2% for the sample worths, but ~15% for the Na void worths.

4.3 Russian and French Calculations

In addition to the calculations as described in this report and carried out at JNC (Japan), the BFS-58-1-I1 experiment has also been the subject of modelling calculations performed at IPPE (Russia) and also at CEA (France). There has been a comparison exercise involving the three sets of calculations [4-2], though when that was carried out the final results of the JNC study (sub-section 4.2) were not available. The following gives a description of key results of the Russian and French studies, as well as some

details of their methods; more detailed information on these calculations was not currently available.

4.3.1 Methods

The Russian calculations made use of the following methods. The nuclear data was taken from ABBN-93[4-3], with the core regions modelled either homogeneously or heterogeneously by the FFCP code[4-4], which used the first collision method in a transport approach and included resonance self-shielding of the main plutonium isotopes using the subgroup method. Three different reactor models were used: TRIGEX[4-5], a 3D diffusion code in hex-Z geometry; MCNP[4-6], a 3D transport code, using Monte-Carlo methods in real geometry; TWODANT[4-7], a 2D transport (S_8) code in RZ geometry.

The French calculations were carried out using the ERANOS[4-8] calculational scheme. Both the unadjusted JEF-2.2[4-9] and the adjusted ERALIB-1[4-10] nuclear datasets were used. The heterogeneous cell code ECCO[4-11] was used to produce self-shielded cross-sections using the subgroup method within each fine energy group and the slowing down treatment. The ERANOS code scheme included both diffusion and transport methods for reactor calculations.

4.3.2 Results

Table 4.8 shows Keff values produced with various modelling options;the differences between transport and diffusion calculation methods are around 1%, which is comparable with about 0.6% difference of the JNC calculations(keff difference between the option VII and VIII shown in Table 4.5). Russian calculations of Na void values are shown in Table 4.9 , they are very similar to the JNC results, showing the same discrepancy with the measurements involving the '19 S/As voided' state.

Sample worths are given in two formats: Table 4.10 shows values, for both France and Russia, calculated using perturbation methods and normalized to the U^{235} reactivity worths; Table 4.11 shows unnormalized Russian values, calculated from direct differences in Keff. Except for cases where the sample worth is very low, and the contaminated Al_2O_3 sample, the C/E values are generally good, particularly for the Russian heterogeneous transport calculations.

Reaction rate ratios are shown in Table 4.12. The C/E values calculated with a homogeneous cell model show some significant variations from 1.0, but (with the exception of U^{236}) all the heterogeneous calculations showed good agreement with experiment, the French ERALIB-1 results were particularly good. This is in contrast with the poor reaction rate ratios from the JNC calculations (Table 4.4).

Table 4.1 Keff values calculated with various options for the model and methods

LEZ FUEL MODEL	ISOTOPES MODELLED	WRAPPER THICKNESS	CELL MODEL	GROUPS	FLUX MESH	FUEL CELL PROGRAM	REACTOR PROGRAM	Keff VALUE
1 smeared type	all	* 0.1	separate wrapper	70	~3 cm	SLAROM	CITATION	0.98064
2 types	all	* 0.1	separate wrapper	70	~3 cm	SLAROM	CITATION	0.98061
2 types, correct ratio	all	* 0.1	separate wrapper	70	standard	SLAROM	CITATION	0.98060
1 smeared type	reduced set	* 0.1	separate wrapper	70	~3 cm	SLAROM	CITATION	0.98177
2 types correct ratio	all	correct	separate wrapper	70	standard	SLAROM	CITATION	1.00535
1 smeared type	reduced set	* 0.1	separate wrapper	70	~3 cm	CASUP	CITATION	0.98201
1 smeared type	reduced set	* 0.1	separate wrapper	70	standard	CASUP	CITATION	0.98200
1 smeared type	all	* 0.1	separate wrapper	18	~3 cm	SLAROM	CITATION	0.98064
1 smeared type	all	* 0.1	separate wrapper	18	~1.5 cm	SLAROM	CITATION	0.97851
2 types	all	* 0.1	no wrapper	70	~3 cm	SLAROM	CITATION	0.97911
2 types	all	* 0.1	wrapper in non-fuel	70	~3 cm	SLAROM	CITATION	0.98462
1 smeared type	reduced set	* 0.1	separate wrapper	18	standard	CASUP	CITATION	0.98198
1 smeared type	all	* 0.1	separate wrapper	70	standard	SLAROM	TWOTRAN2	1.01372
1 smeared type	all	* 0.1	separate wrapper	18	~3 cm	SLAROM	TWOTRAN2	1.01713
1 smeared type	reduced set	* 0.1	separate wrapper	18	standard	CASUP	CITATION	0.98198
1 smeared type	reduced set	* 0.1	separate wrapper	18	standard	CASUP	TWOTRAN2	1.01372
Measured Value								1.00035

Table 4.2 Na void values calculated with various options for the model and methods

CELL MODEL	ENERGY GROUPS	FUEL CELL MODEL *	REACTOR MODEL	REACTIVITY METHOD	Na void reactivity worth, %βeff			
					0-18	0-37	0-19	19-37 **
separate wrapper	70	SLAROM	CITATION	ΔKeff	7.57	15.84	8.24	7.60
no wrapper	70	SLAROM	CITATION	ΔKeff	8.45	17.54	9.14	8.40
wrapper in non-fuel	70	SLAROM	CITATION	ΔKeff	8.42	17.44	9.09	8.34
separate wrapper	70	CASUP	TWOTRAN2	ΔKeff	8.05	16.81	8.73	8.08
separate wrapper	70	CASUP	CITATION	ΔKeff	7.82	16.38	8.51	7.87
separate wrapper	70	CASUP	CITATION	PERKY	7.78	16.27	8.48	-
separate wrapper	18	CASUP	CITATION	PERKY	6.74	14.23	7.40	-
separate wrapper	18	CASUP	CITATION	ΔKeff	6.80	14.36	7.44	6.92
Experimental Values					7.3 ± 1.0	15.4 ± 1.8	12.2 ± 1.0	3.2 ± 0.8

* CASUP calculations use reduced set of isotopes, SLAROM calculations use all isotopes

** No. of S/As voided in initial & final states

Table 4.3 Material sample reactivity worths calculated with various options for the model and methods

ENERGY GROUPS		70		70		70		70	
REACTIVITY METHOD		ΔKeff		ΔKeff		ΔKeff		ΔKeff	
FUEL CELL PROGRAM		SLAROM		SLAROM		SLAROM		SLAROM	
ISOTOPES MODELLED		all isotopes		all isotopes		all isotopes		all isotopes	
REACTOR PROGRAM		CITATION		CITATION		CITATION		CITATION	
LEZ FUEL MODEL		averaged LEZ		2 LEZ types		2 LEZ types		2 LEZ types	
CELL MODEL		separate wrapper		separate wrapper		no wrapper		wrapper in non-fuel	
WRAPPER THICKNESS		* 0.1		* 0.1		* 0.1		* 0.1	
Sample No.	Experimental value, %βeff	%βeff	C/E	%βeff	C/E	%βeff	C/E	%βeff	C/E
1	0.593	0.605	1.020	0.588	0.992	0.596	1.005	0.626	1.056
2	-0.815	-0.859	1.054	-0.862	1.058	-1.136	1.394	-1.176	1.443
3	-1.443	-1.304	0.904	-1.287	0.892	-1.410	0.977	-1.465	1.015
4	-5.665	-5.520	0.974	-5.529	0.976	-6.113	1.079	-6.435	1.136
5	-6.590	-7.034	1.067	-7.009	1.064	-7.898	1.199	-8.273	1.255
6	0.271	0.320	1.181	0.306	1.129	0.330	1.218	0.339	1.251
7	0.094	0.125	1.330	0.119	1.266	0.096	1.021	0.114	1.213
8	0.905	1.316	1.454	1.310	1.448			1.392	1.538
9	1.532	2.262	1.477	2.279	1.488			2.427	1.584
10	2.070	3.318	1.603	3.324	1.606			3.565	1.722
11	0.316	0.282	0.892	0.291	0.921	0.272	0.861	0.240	0.759
12	0.751	0.710	0.945	0.716	0.953	0.712	0.948	0.728	0.969
13	1.444	1.441	0.998	1.397	0.967	1.445	1.001	1.506	1.043
14	-0.081	-0.119	1.469	-0.111	1.370			-0.202	2.494
15	-0.101	-0.140	1.386	-0.134	1.327			-0.263	2.604
16	-0.122	-0.186	1.525	-0.193	1.582			-0.421	3.451
17	0.246	0.221	0.898	0.207	0.841			0.205	0.833
18	0.282	0.247	0.876	0.233	0.826			0.213	0.755
19	-0.783	-0.655	0.837	-0.635	0.811	-0.745	0.951	-0.775	0.990
20	-0.588	-0.498	0.847	-0.486	0.827	-0.575	0.978	-0.591	1.005
21	-0.754	-0.637	0.845	-0.667	0.885	-0.759	1.007	-0.795	1.054
22	-1.323	-1.150	0.869	-1.164	0.880	-1.299	0.982	-1.380	1.043
23	-1.561	-1.421	0.910	-1.424	0.912	-1.618	1.037	-1.690	1.083
24	-3.650	-3.354	0.919	-3.348	0.917	-3.685	1.010	-3.835	1.051
25	-4.942	-4.728	0.9567	-4.722	0.9555	-5.461	1.1050	-5.446	1.1020
26	-6.714	-6.531	0.9727	-6.513	0.9701	-7.293	1.0862	-7.568	1.1272
27	0.146	0.079	0.541	0.070	0.479	0.038	0.260	0.070	0.479
28	0.032	0.049	1.531	0.044	1.375	0.018	0.563	0.047	1.469
29	0.194	0.180	0.928	0.175	0.902			0.164	0.845
30	0.428	0.419	0.979	0.410	0.958			0.360	0.841
31	0.667	0.637	0.955	0.643	0.964			0.597	0.895
32	0.376	0.367	0.976	0.352	0.936			0.307	0.816
33	0.648	0.667	1.029	0.670	1.034			0.640	0.988
34	1.421	1.385	0.975	1.351	0.951			1.439	1.013

Table 4.3 (continued)

ENERGY GROUPS		70		70		70		70	
REACTIVITY METHOD		ΔKeff		SN-PERT		ΔKeff		PERKY	
FUEL CELL PROGRAM		SLAROM		SLAROM		CASUP		CASUP	
ISOTOPES MODELLED		all isotopes		all isotopes		partial isotopes		partial isotopes	
REACTOR PROGRAM		TWOTRAN2		TWOTRAN2		CITATION		CITATION	
LEZ FUEL MODEL		averaged LEZ		averaged LEZ		averaged LEZ		averaged LEZ	
CELL MODEL		separate wrapper		separate wrapper		separate wrapper		separate wrapper	
WRAPPER THICKNESS		* 0.1		* 0.1		* 0.1		* 0.1	
Sample No.	Experimental value, %βeff	%βeff	C/E	%βeff	C/E	%βeff	C/E	%βeff	C/E
1	0.593	0.599	1.010	0.616	1.039	0.552	0.931	0.561	0.946
2	-0.815	-0.910	1.117	-1.018	1.249	-0.868	1.065	-0.870	1.067
3	-1.443	-1.403	0.972	-1.507	1.044	-1.306	0.905	-1.301	0.902
4	-5.665	-6.236	1.101	-6.312	1.114	-5.531	0.976	-5.517	0.974
5	-6.590	-7.926	1.203	-7.991	1.213	-7.041	1.068	-7.023	1.066
6	0.271	0.441	1.627	0.324	1.196	0.311	1.148	0.317	1.170
7	0.094	0.207	2.202	0.110	1.170	0.096	1.021	0.109	1.160
8	0.905	1.378	1.523	1.336	1.476	1.321	1.460	1.331	1.471
9	1.532	2.416	1.577	2.299	1.501	2.310	1.508	2.317	1.512
10	2.070	3.429	1.657	3.348	1.617	3.404	1.644	3.391	1.638
11	0.316	0.365	1.155	0.303	0.959	0.270	0.854	0.279	0.883
12	0.751	0.858	1.142	0.751	1.000	0.679	0.904	0.688	0.916
13	1.444	1.610	1.115	1.534	1.062	1.393	0.965	1.398	0.968
14	-0.081	-0.076	0.938	-0.146	1.802	-0.128	1.580	-0.113	1.395
15	-0.101	-0.155	1.535	-0.193	1.911	-0.148	1.465	-0.148	1.465
16	-0.122	-0.338	2.770	-0.291	2.385	-0.209	1.713	-0.216	1.770
17	0.246	0.338	1.374	0.227	0.923	0.203	0.825	0.204	0.829
18	0.282	0.390	1.383	0.251	0.890	0.224	0.794	0.226	0.801
19	-0.783	-0.752	0.960	-0.773	0.987	-0.662	0.845	-0.663	0.847
20	-0.588	-0.414	0.704	-0.579	0.985	-0.517	0.879	-0.497	0.845
21	-0.754	-0.752	0.997	-0.780	1.034	-0.673	0.893	-0.670	0.889
22	-1.323	-1.169	0.884	-1.358	1.025	-1.187	0.897	-1.168	0.883
23	-1.561	-1.479	0.947	-1.666	1.067	-1.446	0.926	-1.434	0.919
24	-3.650	-3.716	1.018	-3.860	1.058				
25	-4.942	-5.351	1.0828	-5.418	1.0963				
26	-6.714	-7.250	1.0798	-7.438	1.1078				
27	0.146	0.183	1.253	0.062	0.425	0.061	0.418	0.061	0.418
28	0.032	0.079	2.469	0.039	1.219	0.038	1.188	0.037	1.156
29	0.194	0.259	1.335	0.188	0.969	0.168	0.866	0.178	0.918
30	0.428	0.545	1.273	0.422	0.986	0.383	0.895	0.395	0.923
31	0.667	0.779	1.168	0.659	0.988	0.601	0.901	0.613	0.919
32	0.376	0.493	1.311	0.370	0.984	0.331	0.880	0.345	0.918
33	0.648	0.806	1.244	0.702	1.083	0.639	0.986	0.650	1.003
34	1.421	1.558	1.096	1.476	1.039	1.358	0.956	1.355	0.954

Table 4.4 Comparison of calculated and measured values of reaction rate ratios

Fission Rate Ratios	Calculated Values	Measured Values	C/E
U238 / U235	0.01531	0.0118	1.297
Pu239 / U235	0.7587	0.904	0.839
Pu240 / U235	0.1528	0.0958	1.595
Pu241 / U235	1.241	1.40	0.886
Pu238 / Pu239	0.5947	0.394	1.509
Pu240 / Pu239	0.2014	0.108	1.865
Pu241 / Pu239	1.636	1.556	1.051
Pu242 / Pu239	0.1467	0.0753	1.948

Table 4.5 Results of calculations using the 'corrected' model and various methods

CALCULATION METHOD OPTIONS	I		II		VI		VII		VIII	
	CASUP		CASUP		SLAROM		CASUP		CASUP	
	CITATION		CITATION		CITATION		TWOTRAN2		isotropic CIT.	
	ΔKeff		PERKY		PERKY		SN-PERT		PERKY	
PARAMETERS	%βeff	C/E	%βeff	C/E	%βeff	C/E	%βeff	C/E	%βeff	C/E
Keff	1.00571	1.00536	1.00571	1.00536	1.00535	1.00500	1.02147	1.02111	1.01567	1.01531
Na 37 S/As	-16.980	1.103	-16.895	1.097	-16.888	1.097	-16.427	1.067	-16.960	1.101
void 18 S/As	-8.130	1.114	-8.087	1.108	-8.085	1.108	-7.866	1.078	-8.159	1.118
1 U^{235}	0.661	1.115	0.667	1.125	0.671	1.132	0.684	1.153	0.680	1.147
2 U^{238}	-1.292	1.585	-1.306	1.602	-1.296	1.590	-1.370	1.681	-1.366	1.676
4 B^{10}	-7.286	1.286	-7.263	1.282	-7.281	1.285	-7.509	1.326	-7.567	1.336
9 CH_2	2.219	1.448	2.197	1.434	2.207	1.441	2.172	1.418	2.214	1.445
13 Pu^{239}	1.663	1.152	1.644	1.139	1.640	1.136	1.693	1.172	1.680	1.163
19 AmO_2	-0.922	1.178	-0.911	1.163	-0.908	1.160	-0.955	1.220	-0.954	1.218
23 NpO_2	-2.004	1.284	-1.982	1.270	-1.974	1.265	-2.074	1.329	-2.074	1.329
26 Li^6	-8.393	1.250	-8.414	1.253	-8.473	1.262	-8.707	1.297	-8.764	1.305
31 PuO_2 (68%)	0.686	1.028	0.686	1.028	0.679	1.018	0.702	1.052	0.697	1.045
34 PuO_2 (78%)	1.558	1.096	1.548	1.089	1.640	1.154	1.589	1.118	1.575	1.108

Table 4.6 Effects of calculational methods, final transport-corrected results, using the 'corrected' model

	VII / VIII	II / VI	II / I	FINAL RESULT
	Transport Correction	fuel cell method effect	perturbation method effect	case II (CAS/CIT/PKY) TRANSPORT CORRECTED
Keff *	0.00580	0.00036	-	1.01116
Na 37 S/As	0.969	1.0	0.995	1.063
void 18 S/As	0.964	1.0	0.995	1.068
1 U^{235}	1.006	0.994	1.009	1.132
2 U^{238}	1.003	1.008	1.011	1.607
4 B^{10}	0.992	0.998	0.997	1.272
9 CH_2	0.981	0.995	0.990	1.407
13 Pu^{239}	1.008	1.002	0.989	1.148
19 AmO_2	1.001	1.003	0.988	1.164
23 NpO_2	1.0	1.004	0.989	1.270
26 Li^6	0.993	0.993	1.003	1.244
31 PuO_2 (68%)	1.007	1.010	1.0	1.035
34 PuO_2 (78%)	1.009	0.944	0.994	1.099

* for Keff the method effects are differences rather than ratios

Table 4.7 Errors and uncertainties, for the 'corrected' model

	(method effect ratio - 1) x Final Result				Uncertainty
	reactor method effect (C / E)	perturbation method effect (C/E)	cell method effect (C/E)	fractional measurement error	error + half of method effects
Keff *	0.00580	-	0.00036	(n/a)	(n/a)
Na 37 S/As	-0.033	-0.005	0.0	0.117	0.137
void 18 S/As	-0.038	-0.005	0.0	0.137	0.160
1 U^{235}	0.007	0.010	-0.007	0.002	0.014
2 U^{238}	0.005	0.018	0.013	0.004	0.022
4 B^{10}	-0.010	-0.004	-0.003	<0.001	0.009
9 CH_2	-0.027	-0.014	0.007	0.001	0.025
13 Pu^{239}	0.009	-0.013	0.002	0.001	0.013
19 AmO_2	0.001	-0.014	0.003	0.003	0.012
23 NpO_2	0.0	-0.014	0.005	0.001	0.011
26 Li^6	-0.008	0.004	-0.009	<0.001	0.011
31 $Pu^{240}O_2$ (68%)	0.009	0.0	0.010	0.003	0.013
34 $Pu^{239}O_2$ (78%)	0.010	-0.007	-0.062	0.001	0.041

* for Keff the method effects are differences rather than ratios

Table 4.8 Keff results from Russian and French calculations

	NUCLEAR DATA	No. of GROUPS	CELL MODEL	REACTOR MODEL	Keff
RUSSIA	ABBN-93	26	heterogeneous	TWODANT	1.00453
		26	homogeneous	TWODANT	1.00050
		instant	heterogeneous	MCNP	1.00431
		11	heterogeneous	TRIGEX	0.99754
		11	homogeneous	TRIGEX	0.98857
FRANCE	ERALIB-1	1968	ECCO	transport	1.00273
		1968	ECCO	diffusion	0.99000
	JEF-2.2	1968	ECCO	transport	1.00597
		1968	ECCO	diffusion	0.99357

Table 4.9 Na void worth results from Russian calculations

		TRIGEX		TWODANT	MCNP
		homogeneous	heterogeneous		
0 / 19	12.2 ± 1.0	7.61	8.22	8.41	8.2 ± 6.1
19 / 37	3.2 ± 0.8	8.32	7.66	7.77	
0 / 37	15.4 ± 1.8	15.93	15.88	16.18	15.9 ± 7.9
0 / 18	7.3 ± 1.0	7.84	7.55	7.66	

Table 4.10 Material sample worth results from Russian and French perturbation calculations (normalized to U^{235} values)

Material Sample	Measured Value	FRANCE		RUSSIA
		JEF-2.2	ERALIB-1	ABBN-93
U^{235}	1.000	1.000	1.000	1.000
U^{238}	-0.850	1.233	1.278	1.027
B^{10}	-4.140	0.934	0.979	0.966
C	0.0126	1.984	2.143	0.952
Na	0.0079	1.228	1.215	0.720
Pu^{239}	1.160	0.985	1.053	1.009
$Pu^{240}O_2$	-0.890	1.515	1.502	1.035
$Pu^{241}O_2$	1.180	0.930	0.994	0.930
AmO_2	-2.420	0.857	0.895	0.889
NpO_2	-2.320	0.875	0.912	0.958
PuO_2(68%)	0.622	0.855	0.709	1.140
PuO_2(78%)	0.760	0.892	0.976	1.067

Table 4.11 Material sample worth results from Russian Keff difference calculations

	homogeneous TRIGEX	heterogeneous TRIGEX	heterogeneous TWODANT
U235	0.943	0.992	1.007
U238	1.055	0.980	1.007
B10	0.922	0.962	0.981
C	0.974	0.982	0.974
Na	0.947	0.924	0.968
Pu239	1.108	1.189	1.146
Pu240O2	1.444	0.965	1.086
Pu241O2	1.023	1.079	1.122
AmO2	0.819	0.880	0.950
NpO2	0.894	0.918	0.997
Li6	0.976	0.974	1.060
Al2O3	0.370	0.450	0.527
Al	1.041	1.063	1.063
Pu239O2(68%)	1.216	1.147	1.129
Pu239O2(78%)	1.168	1.136	1.083

Table 4.12 Reaction rate ratio results from Russian and French calculations

*	RUSSIA				FRANCE	
	TRIGEX				ERANOS	
	homogeneous	hetero	geneous	heterogeneous	heterogeneous	
		ABBN-93 26 group	ABBN-93 Multigroup	ABBN-93	JEF-2.2	ERALIB-1
U238 / U235	1.19	0.95	0.96	0.96	0.97	0.98
Pu239 / U235	0.92	0.99	1.01	0.98	0.99	1.00
Pu240 / U235	1.19	1.02	1.00	0.98	1.07	1.04
Pu241 / U235	0.91	0.97	0.98	0.94	1.02	1.00
U233 / U235	0.92	0.96	0.97	1.01	0.99	0.99
Th232 / U235	1.23	0.96	0.99	1.01	1.00	1.03
Au97 / U235	0.68	1.10	1.07	0.96	1.10	1.09
Pu238 / Pu239	1.32	1.04	1.05	1.01	1.04	1.04
Pu240 / Pu239	1.33	0.97	0.97	0.95	1.07	1.04
Pu241 / Pu239	0.99	0.97	0.96	0.94	1.02	0.99
Pu242 / Pu239	1.22	0.92	0.94	0.95	0.99	0.95
Np237 / Pu239	1.33	0.98	0.99	0.92	0.94	0.95
Am241 / Pu239	1.30	1.00	1.02	0.97	0.93	0.94
Am243 / Pu239	1.39	1.00	1.02	0.97	0.98	0.95
Cm244 / Pu239	1.19	0.90	0.90	0.94	1.03	1.03
U233 / Pu239	1.00	0.97	0.96	0.95	0.99	1.00
U236 / Pu239	1.59	1.29	1.31	1.29	1.40	1.40

* - all reactions are fission, except Au97 is capture

5 Conclusions

A calculational model of the BFS-58-1-I1 experimental assembly was set up, in RZ geometry, that was a close approximation to the assembly design data as supplied by IPPE. The model was used to calculate values for comparison with experimental measurements of Keff, Na void reactivity worths, material sample reactivity worths and reaction rate ratios.

The calculated value of the assembly Keff exceeded the measured value by 1.1%Δk/k.

Of the four Na void values, the calculated values were in good agreement with measurements for two cases (C/E values ~1.06), but diverged markedly for the other two cases. A similar result was obtained in independent Russian calculations. The discrepancies are just those cases that involve the state of 19 S/As with Na voided. It is judged that experimental problems are the most likely source of the discrepancy, though the experimental records have been re-checked and nothing unusual discovered. However, there remains some possibility that this is some real effect of the Pu fuel with diluent, which existing calculation methods are not equipped to reproduce. Since one of the purposes of the critical experiments was to determine any such unexpected behaviour, it is recommended that future critical assembly experiments include similar measurements.

Many of the material sample reactivity worths were so low that the resulting C/E values were severely affected, or even dominated, by the calculational uncertainties. Choosing a subset of cases with more reasonable values of reactivity worth, C/E values were typically 1.1 to 1.3, values that are rather high but not .

Calculated values of reaction rate ratios showed a greater variation from measurements than was considered reasonable. At present, the reason for this discrepancy is not known.

Independent Russian and French calculations have produced significantly more accurate calculations for sample worths, and especially for reaction rate ratios.

A separate study will investigate the inclusion of these BFS-58-1-I1 experiment results in a set of integral data to be used to create an adjusted nuclear dataset from JENDL-3.2. Whilst the Keff and Na void results are expected to be of use for the adjustment process, the sample worth results are likely to cause some significant adjustments, so they may be of less value; the reaction rate ratios will not be used for the adjustment.

Appendix I - Specification of BFS-58-1-I1 Assembly and Experiments

AI.1 The BFS-58-1-I1 Assembly

This appendix gives details of the construction of the BFS-58-1-I1 assembly and the results of the experiments carried out thereon. The data is a summary of the various information provided by the IPPE. Much of the data was in the report on the ISTC project 1220[1-5], but it has been updated and expanded, mainly as a result of the exchange of e-mail between the parties involved in the calculations. Various misunderstandings lead to incorrect data being used in early calculations; only the later (correct) data is given here.

The BFS-2 assembly consists of a hexagonal array of sub-assemblies (S/As), located on top of a support structure. Each S/A is constructed from a stack of cylindrical blocks, held together by a cylindrical steel tube or wrapper. The gaps between the cylindrical S/As can be used to house various thin specimen rods. There is no special containment, the whole assembly is arranged in atmospheric air.

The S/As are spaced on a hexagonal grid of 50.1 mm a/f. The wrapper tubes are 50 mm outer diameter and have a 1 mm wall thickness. All the material blocks are of 46.7 mm diameter.

A total of 12 different designs of material block were included in the BFS-58-1-I1 assembly. The blocks were of different materials present in the fast reactor core being modelled, with (e.g for Na or Pu) metal cladding to prevent corrosion or contamination. Table AI.1 shows, for each of the 12 block types, the block height and the isotopic number densities homogenized over the whole volume of the block.
(In the B_4C blocks, the boron is of natural composition, 20% B10 atoms and 80% B11.) All number densities are quoted in 10^{24} atoms/cc.

It should be noted that there are two different types of Na block, 'green' Na and 'laser' Na, and that each is available as a normal and an 'empty' version; the number densities of Table AI.1 show the differences between these 4 types. The essential differences are the presence of Na and H isotopes, the 'empty' blocks contain no Na (being used for Na void measurements), the 'laser' blocks contain no H. Additionally, the normal 'laser' block is a slightly different height from all the others; however, multiplying number densities by height gives the same result for all 4 block types, that is they have identical masses of each isotope present.

The BFS-58-1-I1 assembly was a hexagonal array with a total of 1519 S/As. Fortunately, only 6 different designs were

used when building the S/As from stacks of blocks (two of those were almost identical, differing only in whether they used 'laser' or 'green' Na blocks). The layout of the assembly, showing the positions of the 6 different designs of S/A, is in Figure AI.1. The axial block stack design for each S/A design is shown in Figures AI.2 to AI.7 :

diluent fuel (229 S/As)	Figure AI.2
LEZ fuel ('laser' Na) (224 S/As)	Figure AI.3
LEZ fuel ('green' Na) (234 S/As)	Figure AI.4
MEZ fuel (415 S/As)	Figure AI.5
control rod (36 S/As)	Figure AI.6
radial blanket (381 S/As)	Figure AI.7

In each fuel S/A type the core region has a complex pattern or cell of blocks which repeats either 4 or 5 times. In the diluent and LEZ fuel S/A types there is a shield region with a simple repeating cell of Na and B_4C blocks. All other regions consist of just a single block type.

The control rod S/A specification has some minor inconsistency. The region of 125 Na blocks should be either 125.0 cm high (if it is 'green' Na) or 123.75 cm high (if 'laser' Na). However, the Na block extends up to 2.0 cm above the top of an 87.40 cm core region (the 'green' Na LEZ fuel S/A core size); with the below core blanket region this gives a height of 122.83 cm for the control rod Na region.

The radial blanket S/A stack consists of just depleted UO_2 blocks, to a height that is ~75 cm taller than the block stacks in the other S/A designs. This difference in heights corresponds to the thickness of the steel support structure, and there is some uncertainty as to whether the depleted UO_2 extends to the region that corresponds to the steel support in the other S/A types.

Steel specimen rods are positioned in the inter-S/A gaps between MEZ fuel S/As. The rods have a diameter of 8 mm; there are 6 placed round each MEZ S/A, such that the mass from 2 such specimens is associated with each MEZ S/A. Table AI.1 gives the isotopic number density data for these rods in unhomogenized form, it also gives the wrapper tube number density in the same form. No detail is given of the construction of the support structure, but overall homogenized number density data is given for this region in Table AI.1.

The spaces between wrapper tubes, and the gaps between wrapper tube and block, contain atmospheric air. Taking data from standard references, values of number densities for 3 significant isotopes were obtained: O 1.07×10^{-5}, N^{14} 4.26×10^{-5}, N^{15} 1.6×10^{-7}.

AI.2 The BFS-58-1-I1 Experiments

The measurements carried out on BFS-58-1-I1 were of 3 kinds: the reactivity worth of removing sodium from the central region of the core; the reactivity worth of introducing samples of different materials to the core centre; the ratios of various reaction rates, again at the core centre.

For the Na void worth experiments, Na blocks were removed from up to 37 Pu fuel S/As, the 4 central hexagon rings. These are all Pu fuel S/As, in which the core region has 5 identical cells; in the Na void measurements the Na blocks were removed from just the central cell of the core region (20% of the core height). The Na blocks were replaced by 'empty' sodium boxes, identical except that they contain no Na. The experimental values for Na void worth are given in Table AI.2; as with all the measured reactivity values, they are given in terms of the delayed neutron fraction (beff). The table shows 4 different measurements of Na void worth: 19 S/As (rings 1 to 3), 37 S/As (rings 1 to 4) or 18 S/As (just ring 4) voiding, with no other S/As voided during the experiment; and 18 S/As (ring 4) voiding with the 19 S/As of rings 1 to 3 voided throughout the experiment. The measurements of the reactivity of the different states of the assembly were made using a digital reactimeter. In order to keep the assembly close to a Keff of 1.0, during the experiment up to 5 additional fuel S/As wereadded to the periphery of the assembly - no account was taken of these extra S/As in the modelling of the experiments.

For the material sample worth experiments, each sample was in the form of a cylinder, placed in an inter-tube gap close to the core centre and at mid-core height. The samples varied in size; Table AI.3 shows the size, mass and composition of each sample as well as their measured reactivity worths (relative to the delayed neutron fraction). A total of 34 different samples were measured, though these represented just 16 different material compositions, the additional samples being of varying diameters. The measurements were carried out using the oscillation method. (Note that the Al_2O_3 results are unreliable, since the sample is believed to have been contaminated with hydrogen.)

The ratios of reaction rates were measured using a number of different instruments and techniques. All measurements were in the region of the centre of the core. Table AI.4 shows the various measured reaction rate ratios, and the instrument type used for each measurement. The compact fission chamber (CFC) was small enough to be inserted in the inter-wrapper-tube gap. To accommodate the section fission chamber (SFC) and absolute fission chamber (AFC) it was necessary to remove one (central) fuel S/A; to compensate for this and maintain assembly reactivity, 7 radial blanket S/As at the core periphery were replaced by

fuel S/As - no account was taken of these S/As in the modelling of the experiments.

One final parameter for which a measured value is available is the reactivity of the BFS-58-1-I1 assembly, in its basic 'as specified' configuration. The value of that reactivity was 9.8 cents, that is the value of k-effective exceeds criticality (1.0) by 9.8% of the delayed neutron fraction (βeff).

Table AI.1 Composition and dimensions of material blocks and other BFS-2 components

Material	Pu	U-235	Depleted UO2	Al_2O_3	Al_2O_3
Height, mm	3.24	5.65	9.55	10.07	5.73
H			1.468x10-5		
C	1.046x10-4	5.862x10-5	9.052x10-4		
B					
O			3.786x10-2	6.715x10-2	6.564x10-2
Na					
Al	3.984x10-4	1.837x10-4	5.969x10-3	4.477x10-2	4.376x10-2
Si					
Ti	1.623x10-4	9.790x10-5		4.758x10-5	4.648x10-5
Cr	4.350x10-3	2.029x10-3			
Mn	3.425x10-4	2.348x10-4			
Fe	1.562x10-2	7.745x10-3	3.326x10-4	4.120x10-5	4.027x10-5
Ni	2.034x10-3	9.991x10-4			
Ga	1.370x10-3				
U-235		1.434x10-2	7.951x10-5		
U-238		2.500x10-2	1.884x10-2		
Pu-238	1.235x10-6				
Pu-239	2.265x10-2				
Pu-240	1.096x10-3				
Pu-241	5.949x10-5				
Pu-242	2.380x10-6				

Table AI.1 (continued, 1)

Material	'laser' Na (empty)	'laser' Na	'green' Na (empty)	'green' Na	B_4C
Height, mm	10.0	9.9	10.0	10.0	10.01
H			1.928x10-5	1.928x10-5	
C	3.914x10-5	3.953x10-5	3.914x10-5	3.914x10-5	2.015x10-2
B					7.631x10-2
O					9.502x10-5
Na		2.158x10-2		2.137x10-2	
Al	1.489x10-4	1.505x10-4	1.489x10-4	1.489x10-4	3.743x10-4
Si					
Ti	6.075x10-5	6.136x10-5	6.075x10-5	6.075x10-5	
Cr	1.629x10-3	1.645x10-3	1.629x10-3	1.629x10-3	
Mn	1.285x10-4	1.298x10-4	1.285x10-4	1.285x10-4	
Fe	5.841x10-3	5.908x10-3	5.841x10-3	5.841x10-3	1.463x10-4
Ni	7.605x10-4	7.694x10-4	7.605x10-4	7.605x10-4	
Ga					
U-235					
U-238					
Pu-238					
Pu-239					
Pu-240					
Pu-241					
Pu-242					

Table AI.1 (continued, 2)

Material	Al	steel	steel support	wrapper tube	steel specimen
Height, mm	9.95	9.93			
H					
C		3.900x10-4	1.016x10-4	3.631x10-4	3.084x10-4
B					
O					
Na					
Al	5.903 x 10-2	1.485x10-3	4.356x10-4	1.556x10-3	1.322x10-3
Si			3.771x10-4	1.347x10-3	1.142x10-3
Ti		6.065x10-4	1.780x10-4	6.360x10-4	5.391x10-4
Cr		1.622x10-2	5.115x10-3	1.827x10-2	1.546x10-2
Mn		1.279x10-3	2.105x10-4	7.523x10-4	6.366x10-4
Fe	1.139x10-4	5.824x10-2	1.722x10-2	6.151x10-2	5.214x10-2
Ni		7.581x10-3	2.158x10-3	7.711x10-3	6.537x10-3
Ga					
U-235					
U-238					
Pu-238					
Pu-239					
Pu-240					
Pu-241					
Pu-242					

Table AI.2 Measured values of Na void reactivity worth

No. of S/As with Na voided			Na void worth	uncertainty
change in test	initial state	final state	(% βeff)	(% βeff)
18	0	18	7.3	1.0
18	19	37	3.2	0.8
19	0	19	12.2	1.0
37	0	37	15.4	1.8

Table AI.3 Composition, dimensions and measured reactivity worths of material samples

No.	Material	Length mm	Dia. mm	Mass g	Composition, atomic %	Reactivity (% βeff)
1	U-235	130	6.0	16.22	U235 88.6 , U238 11.4	0.5925±0.001
2	U-238	125	3.5	89.07	U - natural	-0.8152±0.003
3	B-10	130	1.0	0.46	B10 82.4 , B11 17.6	-1.4430±0.002
4	B-10	130	2.0	2.09	B10 82.4 , B11 17.6	-5.6651±0.001
5	B-10	130	3.5	2.72	B10 82.4 , B11 17.6	-6.5897±0.008
6	C-12	130	6.0	23.39	C - natural	0.2714±0.002
7	Na	141	6.6	28.21	Na - natural	0.0942±0.002
8	$(CH_2)_n$	130	6.1	2.66	C, H - natural	0.9049±0.001
9	$(CH_2)_n$	130	5.4	4.66	C, H - natural	1.5323±0.002
10	$(CH_2)_n$	130	6.0	6.87	C, H - natural	2.0698±0.004
11	Pu-239	100		6.02	Pu239 95.56 , Pu240 4.04	0.3156±0.001
12	Pu-239	100		14.4	Pu239 95.56 , Pu240 4.04	0.7510±0.002
13	Pu-239	100	2.4	28.44	Pu239 95.56 , Pu240 4.04	1.4444±0.002
14	$Pu^{240}O_2$	121	2.6	11.16	Pu239 9.13 , Pu240 89.22 , Pu241 1.27 , Pu242 0.16 , Am241 0.22	-0.0808±0.002
15	$Pu^{240}O_2$	121	3.6	17.63	Pu239 9.13 , Pu240 89.22 , Pu241 1.27 , Pu242 0.16 , Am241 0.22	-0.1013±0.002
16	$Pu^{240}O_2$	121	4.8	45.08	Pu239 9.13 , Pu240 89.22 , Pu241 1.27 , Pu242 0.16 , Am241 0.22	-0.1220±0.002
17	$Pu^{241}O_2$	121	2.6	4.69	Pu239 0.98 , Pu240 21.98 , Pu241 58.84 , Pu242 11.74 , Am241 6.45 , Np237 0.01	0.2456±0.004
18	$Pu^{241}O_2$	121	3.6	5.19	Pu239 0.98 , Pu240 21.98 , Pu241 58.84 , Pu242 11.74 , Am241 6.45 , Np237 0.01	0.2816±0.001
19	AmO_2	121	3.6	9.50	Am241 99.79	-0.7830±0.002
20	AmO_2	121	2.6	7.05	Am241 99.79	-0.5884±0.002
21	NpO_2	121	2.6	9.69	Np237 99.96	-0.7544±0.001
22	NpO_2	121	3.6	17.4	Np237 99.96	-1.3227±0.002
23	NpO_2	121	5.6	21.67	Np237 99.96	-1.5612±0.002

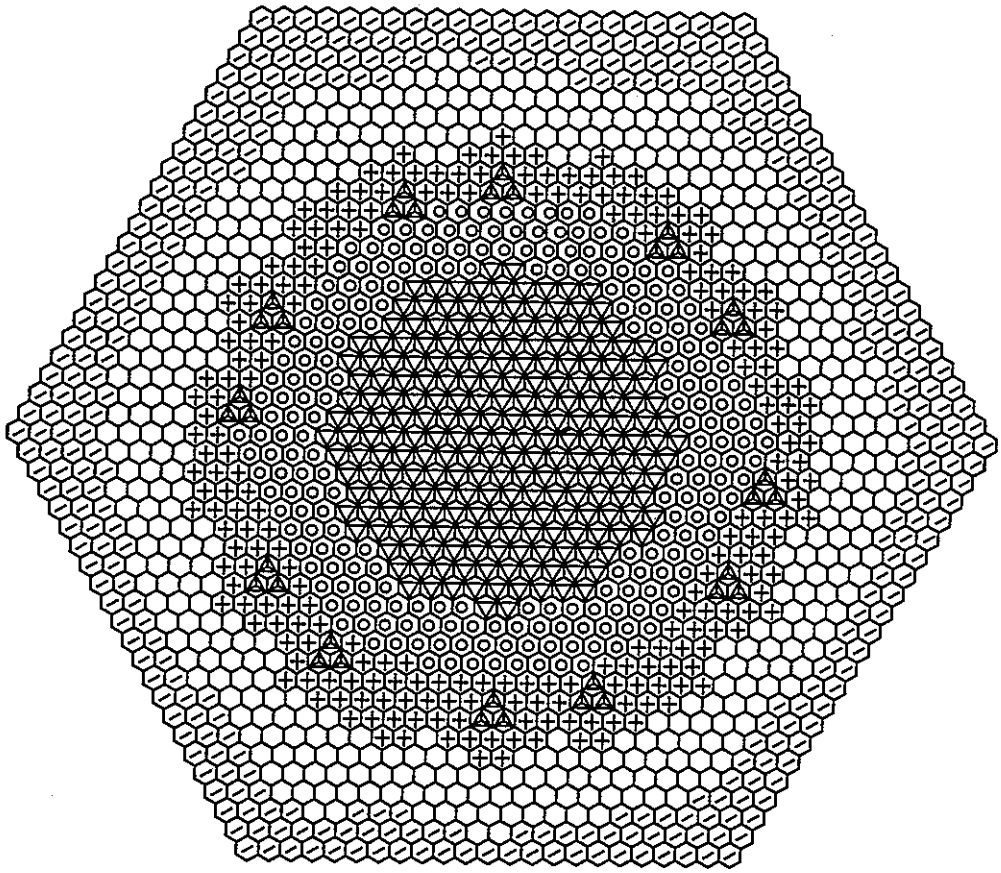
Table AI.3 (continued)

No.	Material	Length mm	Dia. mm	Mass g	Composition, atomic %	Reactivity (% βeff)
24	Li-6	125	3.5	2.333	Li6 90.0 , Li7 10.0	-3.6501±0.004
25	Li-6	125	6.1	3.342	Li6 90.0 , Li7 10.0	-4.9418±0.002
26	Li-6	125	7.1	4.705	Li6 90.0 , Li7 10.0	-6.7143±0.003
27	Al_2O_3	130	6.1	17.444	Al, O - natural	0.1464±0.003
28	Al	125	5.7	34.330	Al - natural	0.0319±0.004
29	PuO_2 (68%)	112	2.6	6.243	Pu238 0.59 , Pu239 67.59 , Pu240 21.32 , Pu241 5.85 , Pu242 2.67 , Am241 1.98	0.1935±0.003
30	PuO_2 (68%)	112	3.6	13.350	Pu238 0.59 , Pu239 67.59 , Pu240 21.32 , Pu241 5.85 , Pu242 2.67 , Am241 1.98	0.4283±0.002
31	PuO_2 (68%)	112	4.8	20.170	Pu238 0.59 , Pu239 67.59 , Pu240 21.32 , Pu241 5.85 , Pu242 2.67 , Am241 1.98	0.6673±0.002
32	PuO_2 (78%)	112	2.6	10.419	Pu238 0.23 , Pu239 77.86 , Pu240 16.76 , Pu241 3.11 , Pu242 1.02 , Am241 1.02 , Np237 0.01	0.3760±0.002
33	PuO_2 (78%)	112	3.6	19.029	Pu238 0.23 , Pu239 77.86 , Pu240 16.76 , Pu241 3.11 , Pu242 1.02 , Am241 1.02 , Np237 0.01	0.6478±0.015
34	PuO_2 (78%)	112	4.8	38.060	Pu238 0.23 , Pu239 77.86 , Pu240 16.76 , Pu241 3.11 , Pu242 1.02 , Am241 1.02 , Np237 0.01	1.4213±0.002

Table AI.4 Measured values of reaction rate ratios

Case no.	Reaction Ratio Measured *	Detector type			
		SSD	CFC	SFC	AFC
1	U238 / U235		0.0118		0.0117
2	Pu239 / U235		0.904		0.903
3	Pu241 / Pu239		1.556		
4	U233 / U235		1.414		
5	Pu242 / Pu239	0.0710	0.0753		
6	Am241 / Pu239	0.0897	0.0886	0.0880	
7	Am243 / Pu239	0.0660	0.0656	0.0632	
8	Np237 / Pu239		0.0971	0.0935	0.0947
9	Pu238 / Pu239	0.390	0.364	0.397	0.394
10	Pu240 / Pu249		0.108	0.106	
11	Cm244 / Pu239		0.119	0.135	
12	Pu240 / U235				0.0958
13	U233 / Pu239			1.554	1.570
14	U236 / Pu239		0.0264		
15	Th232 / U235		0.0027		
16	Pu241 / U235		1.40		1.40
17	Au97 / U235				0.922

* - all reactions are fission, except Au97 is capture



Pu & diluent fuel S/A
LEZ fuel S/A ('laser' Na)
LEZ fuel S/A ('green' Na)
MEZ fuel S/A
Control Rod S/A
Radial Blanket S/A

Figure AI.1 Layout of S/As in BFS-58-1-I1

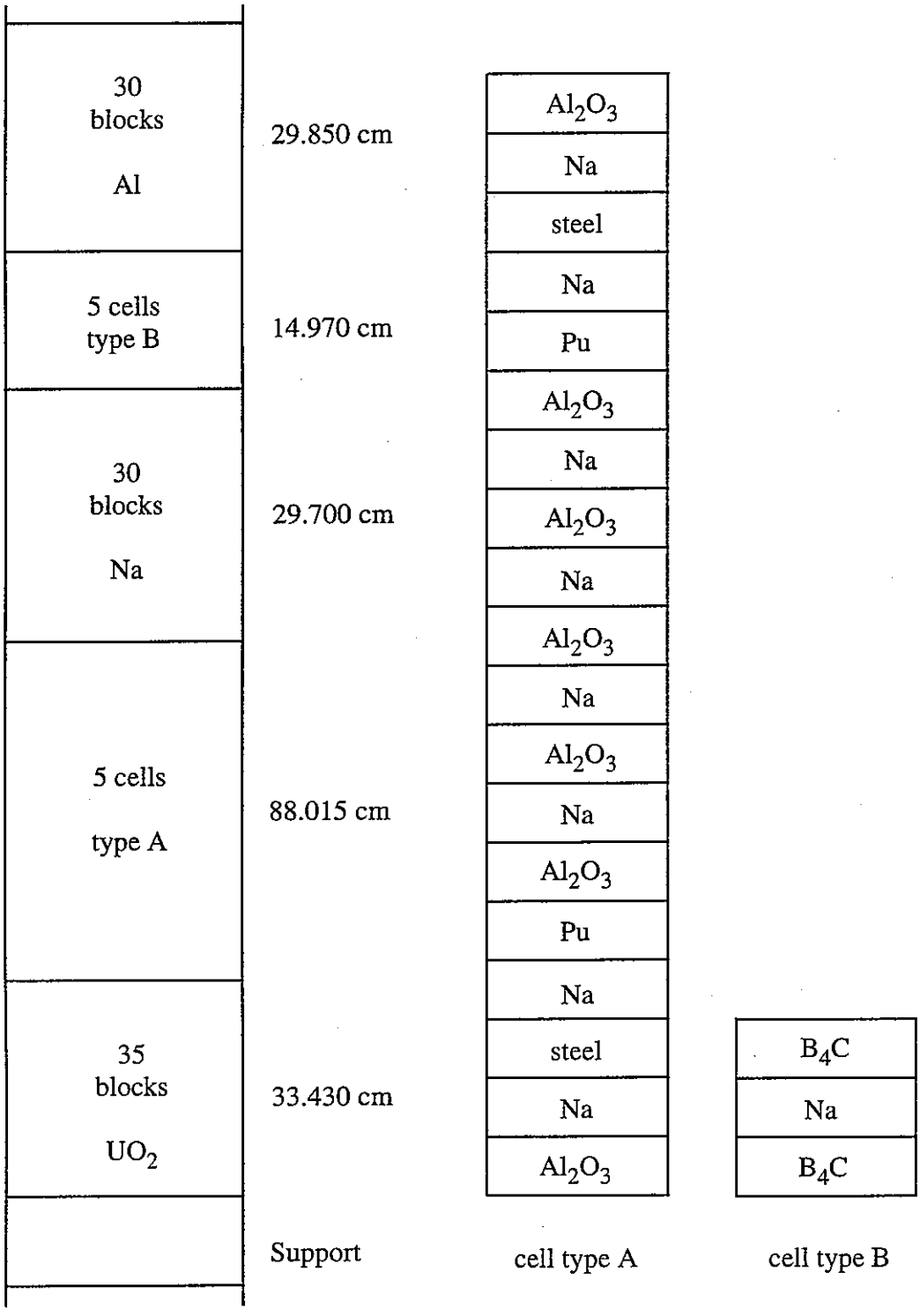


Figure AI.2 Axial structure of Pu & diluent fuel S/A

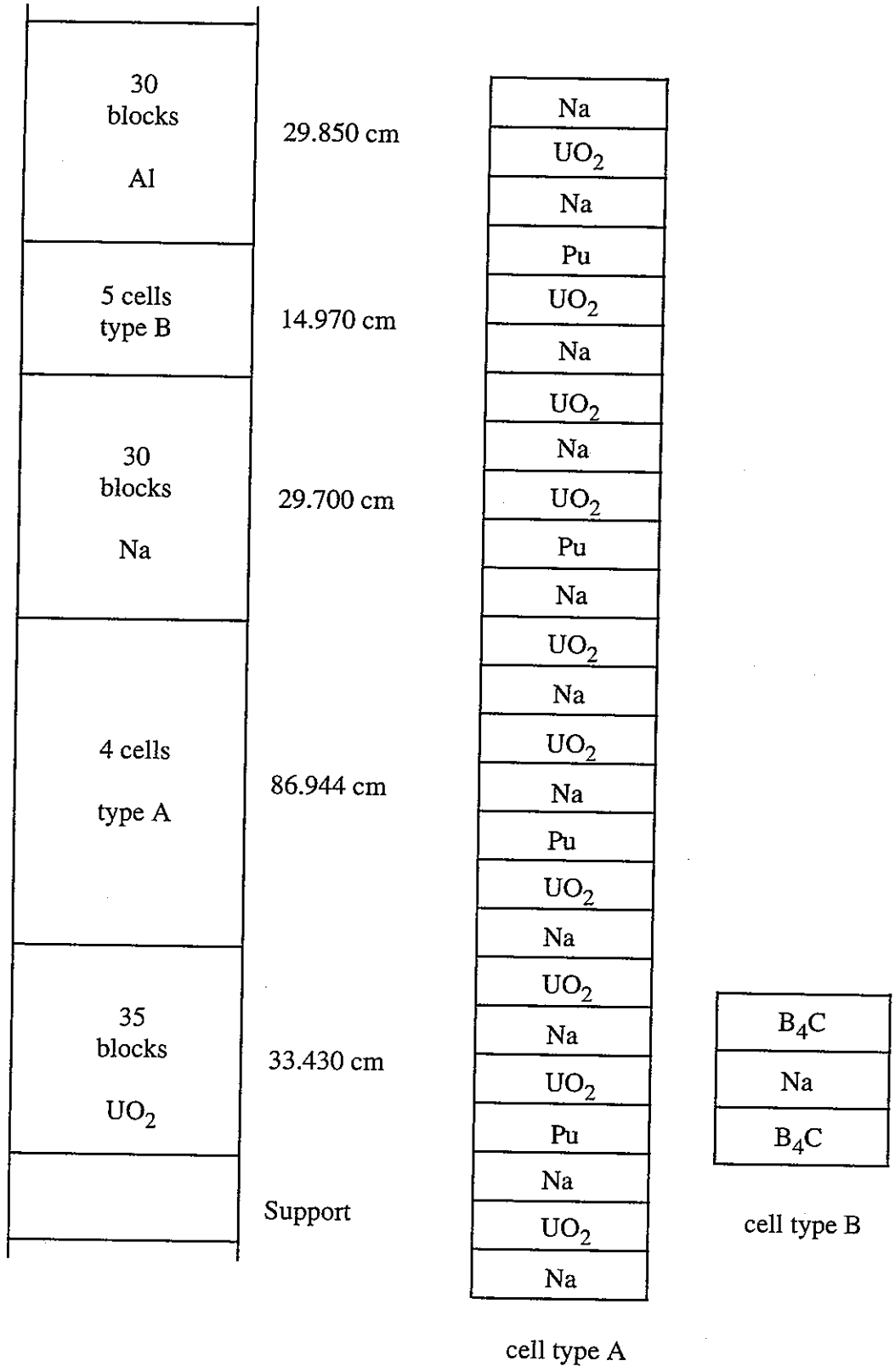


Figure AI.3 Axial structure of LEZ fuel with 'laser' Na S/A

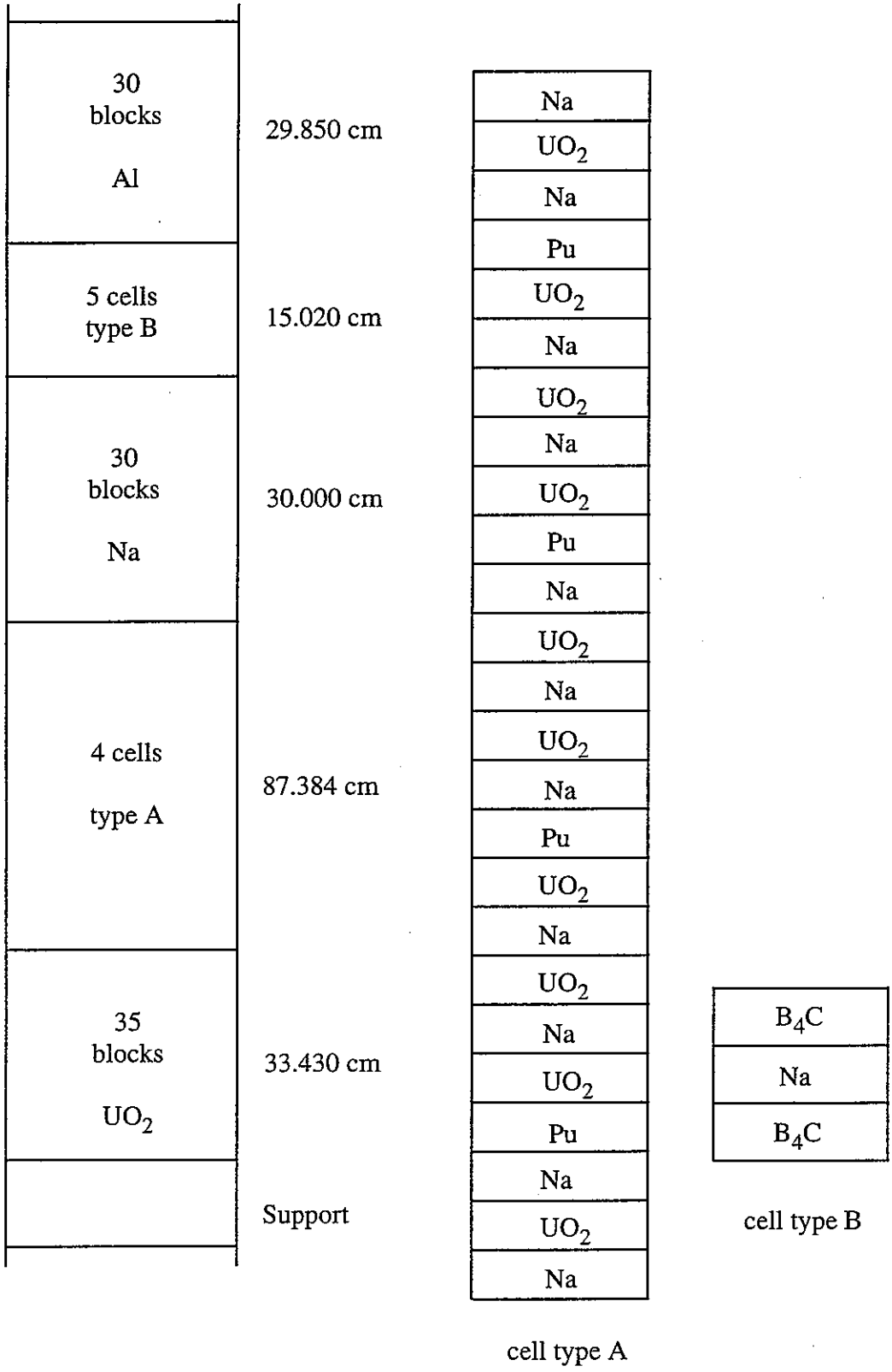


Figure AI.4 Axial structure of LEZ fuel with 'green' Na S/A

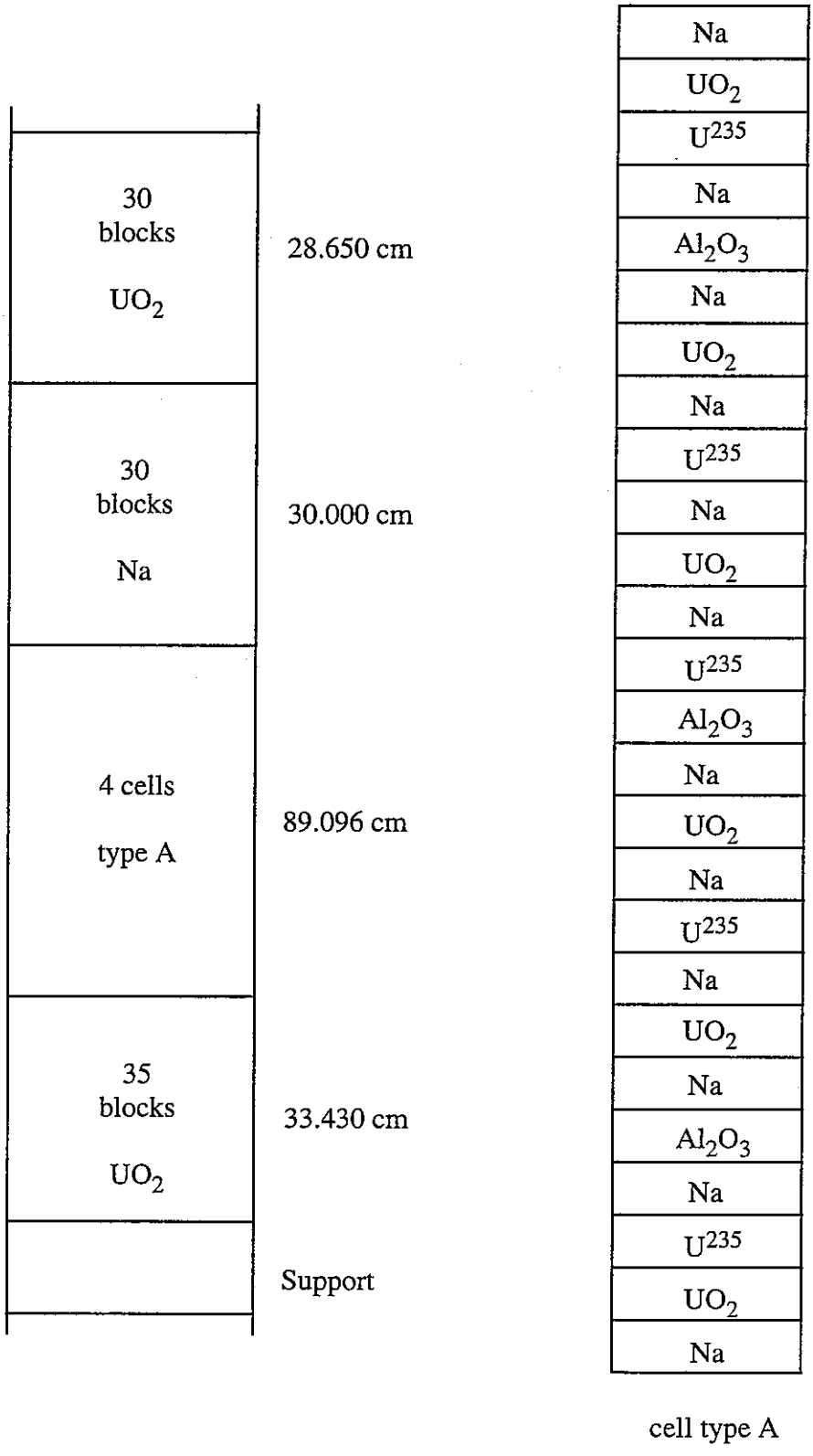


Figure AI.5 Axial structure of MEZ fuel S/A

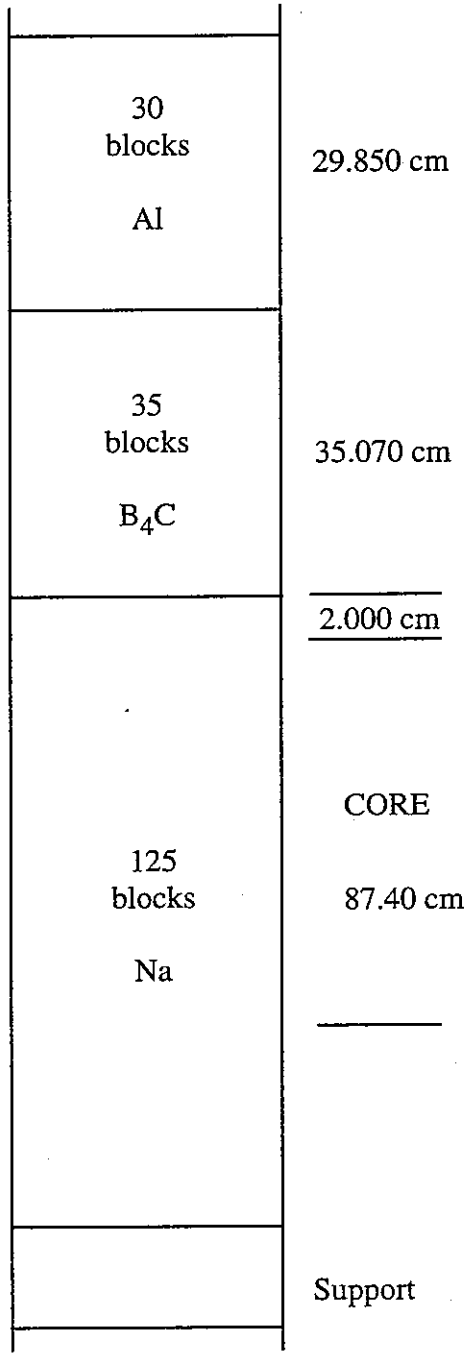


Figure AI.6 Axial structure of control rod S/A

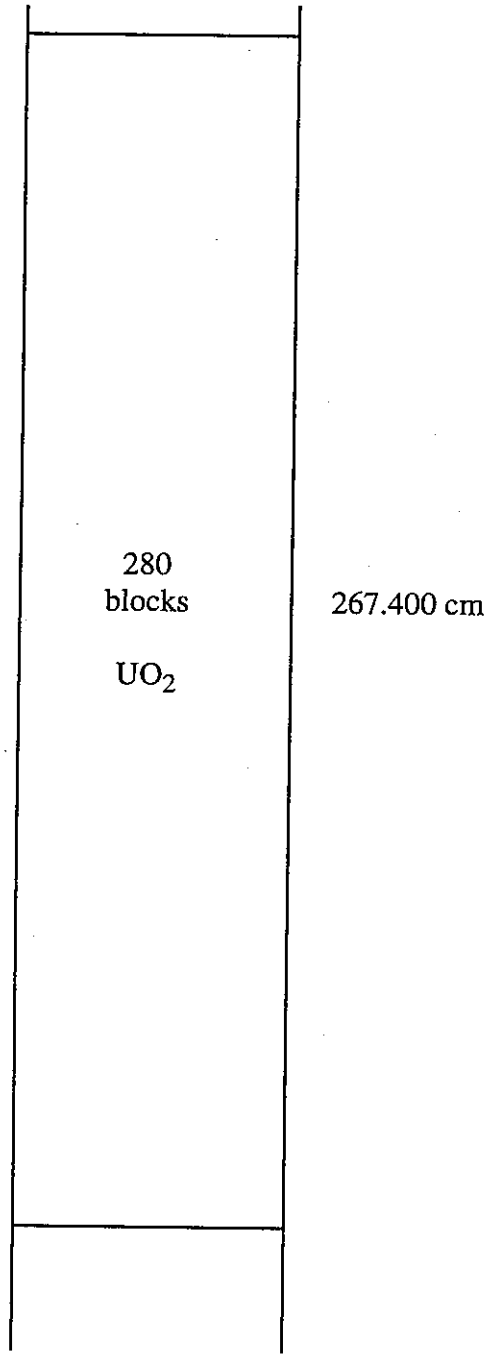


Figure AI.7 Axial structure of radial blanket S/A

Appendix II - Details of Computer Model of BFS-58-1-I1

Appendix I gives the specification of the BFS-58-1-I1 assembly and experiments. In order to produce a practical computer model of the assembly, some simplification of the design was necessary, as described in Sub-section 2.3 of the main text. This appendix gives details of the computer model, and how it was derived from the basic data of appendix I. The initial data variants of sub-section 2.4 are not included in this appendix.

There was some adjustment of the heights of the different axial regions in each S/A design. The changes were made in order to allow uniform heights to be used both throughout the model and for regions such as the core. Figure AII.1 shows the changes made, both to the axial heights of regions and to the number densities of their materials.

The cell models that are used to calculate the nuclear data for the fuel regions incorporate a 1D representation of the structure of these regions. Sub-section 3.2 of the main text describes 3 possible models that were examined, differing in how they incorporate the surrounding wrapper and air into the stack of blocks of various materials. Figure AII.2 shows the fuel cell structures of the wrapper model option adopted for the definitive calculations: the wrapper with air is included as 2 additional blocks placed within the stack. The stack of blocks in the of fuel region is a repeating cell structure (4 cells in MEZ fuel, 5 in others); since each cell possesses reflective symmetry about the centre, only a half-cell was modelled in the nuclear data calculations (for MEZ fuel, the 2 centre blocks in the cell are not symmetric, half of each of these blocks was represented in the model).

Figure AII.2 shows the structure and dimensions of the fuel cell models. The block heights are modified by the same fraction as the core height changes shown in Figure AII.1. The wrapper blocks comprise a fraction 0.21201 of the height of each fuel cell model, equivalent to the fraction of the cross-section of the 50.1 mm a/f hexagon that is not occupied by the 46.7 mm diameter blocks.

The various axial regions of the 6 different S/A designs comprise a total of 12 different material compositions, with an extra material for that part of the inner core region that has Na voided or the sample added during an experiment. The mapping of these various materials onto the RZ geometric representation of the BFS-58-1-I1 assembly for the reactor calculations is as shown in Figure AII.3. Note that the table shows the representation used for Na void calculations, for the sample worth calculations centre core axial region sizes change from '8.8015, 17.6030, 8.8015' to '11.0019, 13.2022, 11.0019', though the underlying flux mesh is unaltered. Table AII.1 relates the material numbers of Figure AII.3 to the axial region descriptions, and also to the names used to identify each

material in the SLAROM and CASUP calculations and the nuclear datasets they create.

The number densities of the various materials are included in the computer input data of appendix III. The basic number densities of the component blocks and other materials were given in appendix I, these were adjusted as indicated in Figure AII.1. Fuel region materials used the block number densities directly; for other regions these were smeared with the wrapper tube etc. number densities. The material samples are modelled by inserting the relevant material to the wrapper blocks in the Pu fuel material; the additional number densities are listed in Table AII.2, note that for certain isotopes - O, C and Al - these number densities have to be added to a pre-existing value.

Table AII.1 Key to material region names and numbers

Region No.	Material Type	Name in SLAROM	Name in CASUP
1	Pu & diluent fuel	DILWWW	ZDLCAS
2	laser LEZ fuel	LLAWWW	ZLLCAS
3	MEZ fuel	MEZWWW	ZMXCAS
4	steel support	SUPORT	SUPORT
5	depleted UO_2	UO2WWW	UO2CAS
6		ABSWWW	ABSCAS
7		ALSWWW	ALSCAS
8		NGRWWW	NGRCAS
9		NLAWWW	NXACAS
10		NLHWWW	NXHCAS
11		NBCWWW	NBCCAS
12	voided Pu fuel	NAVDWR	VODCAS
13	green LEZ fuel	LGRWWW	ZLGCAS
*	Pu fuel, with sample	DWSAMP	SAMPLE
**	Pu fuel (duplicate)	DWNOSM	ZDSMCA

* alternate name for material 12, for sample worth instead of Na void

** an additional material, identical to the first (Pu & diluent fuel), used to replace perturbed material in unperturbed TWOTRAN2 calculations to produce flux for SN-PERT

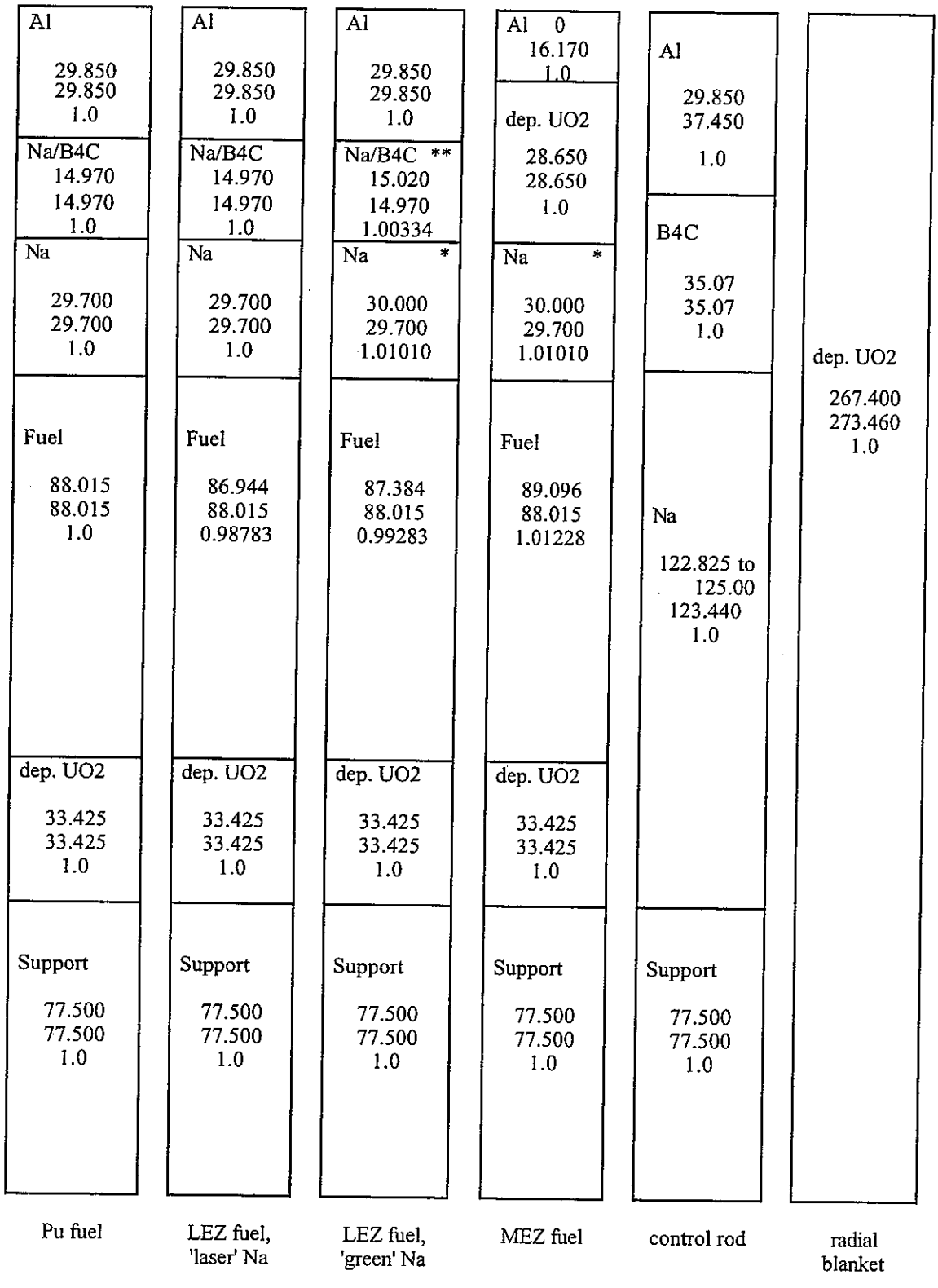
Table AII.2 Additional number density data for material samples

Case No.	Sample Material	Sample Mass, g	Composition added to wrapper regions in SLAROM / CASUP model			
			Isotope	N. D.	Isotope	N.D.
1	U^{235}	16.22	U^{235}	6.0429×10^{-4}	U^{238}	7.7753×10^{-5}
2	U^{238}	89.07	U^{235}	2.6668×10^{-5}	U^{238}	3.6771×10^{-3}
3	B^{10}	0.46	B^{10}	3.6824×10^{-4}	B^{11}	7.8653×10^{-5}
4		2.09	B^{10}	1.6731×10^{-3}	B^{11}	3.5736×10^{-4}
5		2.72	B^{10}	2.1774×10^{-3}	B^{11}	4.6508×10^{-4}
6	C^{12}	23.39	C	1.9275×10^{-2}		
7	Na	28.21	Na	1.2145×10^{-2}		
8	$(CH_2)_n$	2.66	C	1.8791×10^{-3}	H	3.7583×10^{-3}
9		4.66	C	3.2920×10^{-3}	H	6.5840×10^{-3}
10		6.87	C	4.8533×10^{-3}	H	9.7065×10^{-3}
11	Pu^{239}	6.02	Pu^{239}	2.3915×10^{-4}	Pu^{240}	1.0068×10^{-5}
12		14.4	Pu^{239}	5.7205×10^{-4}	Pu^{240}	2.4084×10^{-5}
13		28.44	Pu^{239}	1.1298×10^{-3}	Pu^{240}	4.7565×10^{-5}
14	$Pu^{240}O_2$	11.16	O Pu^{240} Pu^{242}	8.1055×10^{-4} 3.6246×10^{-4} 6.5000×10^{-7}	Pu239 Pu^{241} Am^{241}	3.7091×10^{-5} 5.1594×10^{-6} 8.9376×10^{-7}
15		17.63	O Pu^{240} Pu^{242}	1.2805×10^{-3} 5.7259×10^{-4} 1.0268×10^{-6}	Pu^{239} Pu^{241} Am^{241}	5.8594×10^{-5} 8.1506×10^{-6} 1.4119×10^{-6}
16		45.08	O Pu^{240} Pu^{242}	3.2742×10^{-3} 1.4641×10^{-3} 2.6256×10^{-6}	Pu^{239} Pu^{241} Am^{241}	1.4983×10^{-4} 2.0841×10^{-5} 3.6103×10^{-6}
17	$Pu^{241}O_2$	4.69	O Pu^{240} Pu^{241} Np^{237}	3.3944×10^{-4} 3.7395×10^{-5} 1.9973×10^{-5} 1.7010×10^{-8}	Pu^{239} Pu^{241} Am^{241}	1.6673×10^{-6} 1.0010×10^{-4} 1.0973×10^{-5}
18		5.19	O Pu^{240} Pu^{241} Np^{237}	3.7563×10^{-4} 4.1381×10^{-5} 2.2103×10^{-5} 1.8830×10^{-8}	Pu^{239} Pu^{241} Am^{241}	1.8450×10^{-6} 1.1078×10^{-4} 1.2143×10^{-5}
19	AmO_2	9.50	Am^{241}	3.4362×10^{-4}	O	6.8703×10^{-4}
20		7.05	Am^{241}	2.5500×10^{-4}	O	5.0985×10^{-4}

(to be continued to the next page)

Table AII.2 (continued)

Case No.	Sample Material	Sample Mass, g	Composition added to wrapper regions in SLAROM / CASUP model			
			Isotope	N. D.	Isotope	N.D.
21	NpO_2	9.69	Np^{237}	3.5634×10^{-4}	O	7.1126×10^{-4}
22		17.4	Np^{237}	6.3987×10^{-4}	O	1.2772×10^{-3}
23		21.67	Np^{237}	7.9690×10^{-4}	O	1.5906×10^{-3}
24	Li^6	2.333	Li^6	3.3985×10^{-3}	Li^7	3.7762×10^{-4}
25		3.342	Li^6	4.8684×10^{-3}	Li^7	5.4093×10^{-4}
26		4.705	Li^6	6.8539×10^{-3}	Li^7	7.6154×10^{-4}
27	Al_2O_3	17.444	Al	3.3868×10^{-3}	O	5.0679×10^{-3}
28	Al	34.330	Al	1.2594×10^{-2}		
29	PuO_2(68%)	6.243	O	4.5424×10^{-4}	Pu^{238}	1.3432×10^{-6}
			Pu^{239}	1.5388×10^{-4}	Pu^{240}	4.8538×10^{-5}
			Pu^{241}	1.3318×10^{-5}	Pu^{242}	6.0787×10^{-6}
			Am^{241}	4.5078×10^{-6}		
30		13.350	O	9.7134×10^{-4}	Pu^{238}	2.8723×10^{-6}
			Pu^{239}	3.2905×10^{-4}	Pu^{240}	1.0379×10^{-4}
			Pu^{241}	2.8480×10^{-5}	Pu^{242}	1.2999×10^{-5}
			Am^{241}	9.6394×10^{-6}		
31		20.170	O	1.4676×10^{-3}	Pu^{238}	4.3397×10^{-6}
			Pu^{239}	4.9716×10^{-4}	Pu^{240}	1.5682×10^{-4}
			Pu^{241}	4.3029×10^{-5}	Pu^{242}	1.9639×10^{-5}
			Am^{241}	1.4564×10^{-5}		
32	PuO_2(78%)	10.419	O	7.5848×10^{-4}	Pu^{238}	8.7435×10^{-7}
			Pu^{239}	2.9599×10^{-4}	Pu^{240}	6.3713×10^{-5}
			Pu^{241}	1.1823×10^{-5}	Pu^{242}	3.8775×10^{-6}
			Am^{241}	3.8775×10^{-6}	Np^{237}	3.8020×10^{-8}
33		19.029	O	1.3853×10^{-3}	Pu^{238}	1.5969×10^{-6}
			Pu^{239}	5.4058×10^{-4}	Pu^{240}	1.1636×10^{-4}
			Pu^{241}	2.1593×10^{-5}	Pu^{242}	7.0819×10^{-6}
			Am^{241}	7.0819×10^{-6}	Np^{237}	6.9430×10^{-8}
34		38.060	O	2.7707×10^{-3}	Pu^{238}	3.1939×10^{-6}
			Pu^{239}	1.0812×10^{-3}	Pu^{240}	2.3274×10^{-4}
			Pu^{241}	4.3188×10^{-5}	Pu^{242}	1.4164×10^{-5}
			Am^{241}	1.4164×10^{-5}	Np^{237}	1.3887×10^{-7}



experiment height

model height

N. D. multiplier

* replace 'green' Na with 'laser' Na, then add 'H' isotope (n.d. 1.204×10^{-5})

** replace 'green' Na with 'laser' Na (i.e. use the equivalent Pu S/A region)

Figure AII.1 Height and density adjustments by axial zones

	Al_2O_3	10.070 mm
	wrapper	11.840 mm
	laser Na	9.900 mm
	steel	9.930 mm
	laser Na	9.900 mm
	Pu	3.240 mm
	Al_2O_3	10.070 mm
	laser Na	9.900 mm
	wrapper	11.840 mm
	Al_2O_3	10.070 mm
	laser Na	9.900 mm
#	Al_2O_3	5.035 mm

Pu & diluent fuel

	green Na	10.072 mm
	wrapper	14.800 mm
	UO_2	9.619 mm
	green Na	10.072 mm
	Pu	3.263 mm
	UO_2	9.619 mm
	green Na	10.072 mm
	UO_2	9.619 mm
	wrapper	14.800 mm
	green Na	10.072 mm
	UO_2	9.619 mm
	Pu	3.263 mm
	green Na	10.072 mm
	UO_2	9.619 mm
#	green Na	5.036 mm

LEZ fuel (both types)

	green Na	9.879 mm
	UO_2	9.434 mm
	U^{235}	5.581 mm
	green Na	9.879 mm
	Al_2O_3	5.660 mm
	wrapper	14.800 mm
	green Na	9.879 mm
	UO_2	9.434 mm
	green Na	9.879 mm
	U^{235}	5.581 mm
	green Na	9.879 mm
	UO_2	9.434 mm
	wrapper	14.800 mm
	green Na	9.879 mm
#	U^{235}	2.790 mm
#	Al_2O_3	2.830 mm

MEZ fuel

half-size meshes

Figure AII.2 Cell model structures for fuel regions

Axial Zone Height, cm	Material Numbers (as Table AII.1)										
7.6000	7	7	7	7	7	7	7	7	7	7	7
8.5700	7	7	7	7	7	7	7	7	7	7	5
13.6800	7	7	7	7	7	7	7	7	7	5	5
7.6000	11	11	11	11	11	11	11	7	11	5	5
7.3700	11	11	11	11	11	11	11	6	11	5	5
27.7000	9	9	9	9	9	9	10	6	10	10	5
2.0000	9	9	9	9	9	9	10	8	10	10	5
26.4045	1	1	1	1	1	2	13	8	13	3	5
8.8015	1	1	1	1	1	2	13	8	13	3	5
17.6030	12	1	1	1	1	2	13	8	13	3	5
8.8015	1	1	1	1	1	2	13	8	13	3	5
26.4045	1	1	1	1	1	2	13	8	13	3	5
33.4248	5	5	5	5	5	5	5	8	5	5	5
77.5000	4	4	4	4	4	4	4	4	4	4	5
	2.6304	4.3290	4.5062	4.5345	23.8051	16.1797	6.8702	1.9510	5.9218	18.0067	13.7835

Radial Zone Width, cm

Figure AII.3 Distribution of materials in RZ model

Appendix III - Computer Program Data

Various data files used to create the model used in the analysis are listed in this appendix.

Figure AIII.1 is the input for a SLAROM calculation of nuclear data for the non-fuel material regions; this includes the homogenized number density data. The material names vary depending on whether the results are to be used with fuel region nuclear data created by SLAROM or CASUP, the different names are shown in Table AII.1

The SLAROM input for the various fuel regions are shown in Figure AIII.2, they include a version of the Pu fuel that includes a material sample. The CASUP input data for the fuel regions is shown in Figure AIII.3; in this case a separate computer run is required for each region.

Figure AIII.4 shows data used for a CITATION Keff calculation for an Na void calculation (the case with Na removed from 37 S/As). For varying regions voided of Na, the positions of the material identified as number 12 is varied. For the sample worth calculations, material 12 is limited to the innermost radial mesh, and the axial mesh data is changed as follows:

```
from    4  8.80150  8 17.60300  4  8.80150
to      5 11.00190  6 13.20220  5 11.00190
```

Figure AIII.5 shows the data for the above calculation, but using TWOTRAN2. Note that the materials numbered 12 and 13 have been interchanged, 13 is now the Na void region (this places the perturbed material at the end of the list, for SN-PERT calculations). The axial mesh data change for the sample worth calculations is as follows:

```
from            1         6         4         8         4         6
  and     109.7260  127.3290
to              1         6         5         6         5         6
  and     111.9264  125.1286
```

Data for perturbation calculations by PERKY and SN-PERT are shown in Figures AIII.6 and AIII.7; the programs are used with CITATION and TWOTRAN2, respectively. The datasets shown are for the same cases as in Figures AIII.4 and AIII.5. The perturbation calculations need flux files produced by the associated reactor calculations; they require both direct flux calculations for the perturbed state (Na voided or material sample present) and adjoint flux calculations for the unperturbed state.

To produce the undistorted adjoint flux from CITATION, the dataset of Figure AIII.4 requires the following changes. The first line of data in block '001' changes 1 value,

```
from    0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0
to      0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0
```

In data block '008' the Na voided material, 'VODCAS', is replaced by a material which is identical to the unvoided (unperturbed) Pu fuel, 'ZDSMCA'. An additional block of

data is added, immediately before the line containing just '999'; the new block is as follows:

```
040
  0         0  0  0     2  0  0  0  0         0
```

To produce the undistorted adjoint flux from TWOTRAN2, the dataset of Figure AIII.5 requires the following changes. The first line following the title changes 1 value, as follows:

from	0	0	4	70	11	14	1	0	0	0	1	0
to	1	0	4	70	11	14	1	0	0	0	1	0

In the map of material numbers, the regions that were material 13 (VODCAS, the Na void region) are altered to 1 (ZDLCAS, the Pu fuel).

```
PREP
STEEL SUPPORT
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
  8
 1.0
    6 1.01600E-04  13 4.35600E-04  14 3.77100E-04  22 1.78000E-04
   24 5.11500E-03  25 2.10500E-04  26 1.72200E-02  28 2.15800E-03
SUPORT
PREP
DEPLETED UO2 -  CORRECTED WRAPPER SIZE
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 14
 1.0
    1 1.15700E-05   6 7.39000E-04   8 2.98300E-02  13 4.81400E-03
   14 9.53900E-05  22 4.50400E-05  24 1.29400E-03  25 5.32800E-05
   26 4.61800E-03  28 5.46100E-04 925 6.26500E-05 928 1.48500E-02
  147 6.02000E-06 157 2.25900E-08
UO2CAS
PREP
B4C ABSORBER   -   CORRECTED WRAPPER SIZE
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 13
 1.0
    6 1.59100E-02 105 1.20300E-02 115 4.81100E-02   8 7.63800E-05
   13 4.05100E-04  14 9.53900E-05  22 4.50400E-05  24 1.29400E-03
   25 5.32800E-05  26 4.47100E-03  28 5.46100E-04 147 6.02000E-06
  157 2.25900E-08
ABSCAS
PREP
ALUMINIUM SHIELD  -  ALSO ABOVE BLOCK GAPS  -  CORRECTED WRAPPER SIZE
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 11
 1.0
    6 2.57100E-05   8 1.51400E-06  13 4.66300E-02  14 9.53900E-05
   22 4.50400E-05  24 1.29400E-03  25 5.32800E-05  26 4.44600E-03
   28 5.46100E-04 147 6.02000E-06 157 2.25900E-08
ALSCAS
PREP
"GREEN" NA   -   CORRECTED WRAPPER SIZE
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 13
 1.0
    1 1.51900E-05   6 5.65500E-05   8 1.51400E-06  11 1.68400E-02
   13 2.27500E-04  14 9.53900E-05  22 9.29100E-05  24 2.57800E-03
   25 1.54600E-04  26 8.96500E-03  28 1.14600E-03 147 6.02000E-06
  157 2.25900E-08
NGRCAS
PREP
"LASER" NA   -   CORRECTED WRAPPER SIZE, DATA ERROR CORRECTED
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 12
 1.0
    6 5.68600E-05   8 1.51400E-06  11 1.70000E-02  13 2.28800E-04
   14 9.53900E-05  22 9.33900E-05  24 2.59000E-03  25 1.55600E-04
   26 9.01100E-03  28 1.15200E-03 147 6.02000E-06 157 2.25900E-08
NXACAS
PREP
"LASER" NA , WITH HYDROGEN   -   CORRECTED WRAPPER SIZE, DATA CORRECTED
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 13
 1.0
    1 1.53500E-05
```

```
    6 5.68600E-05   8 1.51400E-06  11 1.70000E-02  13 2.28800E-04
   14 9.53900E-05  22 9.33900E-05  24 2.59000E-03  25 1.55600E-04
   26 9.01100E-03  28 1.15200E-03 147 6.02000E-06 157 2.25900E-08
NXHCAS
PREP
B4C + NA SHIELD   -   CORRECTED WRAPPER SIZE
  1  1 -1  1  0  0  3 -23  0  0  0  0 70
 293.0  0.0 0.0
 14
 1.0
    6 1.06700E-02 105 8.05000E-03 115 3.22000E-02   8 5.16300E-05
   11 5.62300E-03  13 3.46800E-04  14 9.53900E-05  22 6.10300E-05
   24 1.72300E-03  25 8.71000E-05  26 5.97200E-03  28 7.46600E-04
  147 6.02000E-06 157 2.25900E-08
NBCCAS
```

Figure AIII.1 SLAROM non-fuel input [BFSB.DATA(SLANFALL)]

```
PREP
 LEZ FUEL     LASER NA  (NO H)   WITH BUCKLING  FULL WRAPPER
 15  1 -1  2  0  0  3 -23  0  0  0  0 70
 293.0  1.25  0.0
    8  11   7   8  13   7   8  7  11   8   7  13   8   7   8
 1.0072 1.480  0.9619 1.0072 0.3263 0.9619 1.0072 0.9619 1.480
 1.0072 0.9619 0.3263 1.0072 0.9619 0.5036
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   6 1.204000E-04   8 7.088000E-06  13 5.160000E-04  14 4.467000E-04
  22 2.109000E-04  24 6.059000E-03  25 2.495000E-04  26 2.040000E-02
  28 2.557000E-03 147 2.819000E-05 157 1.060000E-07 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   6 1.039000E-04  13 3.955000E-04  22 1.611000E-04  24 4.319000E-03
  25 3.400000E-04  26 1.551000E-02  28 2.019000E-03  31 1.360000E-03
 948 1.226000E-06 949 2.249000E-02 940 1.088000E-03 941 5.906000E-05
 942 2.363000E-06 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 1.204000E-04   8 7.088000E-06  13 5.160000E-04  14 4.467000E-04
  22 2.109000E-04  24 6.059000E-03  25 2.495000E-04  26 2.040000E-02
  28 2.557000E-03 147 2.819000E-05 157 1.060000E-07 /
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 1.039000E-04  13 3.955000E-04  22 1.611000E-04  24 4.319000E-03
  25 3.400000E-04  26 1.551000E-02  28 2.019000E-03  31 1.360000E-03
 948 1.226000E-06 949 2.249000E-02 940 1.088000E-03 941 5.906000E-05
 942 2.363000E-06 /
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /

PATH
 LEZ FUEL
 70 15  2  1  0  0  0
  2 15 15  1 15  0  0  0  4  0  1  1  0  0  180  0
  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15
 0.0  1.0072 2.4872 3.4491 4.4563 4.7826 5.7445 6.7517 7.7136 9.1936
     10.2000 11.1627 11.4890 12.4962 13.4581 13.9617
PIJF
 37  0  5  3  0  0  0  0
  0  0  0.  0.  0.  0.
  0
EDIT
  2  2  1  0  0
LLAWWW
PREP
 LEZ FUEL    GREEN NA  (WITH H)      WITH BUCKLING   FULL WRAPPER
 15  1 -1  2  0  0  3 -23  0  0  0  0 70
 293.0  1.25  0.0
    9  11   7   9  13   7   9  7  11   9   7  13   9   7   9
 1.0072 1.480  0.9619 1.0072 0.3263 0.9619 1.0072 0.9619 1.480
 1.0072 0.9619 0.3263 1.0072 0.9619 0.5036
   1 1.914200E-05
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
```

```
   6 1.204000E-04   8 7.088000E-06  13 5.160000E-04  14 4.467000E-04
  22 2.109000E-04  24 6.059000E-03  25 2.495000E-04  26 2.040000E-02
  28 2.557000E-03 147 2.819000E-05 157 1.060000E-07 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   1 1.914200E-05
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   6 1.039000E-04  13 3.955000E-04  22 1.611000E-04  24 4.319000E-03
  25 3.400000E-04  26 1.551000E-02  28 2.019000E-03  31 1.360000E-03
 948 1.226000E-06 949 2.249000E-02 940 1.088000E-03 941 5.906000E-05
 942 2.363000E-06 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   1 1.914200E-05
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 1.204000E-04   8 7.088000E-06  13 5.160000E-04  14 4.467000E-04
  22 2.109000E-04  24 6.059000E-03  25 2.495000E-04  26 2.040000E-02
  28 2.557000E-03 147 2.819000E-05 157 1.060000E-07 /
   1 1.914200E-05
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   6 1.039000E-04  13 3.955000E-04  22 1.611000E-04  24 4.319000E-03
  25 3.400000E-04  26 1.551000E-02  28 2.019000E-03  31 1.360000E-03
 948 1.226000E-06 949 2.249000E-02 940 1.088000E-03 941 5.906000E-05
 942 2.363000E-06 /
   1 1.914200E-05
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /
   1 1.457000E-05   6 8.987000E-04   8 3.759000E-02  13 5.926000E-03
  26 3.302000E-04 925 7.894000E-05 928 1.870000E-02 /
   1 1.914200E-05
   6 3.886000E-05  11 2.122000E-02  13 1.478000E-04  22 6.031000E-05
  24 1.618000E-03  25 1.276000E-04  26 5.807000E-03  28 7.562000E-04 /

PATH
 LEZ FUEL
 70 15  2  1  0  0  0
  2 15 15  1 15  0  0  0  4  0  1  1  0  0  180  0
  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15
 0.0  1.0072 2.4872 3.4491 4.4563 4.7826 5.7445 6.7517 7.7136 9.1936
     10.2000 11.1627 11.4890 12.4962 13.4581 13.9617
PIJF
 37  0  5  3  0  0  0  0
  0  0  0.  0.  0.  0.
  0
EDIT
  2  2  1  0  0
LGRWWW
PREP
 MEZ FUEL    WITH BUCKLING    FULL WRAPPER
 16  1 -1  2  0  0  3 -23  0  0  0  0 70
 293.0  1.25  0.0
    9   7   9   9   4  11  9   7   9   9   9   7  11  9   9   4
 0.9879 0.9434 0.5581 0.9879 0.5660 1.4800 0.9879 0.9434 0.9879
 0.5581 0.9879 0.9434 1.4800 0.9879 0.2790 0.2830
   1 1.952000E-05
   6 3.962000E-05  11 2.163000E-02  13 1.507000E-04  22 6.150000E-05
  24 1.650000E-03  25 1.301000E-04  26 5.921000E-03  28 7.711000E-04 /
   1 1.486000E-05   6 9.163000E-04   8 3.832000E-02  13 6.042000E-03
  26 3.367000E-04 925 8.049000E-05 928 1.907000E-02 /
   6 5.934000E-05
  13 1.860000E-04  22 9.910000E-05  24 2.054000E-03  25 2.377000E-04
  26 7.840000E-03  28 1.011000E-03 925 1.452000E-02 928 2.531000E-02 /
```

```
  1 1.952000E-05
  6 3.962000E-05  11 2.163000E-02  13 1.507000E-04  22 6.150000E-05
 24 1.650000E-03  25 1.301000E-04  26 5.921000E-03  28 7.711000E-04 /
  8 6.645000E-02  13 4.430000E-02  22 4.705000E-05  26 4.076000E-05 /
  6 1.909000E-04   8 4.859000E-06  13 8.180000E-04  14 7.077000E-04
 22 3.341000E-04  24 9.592000E-03  25 3.950000E-04  26 3.231000E-02
 28 4.051000E-03 147 1.933000E-05 157 7.300000E-08 /
  1 1.952000E-05
  6 3.962000E-05  11 2.163000E-02  13 1.507000E-04  22 6.150000E-05
 24 1.650000E-03  25 1.301000E-04  26 5.921000E-03  28 7.711000E-04 /
  1 1.486000E-05   6 9.163000E-04   8 3.832000E-02  13 6.042000E-03
 26 3.367000E-04 925 8.049000E-05 928 1.907000E-02 /
  1 1.952000E-05
  6 3.962000E-05  11 2.163000E-02  13 1.507000E-04  22 6.150000E-05
 24 1.650000E-03  25 1.301000E-04  26 5.921000E-03  28 7.711000E-04 /
  6 5.934000E-05
 13 1.860000E-04  22 9.910000E-05  24 2.054000E-03  25 2.377000E-04
 26 7.840000E-03  28 1.011000E-03 925 1.452000E-02 928 2.531000E-02 /
  1 1.952000E-05
  6 3.962000E-05  11 2.163000E-02  13 1.507000E-04  22 6.150000E-05
 24 1.650000E-03  25 1.301000E-04  26 5.921000E-03  28 7.711000E-04 /
  1 1.486000E-05   6 9.163000E-04   8 3.832000E-02  13 6.042000E-03
 26 3.367000E-04 925 8.049000E-05 928 1.907000E-02 /
  6 1.909000E-04   8 4.859000E-06  13 8.180000E-04  14 7.077000E-04
 22 3.341000E-04  24 9.592000E-03  25 3.950000E-04  26 3.231000E-02
 28 4.051000E-03 147 1.933000E-05 157 7.300000E-08 /
  1 1.952000E-05
  6 3.962000E-05  11 2.163000E-02  13 1.507000E-04  22 6.150000E-05
 24 1.650000E-03  25 1.301000E-04  26 5.921000E-03  28 7.711000E-04 /
  6 5.934000E-05
 13 1.860000E-04  22 9.910000E-05  24 2.054000E-03  25 2.377000E-04
 26 7.840000E-03  28 1.011000E-03 925 1.452000E-02 928 2.531000E-02 /
  8 6.645000E-02  13 4.430000E-02  22 4.705000E-05  26 4.076000E-05 /

PATH
 MEZ FUEL
 70 16  2  1  0  0  0
  2 16 16  1 16  0  0  0  4  0  1  1  0  0  180  0
  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16
 0.0  0.9879 1.9313 2.4894 3.4773 4.0433 5.5233 6.5112 7.4546 8.4425
      9.0006  9.9885 10.9319 12.4119 13.3998 13.6788 13.9618
PIJF
 37  0  5  3  0  0  0  0
  0  0  0.  0.  0.  0.
  0
EDIT
  2  2  1  0  0
MEZWWW
PREP
 DILUENT FUEL - PU+AL2O3 , BUCKLING REGION 1 ALL ISO. - FULL WRAPPER
 12  1 -1  2  0  0  3 -23  0  0  0  0 70
 293.0  1.25  0.0
   23  11   8   7   8  13   4   8  11   4   8   4
 1.007  1.184  0.990  0.993  0.990  0.324  1.007  0.990  1.184
 1.007  0.990  0.5035
 949 0.000000E+00 940 0.000000E+00 941 0.000000E+00 942 0.000000E+00
 925 0.000000E+00 928 0.000000E+00
   8 6.715000E-02  11 0.000000E+00  26 4.120000E-05  24 0.000000E+00
  28 0.000000E+00  25 0.000000E+00   6 0.000000E+00 157 0.000000E+00
 948 0.000000E+00 105 0.000000E+00 115 0.000000E+00 147 0.000000E+00
   1 0.000000E+00  13 4.477000E-02  14 0.000000E+00
  22 4.758000E-05  31 0.000000E+00 /
   6 1.213000E-04   8 7.139000E-06  13 5.198000E-04  14 4.500000E-04
  22 2.124000E-04  24 6.103000E-03  25 2.513000E-04  26 2.055000E-02
  28 2.576000E-03 147 2.840000E-05 157 1.070000E-07 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   6 3.900000E-04  13 1.485000E-03  22 6.065000E-04  24 1.622000E-02
  25 1.279000E-03  26 5.824000E-02  28 7.581000E-03 /
```

```
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   6 1.046000E-04  13 3.984000E-04  22 1.623000E-04  24 4.350000E-03
  25 3.425000E-04  26 1.562000E-02  28 2.034000E-03  31 1.370000E-03
 948 1.235000E-06 949 2.265000E-02 940 1.096000E-03 941 5.949000E-05
 942 2.380000E-06 /
   8 6.715000E-02  13 4.477000E-02  22 4.758000E-05  26 4.120000E-05 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   6 1.213000E-04   8 7.139000E-06  13 5.198000E-04  14 4.500000E-04
  22 2.124000E-04  24 6.103000E-03  25 2.513000E-04  26 2.055000E-02
  28 2.576000E-03 147 2.840000E-05 157 1.070000E-07 /
   8 6.715000E-02  13 4.477000E-02  22 4.758000E-05  26 4.120000E-05 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   8 6.715000E-02  13 4.477000E-02  22 4.758000E-05  26 4.120000E-05 /

PATH
 DILUENT FUEL
 70 12  2  1  0  0  0
  2 12 12  1 12  0  0  0  4  0  1  1  0  0  180  0
  1  2  3  4  5  6  7  8  9  10  11  12
 0.0  1.007  2.191  3.181  4.174  5.164  5.488  6.495  7.485  8.669
      9.676  10.666  11.1695
PIJF
 37  0  5  3  0  0  0  0
  0  0  0.  0.  0.  0.
  0
EDIT
  2  2  1  0  0
DILWWW
PREP
 DILUENT FUEL - PU+AL2O3 , BUCKLING  - FULL WRAPPER - SAMPLE   NONE
 12  1 -1  2  0  0  3 -23  0  0  0  0 70
 293.0  1.25  0.0
    4  11   8   7   8  13   4   8  11   4   8   4
 1.007  1.184  0.990  0.993  0.990  0.324  1.007  0.990  1.184
 1.007  0.990  0.5035
   8 6.715000E-02  26 4.120000E-05
  13 4.477000E-02
  22 4.758000E-05 /
   6 1.213000E-04   8 7.139000E-06  13 5.198000E-04  14 4.500000E-04
  22 2.124000E-04  24 6.103000E-03  25 2.513000E-04  26 2.055000E-02
  28 2.576000E-03 147 2.840000E-05 157 1.070000E-07 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   6 3.900000E-04  13 1.485000E-03  22 6.065000E-04  24 1.622000E-02
  25 1.279000E-03  26 5.824000E-02  28 7.581000E-03 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   6 1.046000E-04  13 3.984000E-04  22 1.623000E-04  24 4.350000E-03
  25 3.425000E-04  26 1.562000E-02  28 2.034000E-03  31 1.370000E-03
 948 1.235000E-06 949 2.265000E-02 940 1.096000E-03 941 5.949000E-05
 942 2.380000E-06 /
   8 6.715000E-02  13 4.477000E-02  22 4.758000E-05  26 4.120000E-05 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   6 1.213000E-04   8 7.139000E-06  13 5.198000E-04  14 4.500000E-04
  22 2.124000E-04  24 6.103000E-03  25 2.513000E-04  26 2.055000E-02
  28 2.576000E-03 147 2.840000E-05 157 1.070000E-07 /
   8 6.715000E-02  13 4.477000E-02  22 4.758000E-05  26 4.120000E-05 /
   6 3.953000E-05  11 2.158000E-02  13 1.505000E-04  22 6.136000E-05
  24 1.645000E-03  25 1.298000E-04  26 5.908000E-03  28 7.694000E-04 /
   8 6.715000E-02  13 4.477000E-02  22 4.758000E-05  26 4.120000E-05 /

PATH
 DILUENT FUEL
 70 12  2  1  0  0  0
  2 12 12  1 12  0  0  0  4  0  1  1  0  0  180  0
```

```
  1  2  3  4  5  6  7  8  9  10  11  12
 0.0  1.007  2.191  3.181  4.174  5.164  5.488  6.495  7.485  8.669
      9.676  10.666  11.1695
PIJF
 37  0  5  3  0  0  0  0
  0  0  0.  0.  0.  0.
  0
EDIT
  2  2  1  0  0
DWSAMP
```

Figure AIII.2 SLAROM input, fuel
[POC0B17.BFSB.DATA(SLA2FWRP)]

```
 MEZ FUEL    WITH BUCKLING FINAL CASUP, CORRECT WRAPPER SIZE, ERROR FIXD
  1  1  1  0  1  0  0  0  1  0  0  1  0  1 10
 16 16  1 16  1 70  0
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16
  0.9879   0.9434   0.5581   0.9879   0.5660   1.4800   0.9879   0.9434
  0.9879   0.5581   0.9879   0.9434   1.4800   0.9879   0.2790   0.2830
0.0000E+0
300.00000
  9  7  9  9  4 11  9  7  9  9  9  7 11  9  9  4
MATERIAL          9
   6 3.96200E-05  11 2.16300E-02  13 1.50700E-04  24 1.65000E-03
  25 1.30100E-04  26 5.92100E-03  28 7.71100E-04   1 1.95200E-05
  22 6.15000E-05
MATERIAL          7
   1 1.48600E-05   6 9.16300E-04   8 3.83200E-02  13 6.04200E-03
  26 3.36700E-04 925 8.04900E-05 928 1.90700E-02
MATERIAL          9
  13 1.86000E-04  24 2.05400E-03  25 2.37700E-04  26 7.84000E-03
  28 1.01100E-03 925 1.45200E-02 928 2.53100E-02   6 5.93400E-05
  22 9.91000E-05
MATERIAL          9
   6 3.96200E-05  11 2.16300E-02  13 1.50700E-04   1 1.95200E-05
  24 1.65000E-03  25 1.30100E-04  26 5.92100E-03  28 7.71100E-04
  22 6.15000E-05
MATERIAL          4
   8 6.64500E-02  13 4.43000E-02  26 4.07600E-05  22 4.70500E-05
WRAPPER          11
   6 1.90900E-04   8 4.85900E-06  13 8.18000E-04  14 7.07700E-04
  22 3.34100E-04  24 9.59200E-03  25 3.95000E-04  26 3.23100E-02
  28 4.05100E-03 147 1.93300E-05 157 7.30000E-08
MATERIAL          9
   6 3.96200E-05  11 2.16300E-02  13 1.50700E-04   1 1.95200E-05
  24 1.65000E-03  25 1.30100E-04  26 5.92100E-03  28 7.71100E-04
  22 6.15000E-05
MATERIAL          7
   1 1.48600E-05   6 9.16300E-04   8 3.83200E-02  13 6.04200E-03
  26 3.36700E-04 925 8.04900E-05 928 1.90700E-02
MATERIAL          9
   6 3.96200E-05  11 2.16300E-02  13 1.50700E-04   1 1.95200E-05
  24 1.65000E-03  25 1.30100E-04  26 5.92100E-03  28 7.71100E-04
  22 6.15000E-05
MATERIAL          9
  13 1.86000E-04   6 5.93400E-05  24 2.05400E-03  25 2.37700E-04
  26 7.84000E-03  28 1.01100E-03 925 1.45200E-02 928 2.53100E-02
  22 9.91000E-05
MATERIAL          9
   6 3.96200E-05  11 2.16300E-02  13 1.50700E-04   1 1.95200E-05
  24 1.65000E-03  25 1.30100E-04  26 5.92100E-03  28 7.71100E-04
  22 6.15000E-05
MATERIAL          7
   1 1.48600E-05   6 9.16300E-04   8 3.83200E-02  13 6.04200E-03
  26 3.36700E-04 925 8.04900E-05 928 1.90700E-02
WRAPPER          11
   6 1.90900E-04   8 4.85900E-06  13 8.18000E-04  14 7.07700E-04
  22 3.34100E-04  24 9.59200E-03  25 3.95000E-04  26 3.23100E-02
  28 4.05100E-03 147 1.93300E-05 157 7.30000E-08
MATERIAL          9
   6 3.96200E-05  11 2.16300E-02  13 1.50700E-04   1 1.95200E-05
  24 1.65000E-03  25 1.30100E-04  26 5.92100E-03  28 7.71100E-04
  22 6.15000E-05
MATERIAL          9
  13 1.86000E-04   6 5.93400E-05  24 2.05400E-03  25 2.37700E-04
  26 7.84000E-03  28 1.01100E-03 925 1.45200E-02 928 2.53100E-02
  22 9.91000E-05
MATERIAL          4
   8 6.64500E-02  13 4.43000E-02  26 4.07600E-05  22 4.70500E-05
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  1  1  1  0  1  0  0  0
```

```
  1
  1
1.0000E-041.0000E-05        10       600
ZMXCAS
```

file [POC0B17.BFSB.DATA(CAS1MX)]

```
 LEZ FUEL    LASER NA  ,  FINAL CASUP , CORRECTED WRAPPER SIZE
  1  1  1  0  1  0  0  0  1  0  0  1  0  1 10
 15 15  1 15  1 70  0
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15
  1.0072   1.480    0.9619   1.0072   0.3263   0.9619   1.0072   0.9619
  1.480    1.0072   0.9619   0.3263   1.0072   0.9619   0.5036
0.0000E+0
300.00000
  8 11  7  8 13  7  8  7 11  8  7 13  8  7  8
MATERIAL           8
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04  22 6.03100E-05
WRAPPER           11
   6 1.20400E-04   8 7.08800E-06  13 5.16000E-04  14 4.46700E-04
  24 6.05900E-03  25 2.49500E-04  26 2.04000E-02  28 2.55700E-03
  22 2.10900E-04 147 2.81900E-05 157 1.06000E-07
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL           8
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04  22 6.03100E-05
MATERIAL          13
   6 1.03900E-04  13 3.95500E-04  24 4.31900E-03  25 3.40000E-04
  26 1.55100E-02  28 2.01900E-03 949 2.24900E-02 940 1.08800E-03
 941 5.90600E-05 942 2.36300E-06  22 1.61100E-04  31 1.36000E-03
 948 1.22600E-06
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL           8
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04  22 6.03100E-05
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
WRAPPER           11
   6 1.20400E-04   8 7.08800E-06  13 5.16000E-04  14 4.46700E-04
  24 6.05900E-03  25 2.49500E-04  26 2.04000E-02  28 2.55700E-03
  22 2.10900E-04 147 2.81900E-05 157 1.06000E-07
MATERIAL           8
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04  22 6.03100E-05
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL          13
   6 1.03900E-04  13 3.95500E-04  24 4.31900E-03  25 3.40000E-04
  26 1.55100E-02  28 2.01900E-03 949 2.24900E-02 940 1.08800E-03
 941 5.90600E-05 942 2.36300E-06  22 1.61100E-04  31 1.36000E-03
 948 1.22600E-06
MATERIAL           8
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04  22 6.03100E-05
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL           8
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
```

```
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04  22 6.03100E-05
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  1  1  1  0  1  0  0  0
  1
  1
1.0000E-041.0000E-05        10        600
ZLLCAS
```

file [POC0B17.BFSC.DATA(CAS1LL)]

```
 LEZ FUEL    GREEN NA  ,  FINAL CASUP , CORRECTED WRAPPER SIZE
  1  1  1  0  1  0  0  0  1  0  0  1  0  1 10
 15 15  1 15  1 70  0
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15
  1.0072   1.480    0.9619   1.0072   0.3263   0.9619   1.0072   0.9619
  1.480    1.0072   0.9619   0.3263   1.0072   0.9619   0.5036
0.0000E+0
300.00000
  9 11  7  9 13  7  9  7 11  9  7 13  9  7  9
MATERIAL           9
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04   1 1.91420E-05
  22 6.03100E-05
WRAPPER           11
   6 1.20400E-04   8 7.08800E-06  13 5.16000E-04  14 4.46700E-04
  24 6.05900E-03  25 2.49500E-04  26 2.04000E-02  28 2.55700E-03
  22 2.10900E-04 147 2.81900E-05 157 1.06000E-07
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL           9
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04   1 1.91420E-05
  22 6.03100E-05
MATERIAL          13
   6 1.03900E-04  13 3.95500E-04  24 4.31900E-03  25 3.40000E-04
  26 1.55100E-02  28 2.01900E-03 949 2.24900E-02 940 1.08800E-03
 941 5.90600E-05 942 2.36300E-06  22 1.61100E-04  31 1.36000E-03
 948 1.22600E-06
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL           9
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04   1 1.91420E-05
  22 6.03100E-05
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
WRAPPER           11
   6 1.20400E-04   8 7.08800E-06  13 5.16000E-04  14 4.46700E-04
  24 6.05900E-03  25 2.49500E-04  26 2.04000E-02  28 2.55700E-03
  22 2.10900E-04 147 2.81900E-05 157 1.06000E-07
MATERIAL           9
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04   1 1.91420E-05
  22 6.03100E-05
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL          13
   6 1.03900E-04  13 3.95500E-04  24 4.31900E-03  25 3.40000E-04
  26 1.55100E-02  28 2.01900E-03 949 2.24900E-02 940 1.08800E-03
 941 5.90600E-05 942 2.36300E-06  22 1.61100E-04  31 1.36000E-03
 948 1.22600E-06
MATERIAL           9
```

```
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04   1 1.91420E-05
  22 6.03100E-05
MATERIAL           7
   1 1.45700E-05   6 8.98700E-04   8 3.75900E-02  13 5.92600E-03
  26 3.30200E-04 925 7.89400E-05 928 1.87000E-02
MATERIAL           9
   6 3.88600E-05  11 2.12200E-02  13 1.47800E-04  24 1.61800E-03
  25 1.27600E-04  26 5.80700E-03  28 7.56200E-04   1 1.91420E-05
  22 6.03100E-05
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0
  1  1  1  0  1  0  0  0
  1
  1
1.0000E-041.0000E-05        10        600
ZLGCAS
```

file [POC0B17.BFSC.DATA(CAS1LG)]

```
 DILUENT FUEL  -  PU + AL2O3 FINAL CASUP   ALL ISOTOPES  FULL WRAPPER
  1  1  1  0  1  0  0  0  1  0  0  1  0  1 10
 12 12  1 12  1 70  0
  1  2  3  4  5  6  7  8  9 10 11 12
  1.007    1.184    0.990    0.993    0.990    0.324    1.007    0.990
  1.184    1.007    0.990    0.5035
0.0000E+0
300.00000
  4 11  8  7  8 13  4  8 11  4  8  4
MATERIAL           4
   8 6.71500E-02  26 4.12000E-05  13 4.47700E-02  22 4.75800E-05
WRAPPER           11
   6 1.21300E-04   8 7.13900E-06  13 5.19800E-04  14 4.50000E-04
  22 2.12400E-04  24 6.10300E-03  25 2.51300E-04  26 2.05500E-02
  28 2.57600E-03 147 2.84000E-05 157 1.07000E-07
MATERIAL           8
   6 3.95300E-05  11 2.15800E-02  13 1.50500E-04  24 1.64500E-03
  25 1.29800E-04  26 5.90800E-03  28 7.69400E-04  22 6.13600E-05
MATERIAL           7
   6 3.90000E-04  13 1.48500E-03  24 1.62200E-02  25 1.27900E-03
  26 5.82400E-02  28 7.58100E-03  22 6.06500E-04
MATERIAL           8
   6 3.95300E-05  11 2.15800E-02  13 1.50500E-04  24 1.64500E-03
  25 1.29800E-04  26 5.90800E-03  28 7.69400E-04  22 6.13600E-05
MATERIAL          13
   6 1.04600E-04  13 3.98400E-04  24 4.35000E-03  25 3.42500E-04
  26 1.56200E-02  28 2.03400E-03 949 2.26500E-02 940 1.09600E-03
 941 5.94900E-05 942 2.38000E-06  22 1.62300E-04  31 1.37000E-03
 948 1.23500E-06
MATERIAL           4
   8 6.71500E-02  13 4.47700E-02  26 4.12000E-05  22 4.75800E-05
MATERIAL           8
   6 3.95300E-05  11 2.15800E-02  13 1.50500E-04  24 1.64500E-03
  25 1.29800E-04  26 5.90800E-03  28 7.69400E-04  22 6.13600E-05
WRAPPER           11
   6 1.21300E-04   8 7.13900E-06  13 5.19800E-04  14 4.50000E-04
  22 2.12400E-04  24 6.10300E-03  25 2.51300E-04  26 2.05500E-02
  28 2.57600E-03 147 2.84000E-05 157 1.07000E-07
MATERIAL           4
   8 6.71500E-02  13 4.47700E-02  26 4.12000E-05  22 4.75800E-05
MATERIAL           8
   6 3.95300E-05  11 2.15800E-02  13 1.50500E-04  24 1.64500E-03
  25 1.29800E-04  26 5.90800E-03  28 7.69400E-04  22 6.13600E-05
MATERIAL           4
   8 6.71500E-02  13 4.47700E-02  26 4.12000E-05  22 4.75800E-05
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

```
  1  1  1  0  1  0  0  0
  1
  1
1.0000E-041.0000E-05        10        600
ZDLCAS
```

file [POC0B17.BFSC.DATA(CAS1D)]

Figure AIII.3 CASUP input, fuel [various files]

```
CITATION
ZDLCAS    SLAROM
  BFS 58-I1-1  PU BURNER MOCKUP FOR BN600 TYPE NA VOID RINGS 1-4 PERKY
NO AIR-GAP, BUCK., 6-C. NAMES 2 LEZ TYPES - 224/234 S/A, FULL WRAP. D
001
  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0
  1  0  0  1  1  0  0  1  1  2  0  0  0  1  0  0  0  0  0  0  0  0  0
200

003
  0  0  0  0  7  0  0  0  0  0  1  0  0  0  0  0  0  1  0  0  0  0  0
   1.0000E-5   1.0000E-6

004
  1  2.63040  2  4.32900  2  4.50620  2  4.5345  10 23.80510  5 16.17970
  2  6.87020  1  1.95100  2  5.9218   6 18.00670  4 13.78350
  1  7.60000  1  8.57000  2 13.68000  1  7.60000  1  7.37000  5 27.70000
  1  2.00000  6 26.40450  4  8.80150  8 17.60300  4  8.80150  6 26.40450
  6 33.42480 10 77.50000
005
  7  7  7  7  7  7  7  7  7  7  7
  7  7  7  7  7  7  7  7  7  7  5
  7  7  7  7  7  7  7  7  7  5  5
 11 11 11 11 11 11 11  7 11  5  5
 11 11 11 11 11 11 11  6 11  5  5
  9  9  9  9  9  9 10  6 10 10  5
  9  9  9  9  9  9 10  8 10 10  5
  1  1  1  1  1  2 13  8 13  3  5
  1  1  1  1  1  2 13  8 13  3  5
 12 12 12 12  1  2 13  8 13  3  5
  1  1  1  1  1  2 13  8 13  3  5
  1  1  1  1  1  2 13  8 13  3  5
  5  5  5  5  5  5  5  8  5  5  5
  4  4  4  4  4  4  4  4  4  4  5
008
-70 70  0 13  2  1  1  3     1
  1
ZDLCAS    SLAROM
  2
ZLLCAS    SLAROM
  3
ZMXCAS    SLAROM
  4
SUPORT    SLAROM
  5
UO2CAS    SLAROM
  6
ABSCAS    SLAROM
  7
ALSCAS    SLAROM
  8
NGRCAS    SLAROM
  9
NXACAS    SLAROM
 10
NXHCAS    SLAROM
 11
NBCCAS    SLAROM
 12
VODCAS    SLAROM
 13
ZLGCAS    SLAROM

ZDLCAS    SLAROM
023
  0  0  0  7
999
```

Figure AIII.4 CITATION input [POC0B17.BFSB.DATA(CIT2ZP14)]

```
TWOTRAN2           0
ZDLCAS     SLAROM
   70   70   13    0    0    2
   0    0    6    6                                                  0  40  70
     1
 TITLE CARD -  BFS 58-I1-1 NA VOID -  70 GROUPS, RING 1-4 VOID, DIRECT
     0     0     4    70    11    14     1     0     0     0     1     0
    13  0 13     0     5     6    35     0     0 0 0 0     0    20     0
     0     0     2     0     0120001     1     0     0     1  1000
         0.0          0.0          0.0          0.0          0.0          0.0
    0.000001          1.0          0.0          0.0
           1            2            2            2           10            5
           2            1            2            6           43
           1            1            2            1            1            5
           1            6            4            8            4            6
           6          103
XS@
ZDLCAS     SLAROM
ZLLCAS     SLAROM
ZMXCAS     SLAROM
SUPORT     SLAROM
UO2CAS     SLAROM
ABSCAS     SLAROM
ALSCAS     SLAROM
NGRCAS     SLAROM
NXACAS     SLAROM
NXHCAS     SLAROM
NBCCAS     SLAROM
ZLGCAS     SLAROM
VODCAS     SLAROM
      0.0000       2.6304       6.9594      11.4656      16.0001      39.8052
     55.9849      62.8551      64.8061      70.7279      88.7346     102.5181
3
      0.0000       7.6000      16.1700      29.8500      37.4500      44.8200
     72.5200      74.5200     100.9245     109.7260     127.3290     136.1305
    162.5350     195.9598     273.45983
           7            7            7            7            7            7
           7            7            7            7           79
           7            7            7            7            7            7
           7            7            7            7           59
           7            7            7            7            7            7
           7            7            7            5           59
          11           11           11           11           11           11
          11            7           11            5           59
          11           11           11           11           11           11
          11            6           11            5           59
           9            9            9            9            9           10
          10            6           10           10           59
           9            9            9            9            9           10
          10            8           10           10           59
           1            1            1            1            1            2
          12            8           12            3           59
           1            1            1            1            1            2
          12            8           12            3           59
          13           13           13           13            1            2
          12            8           12            3           59
           1            1            1            1            1            2
          12            8           12            3           59
           1            1            1            1            1            2
          12            8           12            3           59
           5            5            5            5            5            5
           5            8            5            5           59
           4            4            4            4            4            4
           4            4            4            4           53
KAI
ZDLCAS     SLAROM
170 1.0      3
```

Figure AIII.5 TWOTRAN2 input [POC0B17.BFSB.DATA(TT70WC3D)]

```
PERKY
ZDLCAS    SLAROM
    70 GROUP EXACT ,  CASUP X-SECTIONS,  NA VOIDED , FULL WRAPPER
001
  1 70    14  1  1  0  0  1
003
  1  0  0
 14 14  0  0  1  2  3  4  5  6  7  8  9 10 11 12 13 14
DILCAS    SLAROM
 70 30  0  2  0  0  1  1  1
ZDLCAS    SLAROM
ZLLCAS    SLAROM
ZMXCAS    SLAROM
SUPORT    SLAROM
UO2CAS    SLAROM
ABSCAS    SLAROM
ALSCAS    SLAROM
NGRCAS    SLAROM
NXACAS    SLAROM
NXHCAS    SLAROM
NBCCAS    SLAROM
ZDSMCA    SLAROM
ZLGCAS    SLAROM
VODCAS    SLAROM
004
  5
008
  1  0  1  1 12
VODCAS    SLAROM
 12 14
999
```

Figure AIII.6 PERKY input [POC0B17.BFSB.DATA(PKYW70V)]

```
SNPERT              0
ZDLCAS     SLAROM
   70    30    13     0     0     2
 &SNOD
   ISNOD=4
 &END
   1    1    1
SNPERT EXACT PERTURBATION FROM TWOTRAN-2 RESULT   FINAL
002
 70G,2D-RZ,SODIUM-VOID WORTH CAL.,BFS-58-1-I1 RINGS 1-4 VOID
          -1
 &TRANS
    NOUT=4*0 ,NGEOM=1
 &END
 70G,2D-RZ,SODIUM-VOID WORTH CAL.,BFS-58-1-I1 RINGS 1-4 VOID
 &DATA
    NOUT=6,4*0,6,  ICON(2)=0,  NUNIT= 8, 9, 9,  KDOWN= 29,
    LIBRA = 11*7,
            10*7,  1*5,
             9*7,  2*5,
            7*11,  1*7, 1*11,  2*5,
            7*11,  1*6, 1*11,  2*5,
             5*9, 2*10,  1*6, 2*10,  1*5,
             5*9, 2*10,  1*8, 2*10,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             7*5,  1*8,  3*5,
            10*4,  1*5,
    LIBRAP= 11*7,
            10*7,  1*5,
             9*7,  2*5,
            7*11,  1*7, 1*11,  2*5,
            7*11,  1*6, 1*11,  2*5,
             5*9, 2*10,  1*6, 2*10,  1*5,
             5*9, 2*10,  1*8, 2*10,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             4*13, 1*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             5*1,  1*2, 1*12,  1*8,  1*12,  1*3,  1*5,
             7*5,  1*8,  3*5,
            10*4,  1*5,
    IPERTR= 11*0,
            11*0,
            11*0,
            11*0,
            11*0,
            11*0,
            11*0,
            11*0,
            11*0,
            11*0,
             4*1,  7*0,
            11*0,
            11*0,
            11*0,
            11*0,
 &END
XS@
ZDLCAS     SLAROM
ZLLCAS     SLAROM
ZMXCAS     SLAROM
SUPORT     SLAROM
UO2CAS     SLAROM
ABSCAS     SLAROM
ALSCAS     SLAROM
NGRCAS     SLAROM
```

```
NXACAS     SLAROM
NXHCAS     SLAROM
NBCCAS     SLAROM
ZLGCAS     SLAROM
VODCAS     SLAROM
000
```

Figure AIII.7 SN-PERT input [POC0B17.BFSPERT.DATA(NAVTT3)]

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