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NUCLEAR ENERGY AGENCY
NUCLEAR SCIENCE COMMITTEE

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PBMR COUPLED NEUTRONICS/THERMAL-HYDRAULICS TRANSIENT BENCHMARK THE PBMR-400 CORE DESIGN

VOLUME 1
THE BENCHMARK DEFINITION

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English - Or. English

PBMR Coupled Neutronics/Thermal-hydraulics Transient Benchmark

The PBMR-400 Core Design

Volume 1

The Benchmark Definition

NUCLEAR ENERGY AGENCY

Organisation for Economic Co-operation and Development

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

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OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

Foreword

The Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD) has accepted, through the Nuclear Science Committee (NSC), the inclusion of the Pebble Bed Modular Reactor (PBMR) coupled neutronics/thermal-hydraulics transient benchmark problem as part of its official activities.

The benchmark work will be published in three volumes:

- Volume 1: The Benchmark Definition [This document NEA/NSC/DOC(2013)10].

  The document contains the final benchmark specification as far as the physical properties, calculational tasks of participants, and required results are concerned. The document content was finalised after the third meeting held at the OECD Headquarters in February 2007.

- Volume 2: Steady-state Cases [This document will be published in 2013, NEA/NSC/DOC(2013)11].

  This document contains the final steady-state cases, results and comparisons.

- Volume 3: Transient Cases [This document will be published in 2013, NEA/NSC/DOC(2013)12].

  This document contains the final transient cases, results and comparisons.

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1. Introduction

Background

The PBMR is a high-temperature gas-cooled reactor (HTGR) concept, which has attracted the attention of the nuclear research and development community. The deterministic neutronics, thermal-hydraulics and transient analysis tools and methods available to design and analyse PBMRs have, in many cases, lagged behind the state of the art compared to other reactor technologies. This has motivated not only the testing of existing methods for HTGRs, but also the development of more accurate and efficient tools to analyse the neutronics and thermal-hydraulic behaviour for the design and safety evaluations of the PBMR. In addition to the development of new methods, such activities include defining appropriate benchmarks to verify and validate the new methods in computer codes.

The benchmark is complementary to other on-going or planned efforts in the reactor physics community. The PBMR 268 MW benchmark problem, initiated by PBMR (Proprietary) Limited, Penn State University (PSU) and Nuclear Research and Consultancy Group (NRG), served as the predecessor of this effort. The work was concluded in 2005 and the efforts were focused on this benchmark. The PBMR 400 MW core design is also a test case in the IAEA CRP-5 [5], but important differences exist between the test case definitions and approaches. The OECD benchmark includes additional steady-state and transient cases including reactivity insertion transients not included in the CRP5 effort. Furthermore, it makes use of a common set of cross-sections (to eliminate uncertainties between the usages of different cross-section libraries by different codes) and includes specific simplifications to the design to limit the need for participants to introduce approximations into their models.

This report defines the "OECD/NEA/NSC PBMR Coupled Neutronics/Thermal-hydraulics Transient Benchmark of the PBMR-400 Core Design". This chapter gives more information on the day-to-day management of the OECD benchmark with information on the OECD sponsorship, participation and the programme committee.

The scope of the benchmark is described also in this chapter, with the rest of the report used for the detailed definition of the benchmark problem.

Governance

Sponsorship

Three workshops for the Coupled Neutronics/Thermal-hydraulics Transient Benchmark of the PBMR-400 Core Design were held at the OECD headquarters in Paris, France, with the support of the Nuclear Science Committee (NSC) of the Nuclear Energy Agency (NEA) of the OECD and the supervision of the Working Party on Scientific Issues in Reactor Systems (WPRS).

Participation in the benchmark and workshops

Participation in the benchmark workshops was sponsored by the Nuclear Science Committee (NSC) and was restricted, for efficiency, to experts (research laboratories, safety authorities, regulatory agencies, utilities, owners' groups, vendors, etc.) from OECD member countries nominated by delegates to the Committees in consultation with official authorities concerned and with the assistance of members of the Nuclear Science Committee and in particular to participants in this study.

The meetings were also open to experts from IAEA member countries, which are in a position to provide a substantive contribution to this study. The NEA Secretariat arranged participation of these experts and this included participants involved in the Generation IV International Forum Very High Temperature Reactor (VHTR) studies.

Organisation and Programme Committee of the benchmark workshops

An Organisation and Programme Committee has been proposed to make the necessary arrangements for the benchmark workshops and to organise the sessions, draw up the final programme, appoint session chairmen, etc. Its proposed members are listed on pages 111-112.

Scope and technical content of the benchmark

The scope of the benchmark is to establish a well-defined problem, based on a common given set of cross-sections, to compare methods and tools in core simulation and thermal-hydraulics analysis with a specific focus on transient events through a set of multi-dimensional computational test problems.

In addition, the benchmark exercise has the following objectives:

- to establish a standard benchmark for coupled codes (neutronics/thermal-hydraulics) for PBMR design;
- to conduct code-to-code comparison using a common cross-section library, important for verification and validation;
- to obtain a detailed understanding of the events and processes;
- to benefit from different approaches, understanding limitations and approximations;
- to organise a special session at conference/special issue of publication (good exposure).

The technical topics, presented in the final documentation of the benchmark activity, are as follows:

- the PBMR benchmark definition;
- steady-state test case definitions;
- transient test case definitions;
- specific technical issues of the benchmark such as cross-sections, correlations and formats of results;
- information of codes and methods used by participants;
- results and discussions of these results;
- conclusions and recommendations.

2. The PBMR nuclear power plant

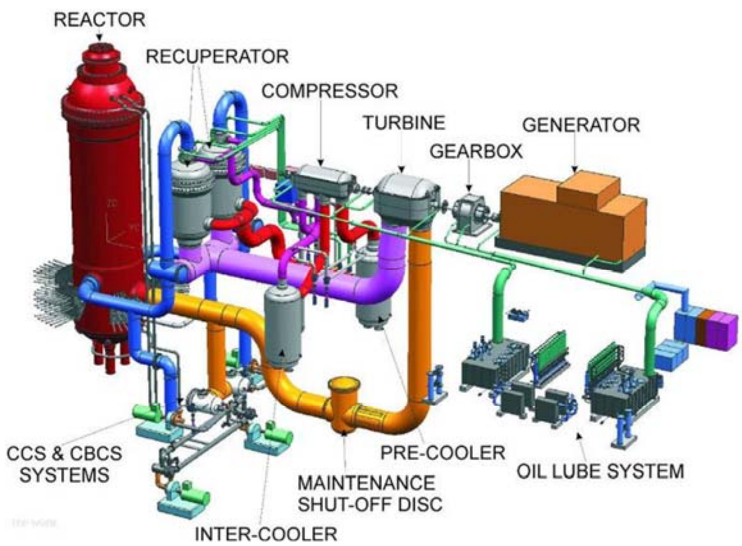
In the mid-1990s the Pebble Bed Modular Reactor (PBMR) came to the forefront as a possible option for the installation of new generating capacity by Eskom, the electric utility of South Africa. The PBMR is a pebble-type high-temperature gas-cooled reactor (HTGR). This PBMR power plant incorporates a closed cycle primary coolant system utilising helium to transport heat energy directly from the modular pebble bed reactor to a recuperative Brayton cycle power conversion unit with a single-shaft turbine/compressor/generator. This replacement of the steam cycle that is common in present nuclear power plants (NPPs) with a direct gas cycle provides the benefits of simplification, a substantial increase in overall system efficiency and inherent safety with the attendant lowering of capital and operational costs.

Table 1: Major design and operating characteristics of the PBMR

PBMR Characteristic	Value
Installed thermal capacity	400 MW(t)
Installed electric capacity	165 MW(e)
Load following capability	100-40-100%
Availability	≥ 95%
Core configuration	Vertical with fixed centre graphite reflector
Fuel	TRISO ceramic coated U-235 in graphite spheres
Primary coolant	Helium
Primary coolant pressure	9 MPa
Moderator	Graphite
Core outlet temperature	900°C.
Core inlet temperature	500°C.
Cycle type	Direct
Number of circuits	1
Cycle efficiency	≥ 41%
Emergency planning zone	400 meters

The PBMR functions under a direct Brayton cycle with primary coolant helium flowing downward through the core and exiting at 900°C. The helium then enters the turbine, relinquishing energy to drive the electric generator and compressors. After leaving the turbine, the helium then passes consecutively through the low-pressure primary side of the recuperator, then the pre-cooler, the low pressure compressor, intercooler, high-pressure compressor and then on to the high-pressure secondary side of the recuperator before re-entering the reactor vessel at 500°C. Figure 1 provides a schematic presentation of the PBMR reactor and the power conversion unit (PCU) layout.

Figure 1: Layout of the PBMR power conversion system



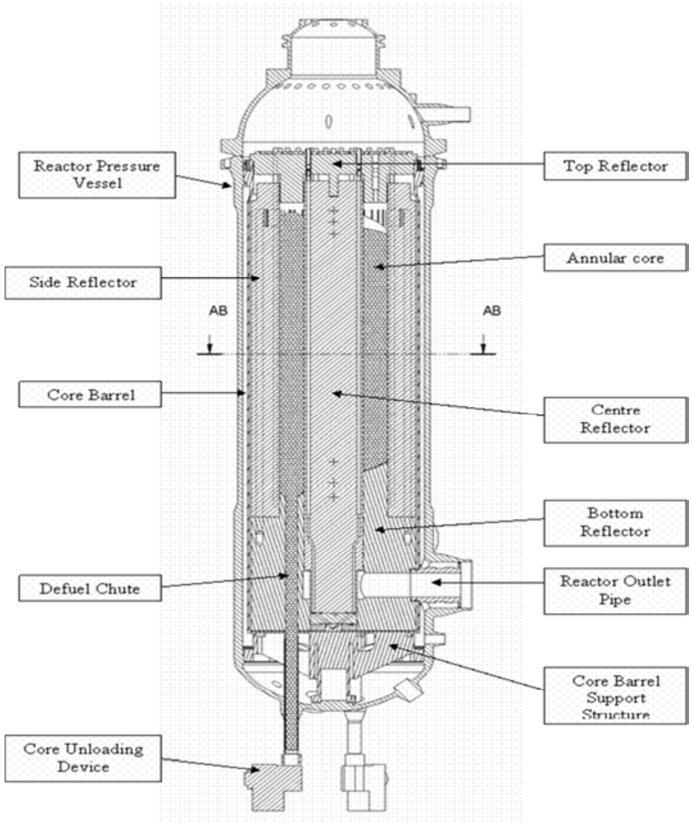
Power is adjusted by regulating the mass flow rate of gas inside the primary circuit. This is achieved by a combination of compressor bypass and system pressure changes. Increasing the pressure results in an increase in mass flow rate, which results in an increase in the power removed from the core. Power reduction is achieved by removing gas from the circuit. A helium inventory control system is used to provide an increase or a decrease in system pressure.

3. The PBMR-400 reactor unit specification

The reference CORE design description

Figure 2 shows the PBMR reactor unit and core layout.

Figure 2: PBMR reactor unit layout



The following are the most important characteristics of the PBMR core:

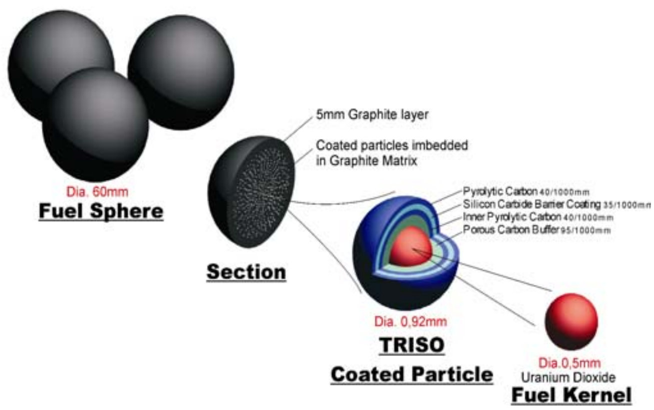
- an annular core with an outer diameter of 3.7 m and a "fixed central reflector" with an outer diameter of 2 m;
- an effective cylindrical core height of 11 m;
- a graphite side reflector of ~90 cm;
- The reactivity control system (RCS) consisting of 24 partial-length control rod positions in the side reflector, with 12 upper control rods and 12 lower shut-down rods when fully inserted. During normal operation all 24 rods operate together. The rods have an effective length (B4C neutron-absorbing material) of 6.5 m.

- The reserve shut-down system (RSS) consisting of eight small absorber sphere (SAS) systems positioned in the fixed central reflector and filled with 1 cm diameter absorber spheres containing B4C when required.
- Three fuel loading positions and three fuel unloading tubes, positioned equidistant in the centre of the fuel annulus.

The core contains ~ 452 000 fuel spheres or "pebbles" with a packing fraction of 0.61. The uranium loading is 9 g per fuel-sphere with the U^{235} enrichment at 9.6 wt%. The inner 5 cm of the fuel sphere contains about 15 000 UO_2 TRISO coated micro-spheres within a graphite matrix and surrounded by an outer graphite fuel-free zone. Each coated particle acts as a fission product barrier. Details are given in Appendix A (Table A.1) with a graphical representation in Figure 3.

The fuelling scheme employed is the continuous on-line multi-pass method similar to the designs used in Germany. Fresh fuel elements are added to the top of the reactor while used fuel pebbles are removed at the bottom to keep the reactor at full power. On average, each fuel pebble makes six passes through the reactor before being finally discharged to the spent fuel storage tanks with a target burn-up of > 90 000 MWd/tU. The fuel handling system consists of a core unloading device in each of the three de-fuelling chutes from where the fuel is moved pneumatically to the burn-up assaying equipment. After the burn-up has been determined, the fuel is routed either to the spent fuel tanks or back to the core, depending on its burn-up. The fuel spheres are re-loaded into the core through three fuelling lines.

Figure 3: Pebble bed fuel



For shut-down purposes and for minor reactivity adjustments, two diverse reactivity control systems are used. The one system, the reactivity control system (RCS), consists of 24 absorber rod systems. This is divided into the 12 control rods and 12 shut-down rods. The design of the control and shut-down rods is identical and the positions during operation will be, within a small band, the same. The driving systems are also identical: each has a stepper motor with a gearbox that finally drives a chain wheel that positively locates the chain on which the control rod is supported. When inserted to its maximum depth into the side reflector, the 12 control rods move to a depth of 6.5 m below the bottom of the top reflector (the upper set) and the shut-down rods move to the lower part of the core to a depth of 10 m. This results in an overlap of all rods around the centre of the core. The RCS rods move in borings in the side reflector.

The other system, the reserve shut-down system (RSS), consists of 10 mm diameter B_4C absorber spheres which during a shut-down are dropped into the eight borings in the central reflector. The spheres are normally stored in containers at the top of the core structures, and are released by opening a valve system.

Simplifications introduced in benchmark models

The reference design for the PBMR-400 benchmark problem is derived from the PBMR 400 MW DPP design described above. Several simplifications were made to the design in this specification in order to minimise the need for any further approximations. During this process, care has been taken to ensure that all the important characteristics of the reactor design were preserved. This ensures that the results from the benchmark will be representative of the actual design's characteristics.

The simplifications make the core design essentially two-dimensional (r, z). It includes flattening of the pebble bed's upper surface and the removal of the bottom cone and de-fuel channel, which result in a flat-bottom reflector. Flow channels within the pebble bed have been simplified to be parallel and at equal speed. Control rods in the side reflector are modelled as a cylindrical skirt (also referred to as a grey curtain) with a given B-10 concentration. Only one of the transient cases, the single control rod ejection event, requires a three-dimensional model. In this case, an equivalent boron concentration is defined for a specific mesh or region where the control rods are situated.

Thermal-hydraulic simplifications include the specification of stagnant helium (no mass flow) between the side reflector and barrel and the barrel and reactor pressure vessel (RPV). Stagnant air (no mass flow) is defined between the RPV and heat sink (outer boundary). The coolant flow is simplified to the main engineered flow paths, i.e. upwards flow from the inlet below the core within a porous ring in the side reflector and downwards flow through the pebble bed to the outlet plenum. No reflector cooling or leakage paths were defined. In the fixed central reflector, the 10 cm hole in the middle, the cooling dowels and cooling slits were also removed. Other engineered coolant flows excluded are the control rod cooling flow, the core barrel leakage flow and the cooling effect of the core barrel conditioning system (CBCS) that would keep the barrel temperature within a temperature range during operation.

The effect of excluding specific coolant flows is to some extent balanced by the assumption that all heat sources, from fission, will be deposited locally, i.e. in the fuel and that no other heat sources exist outside the core, as for example, neutron absorption in the control rods. Simplifications are also made in the material thermal properties as far as constant values or specific correlations are employed. These assumptions are clearly listed in the following sections.

4. Core layout and the neutronic data

Reactor and core structure geometry and dimensions

The benchmark reactor unit geometry is defined in this section. Figure 4 shows the general material layout.

Figure 4: Core layout

	0	10	41	73.6	80.55	92.05	100	117	134	151	168	185	192.95	204.45	211.4	225	243.6	260.6	275	287.5	292.5	310	328	462	463
-235		10	31	32.6	6.95	11.5	7.95	17	17	17	17	17	7.95	11.5	6.95	13.6	18.6	17	14.4	12.5	5	17.5	18	134	1
-200	35	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	He	RPV	Air	RCCS
-150	50	CC	CC	CC	CC	RSS	CC	TR	TR	TR	TR	TR	SR	RCS	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
-100	50	CC	CC	CC	CC	RSS	CC	TR	TR	TR	TR	TR	SR	RCS	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
-50	50	CC	CC	CC	CC	RSS	CC	TR	TR	TR	TR	TR	SR	RCS	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
0	50	CC	CC	CC	CC	RSS	CC	V	V	V	V	V	SR	RCS	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
50	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	IP	RCS	IP	IP	IP	RC	SR	He	CB	He	RPV	Air	RCCS
100	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
150	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
200	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
250	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
300	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
350	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
400	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
450	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
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550	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
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750	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
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1100	50	CC	CC	CC	CC	RSS	CC	F	F	F	F	F	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
1150	50	CC	CC	CC	CC	RSS	CC	BR	BR	BR	BR	BR	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
1200	50	CC	CC	CC	CC	RSS	CC	BR	BR	BR	BR	BR	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
1250	50	CC	CC	CC	CC	RSS	CC	BR	BR	BR	BR	BR	SR	RCS	SR	SR	SR	RC	SR	He	CB	He	RPV	Air	RCCS
1300	50	CC	CC	CC	CC	CC	CC	BR	BR	BR	BR	BR	SR	SR	SR	SR	SR	IP	SR	He	CB	He	RPV	Air	RCCS
1350	50	CC	CC	CC	CC	CC	CC	BR	BR	BR	BR	BR	SR	SR	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
1400	50	CC	CC	CC	CC	CC	CC	OP	OP	OP	OP	OP	SR	SR	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
1450	50	CC	CC	CC	CC	CC	CC	BR	BR	BR	BR	BR	SR	SR	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
1500	50	CC	CC	CC	CC	CC	CC	BR	BR	BR	BR	BR	SR	SR	SR	SR	SR	SR	SR	He	CB	He	RPV	Air	RCCS
1535	35	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	BP	He	RPV	Air	RCCS

CORE LAYOUT DEFINITIONS

F	REACTOR CORE CONTAINING THE FUEL
V	HELIUM GAP BETWEEN FUEL AND TOP REFLECTOR: VOID
CC	CENTRAL REFLECTOR: GRAPHITE
TR	TOP REFLECTOR: GRAPHITE
BR	BOTTOM REFLECTOR: GRAPHITE
SR	SIDE REFLECTOR: GRAPHITE
RCS	REACTOR CONTROL SYSTEM CHANNEL : GRAPHITE / GREY CURTAIN AREA
RSS	RESERVE SHUTDOWN SYSTEM CHANNEL : GRAPHITE / GREY CURTAIN AREA
IP	INLET PLENUM TOP / BOTTOM : GRAPHITE
RC	RISER CHANNEL IN SIDE REFLECTOR : GRAPHITE
OP	OUTLET PLENUM BOTTOM : GRAPHITE
He	STAGNANT HELIUM
TP	TOP PLATE : IRON : ADIABATIC BOUNDARY
BP	BOTTOM PLATE : IRON : ADIABATIC BOUNDARY
CB	CORE BARREL : IRON
RPV	REACTOR PRESSURE VESSEL : IRON
Air	STAGNANT AIR
RCCS	REACTOR CAVITY COOLING SYSTEM : 20C TH BOUNDARY
	NEUTRONIC BOUNDARY CONDITIONS

Figure 4 provides the material mesh dimensions (r, z) as well as the general material regions of the core. First, this figure represents half of the reactor with a symmetry axis on the zero radius line in the centre of the reactor. The pebble bed core is the 85 cm thick annulus represented by “F”. Just above the fuel is a “void” area of course filled with helium. The graphite reflector has been divided into four regions called the central column (CC), the top reflector (TR), the bottom reflector (BR) and the side reflector (SR). Beyond the side reflector is a helium gap (He) between the graphite blocks of the SR and core barrel (CB). This is followed by another helium gap and the reactor pressure vessel (RPV). Outside the RPV, an air gap of 134 cm is found before the reactor cavity cooling system (RCCS) is defined as the outer boundary of the benchmark model.

Above the top reflector of 150 cm, the 35 cm thick top plate (TP) is the upper boundary. Similarly, the bottom plate (BT) forms the lower boundary of the problem below 400 cm of the bottom reflector.

The helium coolant path is bordered by the solid lines shown within the model. The side reflector contains the lower inlet plenum (IP) where the coolant gas enters and flows upward through the riser channels (RC) into the upper IP. The gas then flows down through the core, through slits in the bottom reflector into the outlet plenum from where it enters into the PCU. The side reflector also contains the RCS channels while the central column contains the RSS channels. In the current benchmark definition, the RSS is never filled with any neutron absorber material and is therefore treated as the rest of the central column. Only the upper few meshes of the RCS are typically filled with the control rods, see shaded area, while the rest of the axial meshes are then assumed to be the same as the side reflector.

In Table 2 the dimensions are provided in detail. More precise descriptions of the neutronics and thermal-hydraulic characteristics associated with each region are provided later.

Table 2: Core geometrical specifications at room temperatures

No.	Description	Unit	Value
1	Equivalent core outer radius.	m	1.85
2	Cylindrical height of the core (flattened core surface at the top and flat-bottom reflector).	m	11.0
3	Total core volume.	m^3	83.7155
4	Fixed central column graphite reflector radius.	m	1.0
5	Effective height of the upper void cavity (levelled core surface to bottom of top reflector).	m	0.5
6	Effective annular thickness of the side reflector (graphite).	m	0.9
7	Inner radius of the core barrel	m	2.88
8	The wall thickness of the core barrel.	m	0.05
9	The inner radius of the RPV.	m	3.1
10	The wall thickness of the RPV.	m	0.18
11	Radius of cooling system/20 °C temperature isothermal boundary.	m	4.62
12	Radii of five material meshes in core (five radial material meshes in core, equal width).	m	1.17 1.34 1.51 1.68 1.85
13	Thickness of core radial meshes (all equal).	m	0.17
14	Axial material mesh: 11.0 m/22 meshes (in core).	m	0.5
15	Outlet plenum inner radius.	m	1.0
16	Outlet plenum outer radius.	m	1.85
17	Outlet plenum height.	m	0.5
18	Inlet plenum inner radius.	m	2.436
19	Inlet plenum outer radius.	m	2.606
20	Inlet plenum height.	m	0.5
21	Helium riser channel skirt/porous region inner radius.	m	2.436
22	Helium riser channel skirt /porous region outer radius.	m	2.606
23	Distance from bottom of core to top of the inlet plenum.	m	1.5
24	Centre line axial distance between inlet and outlet plenum.	m	1.0
25	Top inlet plenum inner radius.	m	1.85
26	Top inlet plenum outer radius.	m	2.606
27	Top inlet plenum height.	m	0.5
28	Distance from bottom of top reflector to bottom of top inlet plenum (in the side reflector).	m	1.0
29	Total height of top reflector.	m	1.5
31	Total height of bottom reflector (distance from top of bottom plate to bottom of core).	m	4.0
32	Top steel plate thickness.	m	0.35
33	Bottom steel plate thickness.	m	0.35

Neutronic definition

The neutronic solution of the benchmark problem is only required on a geometrical subset or a smaller part of the reactor. Beside the fact that it is the traditional way used in VSOP analysis employed initially to define this problem, it also makes a good sense to do so. All neutronically important regions are included, but regions far from the core, where flux solutions may be problematic, were excluded.

The neutronics model was selected with the following boundaries: the top of the top reflector (150 cm above the core), 150 cm into the bottom reflector, just above the inlet plenum, and radially the core barrel forms the outer boundary. This model is shown in Figure 5.

It should be noted that only a few material regions can be distinguished. The core (in red) is indicated by material numbers > 100 defined from the column and row numbers, i.e. (205) represent Column 2 and the fifth mesh downward within the core. Then the "void" areas showed a zero above the core and between the side reflector and the core barrel, which are Material 1 and Material 3, respectively. The RCS channel now shows the insertion depth of the control rods (Material 2 to be used). The rest of the core is graphite, Material 1.

Figure 5: Neutronic material definition

	0	10	41	73.6	80.55	92.05	100	117	134	151	168	185	192.95	204.45	211.4	225	243.6	260.6	275	287.5	292.5
-200		10	31	32.6	6.95	11.5	7.95	17	17	17	17	17	7.95	11.5	6.95	13.6	18.6	17	14.4	12.5	5
-150	50	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	0	3
-100	50	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	0	3
-50	50	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	0	3
0	50	1	1	1	1	1	1	0	0	0	0	0	1	2	1	1	1	1	1	0	3
50	50	1	1	1	1	1	1	101	201	301	401	501	1	2	1	1	1	1	1	0	3
100	50	1	1	1	1	1	1	102	202	302	402	502	1	2	1	1	1	1	1	0	3
150	50	1	1	1	1	1	1	103	203	303	403	503	1	2	1	1	1	1	1	0	3
200	50	1	1	1	1	1	1	104	204	304	404	504	1	1	1	1	1	1	1	0	3
250	50	1	1	1	1	1	1	105	205	305	405	505	1	1	1	1	1	1	1	0	3
300	50	1	1	1	1	1	1	106	206	306	406	506	1	1	1	1	1	1	1	0	3
350	50	1	1	1	1	1	1	107	207	307	407	507	1	1	1	1	1	1	1	0	3
400	50	1	1	1	1	1	1	108	208	308	408	508	1	1	1	1	1	1	1	0	3
450	50	1	1	1	1	1	1	109	209	309	409	509	1	1	1	1	1	1	1	0	3
500	50	1	1	1	1	1	1	110	210	310	410	510	1	1	1	1	1	1	1	0	3
550	50	1	1	1	1	1	1	111	211	311	411	511	1	1	1	1	1	1	1	0	3
600	50	1	1	1	1	1	1	112	212	312	412	512	1	1	1	1	1	1	1	0	3
650	50	1	1	1	1	1	1	113	213	313	413	513	1	1	1	1	1	1	1	0	3
700	50	1	1	1	1	1	1	114	214	314	414	514	1	1	1	1	1	1	1	0	3
750	50	1	1	1	1	1	1	115	215	315	415	515	1	1	1	1	1	1	1	0	3
800	50	1	1	1	1	1	1	116	216	316	416	516	1	1	1	1	1	1	1	0	3
850	50	1	1	1	1	1	1	117	217	317	417	517	1	1	1	1	1	1	1	0	3
900	50	1	1	1	1	1	1	118	218	318	418	518	1	1	1	1	1	1	1	0	3
950	50	1	1	1	1	1	1	119	219	319	419	519	1	1	1	1	1	1	1	0	3
1000	50	1	1	1	1	1	1	120	220	320	420	520	1	1	1	1	1	1	1	0	3
1050	50	1	1	1	1	1	1	121	221	321	421	521	1	1	1	1	1	1	1	0	3
1100	50	1	1	1	1	1	1	122	222	322	422	522	1	1	1	1	1	1	1	0	3
1150	50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	3
1200	50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	3
1250	50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	3

Void representation

In the neutronics specification only two "void" regions have been specified, being (i) the 50 cm between the top of the pebble bed and the bottom of the top reflector (shown as zero), and (ii) the helium gap between the side reflector and core barrel (also shown as zero). These regions are of course not really void but filled with helium at pressure. Even though helium's neutron cross-sections are not negligible, it would be ignored in this benchmark. It should be noted that no other region is modelled as void in the neutronics model and that other helium- or air-filled regions fall outside the region of neutronic importance. Regions where the helium coolant flows were modelled as porous regions, containing graphite and helium. In the neutronics modelling no adjustments have been made in the neutron cross-sections to represent the porous nature and the same cross-sections than for the non-porous regions must be used.

In the diffusion calculations, directional-dependent diffusion coefficients are used to represent the neutron streaming effects using the method in [2]. A factor is multiplied to the diffusion coefficient for the r- and z-direction, for (i) 0.10068 for r- and 0.53660 for the z-direction and for (ii) 0.02149 and 0.66241, respectively. For the annulus, 42.5 cm should be used and for the helium gap, 12.5 cm should be used as the respective diffusion coefficients. The theory was developed for cylindrical void areas and the values given have not been verified for annular voids. The effect of the directional diffusion coefficients is typically small and other approximations to represent the voids should not introduce large differences.

These simplifications were not made in the thermal-hydraulic specification where the material properties of the porous regions have been adjusted, i.e. adjustments were made in the densities (porosity assumed to be 20%) where helium flow is defined. This implies that adjustments must be made to the heat capacity and thermal conductivity of these regions compared to the surrounding graphite regions.

Equilibrium fuel cross-section specifications

The equilibrium core is defined as the reactor operational state achieved after a considerable time of operating at a specific set of conditions. For the benchmark problem the operating conditions are defined to be at full power and with the control rods inserted 2.0 m below the bottom of the top reflector and therefore 1.5 m alongside the pebble bed. Once equilibrium is reached, no significant changes can be observed in the properties of the core. For example, the k_{eff}, power profile, temperatures and isotopic concentration distribution change no longer.

The benchmark does not require the calculation of the equilibrium core. The benchmark definition provides the macroscopic cross-sections required to perform the steady-state and transient analysis. This approach will facilitate better and well-defined comparisons but also allow broader participation in the benchmark since calculational tools, which do not have the pebble bed multi-pass fuel circulation (MEDUL) or fuel depletion functionality, can then also participate.

The cross-sections are generated making use of the isotopic distribution calculated in VSOP99 (data are included in Appendix A for completeness). Making use of the given thermal-hydraulics properties, a THERMIX model was utilised to get the typical temperature distribution. The isotopic compositions were calculated in the five flow channels defined and for the 22 equally spaced axial meshes within the pebble bed axial height. This results in 5 x 22 sets of fuel material definitions that will be identified by their flow channel and axial mesh position, i.e. Region (1,15) represents the 15th axial mesh of flow channel 1, located next to the central column. Details on the simplified depletion chain and isotopes included are found in Appendix A.

Boundary conditions

Table 3: Neutronics boundary conditions

No.	Description	Unit	Value
	Neutronic Model Boundaries		
1	Radial; outer boundary of the reactor barrel.	m	2.925
2	Top (beyond 150 cm of top reflector, *i.e. two* metres above the core).	m	- 2.0
3	Bottom (beyond 150 cm of bottom reflector).	m	12.5
4	Type of boundary conditions (on all boundaries).		Black/vacuum

5. Description of the cross-section tables

This chapter outlines the format and origin of the cross-section tables which were generated for the PBMR benchmark. The exposure and burn-up history for the equilibrium cycle are taken into account implicitly into the cross-section libraries by defining the different fuel mixtures. The average isotopic composition of the different regions of the core was determined as discussed in this section.

Two sets of cross-sections are provided. The first set is referred to as the simplified set since the macroscopic cross-sections provided are constant and thus contain no dependence on changing core conditions or state parameters (see this section). This set is therefore only useful to test and initiate the neutronics models.

The second set contains cross-sections as a function of all the state parameters and is therefore used for the actual calculations, steady-state starting condition and transient analysis (see this section).

Number densities used to generate cross-sections

The number densities, tabulated in Appendix A, were generated by the VSOP-99 code. In accordance with the specifications, the annular core region was sub-divided into five radial meshes or flow channels and 22 axial meshes. Therefore, there are 110 number density sets for the fuel regions. Additionally, the number densities for the central column/graphite reflector, control rods (homogeneous absorber material) and core barrel are also supplied.

Simplified cross-section sets

The purpose of the simplified cross-section set is to provide a reference that can be used to test and compare standalone neutronic predictions by using the same cross-sections with no thermal-hydraulic or spectrum feedback. This will help to understand and quantify the differences introduced by the different neutronics models used and assist in the process to narrow them down. It also enables participants to use card input cross-section data that is available in many codes. The set is generated from the VSOP equilibrium core calculation, the same used to generate the number densities reported above. The calculation was performed in two energy groups with a thermal cut-off of 3.059 eV.

The format of the library is described as follows:

```
*
********************************
* OECD-PBMR400-Simplified.XS   *
********************************
*
*
* Each material set has:
*
*  - ID number and description in quotes
*  - Number of parameters (always 5)
*  - Number of data points for each parameter (always 0 0 0 0 0)
*
***************************************************************************
```

```
* The first records of the data in each table is the points (or values) of
* all the state parameters specified for the material. Since the simplified
* library have no dependencies (=0) this record is not given!
*
* THE TABLES REFER TO,IN ORDER OF APPEARANCE:
*
* - Diffusion Coefficient, fast group [cm]
* - Macroscopic Absorption Cross-section, fast group [cm-1]
* - Macroscopic Nu-fission Cross-section, fast group [cm-1]
* - Macroscopic Fission Cross-section, fast group [cm-1]
* - Macroscopic Scattering Cross-Section from fast(1) to thermal(2) group [cm-1]
* - Inverse velocity, fast group [s.cm-1]
* - Fraction Beta(1) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(2) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(3) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(4) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(5) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(6) of delayed neutrons, fast group [dimensionless]
* - Kappa, Energy release per fission, fast group [MeV]
* - Microscopic Absorption Xenon Cross-section, fast group [cm2]
*
*
* - Diffusion Coefficient, thermal group [cm]
* - Macroscopic Absorption Cross-section, thermal group [cm-1]
* - Macroscopic Nufission Cross-section, thermal group [cm-1]
* - Macroscopic Fission Cross-section, thermal group [cm-1]
* - Macroscopic Scattering Cross-Section from thermal(2) to fast(1) group [cm-1]
* - Inverse velocity, thermal group [s.cm-1]
* - Fraction Beta(1) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(2) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(3) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(4) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(5) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(6) of delayed neutrons, thermal group [dimensionless]
* - Kappa, Energy release per fission, thermal group [MeV]
* - Microscopic Absorption Xenon Cross-section, thermal group [cm2]
*
* - Iodine yield [dimensionless]
* - Xenon yield [dimensionless]
*
*THERE ARE TOTAL 30 TABLES FOR EACH MATERIAL SET
*
*******************************************************************************
*
```

In this simplified case, no dependence on state parameters is present, or in other words, only a single value is given in the generation of each of these parameters. Thus although the number of parameters are still shown as five, the number of data points are all zero. The record containing the list of all the state parameters is thus not given.

In order to take temperature and spectrum effects of the reflector regions into account a more realistic cross-section set is obtained and several cross-section sets had to be generated for the graphite reflector. In total, 190 data sets are included in the library with the materials simply numbered from 1 to 190 as indicated in Figure 6. The five flow channels, each with 22 axial regions, make up 110 materials, with the balance mainly made up by graphite at different temperatures and with different fine-group spectra and therefore different few-group cross-sections. The different material numbers correspond to the so-called spectrum regions selected in the VSOP model. Note that xenon, at the equilibrium conditions calculated in VSOP99, was included in the macroscopic cross-sections provided and should therefore not be treated explicitly. This is the reason why the microscopic cross-sections for xenon were set to zero.

The cross-section file name “OECD-PBMR400-Simplified.XS” ASCII data file should be used. The two void areas represented by Materials 111 and 189 are included in the library, but all cross-sections were set equal to zero. Special treatment for these void regions would be required and one approach applicable to diffusion theory can be used as described in Section 4.

Figure 6: Simplified cross-section set material numbers

	0	*10*	*41*	*73.6*	*80.55*	*92.05*	*100*	*117*	*134*	*151*	*168*	*185*	*192.95*	*204.45*	*211.4*	*225*	*243.6*	*260.6*	*275*	*287.5*	*292.5*
-200		10	31	32.6	6.95	11.5	7.95	17	17	17	17	17	7.95	11.5	6.95	13.6	18.6	17	14.4	12.5	5
-150	50	133	133	133	133	155	116	113	113	113	113	113	135	164	144	144	152	152	152	189	190
-100	50	133	133	133	133	155	116	113	113	113	113	113	135	164	144	144	152	152	152	189	190
-50	50	133	133	133	133	155	116	112	112	112	112	112	135	164	144	144	152	152	152	189	190
0	50	133	133	133	133	155	116	111	111	111	111	111	135	165	144	144	152	152	152	189	190
50	50	134	134	134	125	156	117	1	23	45	67	89	136	166	145	145	153	153	153	189	190
100	50	134	134	134	125	156	117	2	24	46	68	90	136	167	145	145	153	153	153	189	190
150	50	134	134	134	126	157	118	3	25	47	69	91	137	168	146	146	153	153	153	189	190
200	50	134	134	134	126	157	118	4	26	48	70	92	137	169	146	146	153	153	153	189	190
250	50	134	134	134	126	157	118	5	27	49	71	93	137	170	146	146	153	153	153	189	190
300	50	134	134	134	127	158	119	6	28	50	72	94	138	171	147	147	153	153	153	189	190
350	50	134	134	134	127	158	119	7	29	51	73	95	138	172	147	147	153	153	153	189	190
400	50	134	134	134	127	158	119	8	30	52	74	96	138	173	147	147	153	153	153	189	190
450	50	134	134	134	127	158	119	9	31	53	75	97	138	174	147	147	153	153	153	189	190
500	50	134	134	134	128	159	120	10	32	54	76	98	139	175	148	148	153	153	153	189	190
550	50	134	134	134	128	159	120	11	33	55	77	99	139	176	148	148	153	153	153	189	190
600	50	134	134	134	128	159	120	12	34	56	78	100	139	177	148	148	153	153	153	189	190
650	50	134	134	134	128	159	120	13	35	57	79	101	139	178	148	148	153	153	153	189	190
700	50	134	134	134	129	160	121	14	36	58	80	102	140	179	149	149	153	153	153	189	190
750	50	134	134	134	129	160	121	15	37	59	81	103	140	180	149	149	153	153	153	189	190
800	50	134	134	134	129	160	121	16	38	60	82	104	140	181	149	149	153	153	153	189	190
850	50	134	134	134	129	160	121	17	39	61	83	105	140	182	149	149	153	153	153	189	190
900	50	134	134	134	130	161	122	18	40	62	84	106	141	183	150	150	153	153	153	189	190
950	50	134	134	134	130	161	122	19	41	63	85	107	141	184	150	150	153	153	153	189	190
1000	50	134	134	134	130	161	122	20	42	64	86	108	141	185	150	150	153	153	153	189	190
1050	50	134	134	134	131	162	123	21	43	65	87	109	142	186	151	151	153	153	153	189	190
1100	50	134	134	134	131	162	123	22	44	66	88	110	142	187	151	151	153	153	153	189	190
1150	50	132	132	132	132	163	124	114	114	114	114	114	143	188	151	151	154	154	154	189	190
1200	50	132	132	132	132	163	124	115	115	115	115	115	143	188	151	151	154	154	154	189	190
1250	50	132	132	132	132	163	124	115	115	115	115	115	143	188	151	151	154	154	154	189	190

Initial steady-state and transient cross-section tables

Five-dimensional tables are used to represent the instantaneous variation in cross-section due to changes in the reactor. The cross-section models are designed to cover the initial steady-state conditions and the expected ranges of change of the five selected instantaneous feedback parameters in the transients to be simulated in the benchmark. The set is generated from the SPECTRUM code using the equilibrium core number densities with two energy groups with a thermal cut-off of 3.059 eV.

Cross-sections were generated for all the combinations of the given state parameters. The five state parameters are:

- fuel temperature;
- moderator temperature;
- fast buckling;
- thermal buckling;
- xenon concentration.

In all of the fuel material cross-section tables, there were four fuel temperatures, seven moderator temperatures, three fast buckling values, three thermal buckling values, and three xenon number densities, while for all the non-fuel materials no fuel temperature or xenon variations were included.

The cross-section file name "OECD-PBMR400.XS", an ASCII data file, should be used.

State parameters

The ranges chosen for each parameter were selected based on the reactor conditions for normal operation as well as for accident conditions. The following values for the five state parameters were selected:

- fuel temperature (Doppler temperature): 300 K, 800 K, 1 400 K, 2400 K;
- moderator temperature: 300 K, 600 K, 800 K, 1 100 K, 1 400 K, 1 800 K, 2 400 K;
- xenon concentrations expressed as homogenised concentrations: 0.0 (or very small 1.0E-15), 2.0E-11, 8.0E-10 [#/barn.cm];
- buckling terms: separate values for fast and thermal buckling and also for fissionable and non-fissionable material were defined with three values each as shown in Table 4.

Table 4: Buckling terms [cm^{-2}] for cross-section generation

Fuel		Reflector	
Fast	Thermal	Fast	Thermal
-1.0E-04	-2.5E-03	-6.5E-01	-1.1E-03 [1]
1.0E-04	-1.0E-05	-1.0E-04	5.0E-05
4.0E-03	5.0E-03	1.0E-02	1.0E-02

The input buckling terms into SPECTRUM given above yield physical cross-sections (no negative values) and covered most of the total leakage (buckling) range for the materials as calculated by TINTE at steady-state and during most transient states. In other words, only limited extrapolation took place.

Buckling is defined as follows:

$$\beta^2 = \frac{L}{D.\phi.V} \text{ [cm}^{-2}\text{];}$$

Where:

β^2 is the buckling;

L is the total out-leakage from a given mesh or region [#.s^{-1}];

D is the diffusion coefficient [cm];

ϕ is the average flux [#.cm^{-2}.s^{-1}]; and

V is the region volume [cm^3].

Note that a net inflow of neutrons will lead to a negative leakage value and thus a negative buckling.

[1] An exception was made for Material 2 that is the absorber material representing the control rods where -1.1E-02 was used as the negative thermal buckling value.

Layout of data in cross-section tables

The cross-section data provided in the cross-section tables is given below. The data format is similar to the Simplified Cross-Section Library described before, but now the dependence on the state parameters is included. The library was also expanded to include the radial and axial diffusion coefficients for the two energy groups, compared to a single value given for the simplified library, and a transport-corrected total macroscopic cross-section was also added.

The description is given below. For each material an ID number and description (text in quotes) are provided, followed by the number of state parameters (always five in this library) and the number of data points for each state parameter. The integer numbers, which appear in the respective position, represent the number of data points for the respective state parameter. In other words, this is the number of times that particular parameter is varied. For instance, four appear for T Fuel while seven appear for T moderator. This implies that the cross-sections were produced by varying the fuel temperature four times while the moderator temperature was varied seven times. Thus the cross-section tables have four fuel temperature points and seven moderator temperature points. The same applies to the other three parameters.

The following nuclear data tables are divided into Fast (Group 1) and Thermal (Group 2) cross-sections and other data. The description (ID, etc.) and tables are repeated for each material and are presented in the following order:

```
*
********************************
*         OECD-PBMR400         *
********************************
*
*
* Each material set has:
*
*   - ID number and description in quotes
*   - Number of parameters
*   - Number of data points for each parameter
*
****************************************************************************
* The first records of the data in each table is the points (or values) of
* all the state parameters specified for the material. The order is
* thus very important. The first four values are fuel temperatures,
* the next seven values are moderator  temperatures, the following
* three are the fast buckling, then three thermal bucklings and the
* last three are the Xenon number densities.
*
*
* THE TABLES REFER TO,IN ORDER OF APPEARANCE:
*
* - Diffusion Coefficient Radial, fast group [cm]
* - Diffusion Coefficient Axial, fast group [cm]
* - Macroscopic Transport Corrected Total Cross-section, fast group [cm-1]
* - Macroscopic Absorption Cross-section, fast group [cm-1]
* - Macroscopic Nu-fission Cross-section, fast group [cm-1]
* - Macroscopic Fission Cross-section, fast group [cm-1]
* - Macroscopic Scattering Cross-Section from fast(1) to thermal(2) group [cm-1]
* - Inverse velocity, fast group [s.cm-1]
* - Fraction Beta(1) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(2) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(3) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(4) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(5) of delayed neutrons, fast group [dimensionless]
* - Fraction Beta(6) of delayed neutrons, fast group [dimensionless]
```

```
* - Kappa, Energy release per fission, fast group [MeV]
* - Microscopic Absorption Xenon Cross-section, fast group [cm2]
*
*
* - Diffusion Coefficient Radial, thermal group [cm]
* - Diffusion Coefficient Axial, thermal group [cm]
* - Macroscopic Transport Corrected Total Cross-section, thermal group [cm-1]
* - Macroscopic Absorption Cross-section, thermal group [cm-1]
* - Macroscopic Nufission Cross-section, thermal group [cm-1]
* - Macroscopic Fission Cross-section, thermal group [cm-1]
* - Macroscopic Scattering Cross-Section from thermal(2) to fast(1) group [cm-1]
* - Inverse velocity, thermal group [s.cm-1]
* - Fraction Beta(1) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(2) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(3) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(4) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(5) of delayed neutrons, thermal group [dimensionless]
* - Fraction Beta(6) of delayed neutrons, thermal group [dimensionless]
* - Kappa, Energy release per fission, thermal group [MeV]
* - Microscopic Absorption Xenon Cross-section, thermal group [cm2]
*
* - Iodine yield [dimensionless]
* - Xenon yield [dimensionless]
*
*THERE ARE TOTAL 34 TABLES FOR EACH MATERIAL SET
*
******************************************************************************
*
```

In Table 5 the key to the cross-section table listing per material is provided while the specific state-parameter variations are listed in Table 6. The manner in which the parameters were varied to create the libraries is important. This depends on the order in which the parameters in the library are labelled.

- First, all four variables of fuel temperature are varied while the points of other parameters are kept constant.
- Next, the second parameter (moderator temperature) is changed seven times while the points of other parameters are kept constant.
- Lastly, this process is followed until all the parameters have been changed as per the specified number of points.

Table 5: Key to macroscopic cross-section tables

T_{f1}	T_{f2}	T_{f3}	T_{f4}	T_{m1}
T_{m2}	T_{m3}	T_{m4}	T_{m5}	T_{m6}
T_{m7}	B_{f1}	B_{f2}	B_{f3}	B_{t1}
B_{t2}	B_{t3}	X_1	X_2	X_3
Σ_1	Σ_2	Σ_3	Σ_4	Σ_5
Σ_6	Σ_7	Σ_8	Σ_9	Σ_{10}
Σ_{11}	…	…	…	…
Σ_{756}				

Where:

T_f is the fuel temperature;

T_m is the moderator temperature;

B_f is the fast buckling;

B_m is the thermal buckling;

X is the xenon number density;

Σ is the macroscopic cross-section.

The layout of cross-section tables is as follows:

Σ_1 is a function of $(T_{f1},T_{m1},B_{f1},B_{t1},X_1)$;

Σ_2 is a function of $(T_{f2}, T_{m1},B_{f1},B_{t1},X_1)$;

Σ_3 is a function of $(T_{f3}, T_{m1},B_{f1},B_{t1},X_1)$;

Σ_4 is a function of $(T_{f4}, T_{m1},B_{f1},B_{t1},X_1)$;

Σ_5 is a function of $(T_{f1}, T_{m2},B_{f1},B_{t1},X_1)$;

Σ_6 is a function of $(T_{f2}, T_{m2},B_{f1},B_{t1},X_1)$;

Σ_7 is a function of $(T_{f3}, T_{m2},B_{f1},B_{t1},X_1)$;

Σ_8 is a function of $(T_{f4}, T_{m2},B_{f1},B_{t1},X_1)$;

Σ_9 is a function of $(T_{f1},T_{m3},B_{f1},B_{t1},X_1)$;

Σ_{10} is a function of $(T_{f2},T_{m3},B_{f1},B_{t1},X_1)$;

…Σ_{29} is a function of $(T_{f1},T_{m1},B_{f2},B_{t1},X_1)$;

…Σ_{85} is a function of $(T_{f1},T_{m1},B_{f1},B_{t2},X_1)$;

…Σ_{253} is a function of $(T_{f1},T_{m1},B_{f1},B_{t1},X_2)$;

…Σ_{756} is a function of $(T_{f4},T_{m7},B_{f3},B_{t3},X_3)$.

It should be noted that the number of variations for each state parameter may in principle be changed to allow for a better representation of the dependencies of the cross-sections. The combination that was used for the supplied cross-section tables was based on the range possible with the spectrum code used and tests performed with the TINTE code. The values used for the fast and thermal buckling were shown to be adequate for steady-state and most transients (a limited amount of extrapolation was seen). In general, the range could not be extended further since larger, positive and negative, buckling values led to problems in the spectrum calculation resulting in negative or unphysical cross-sections.

The design of the cross-section tables allows each material not only to have its own number of variations for each state parameter but also its own set of base values and its own set of fuel temperatures. Although this freedom was not used for the fuel materials (101 … 522), it was used to define a different thermal buckling range for Material 2, the absorber region representing the control rods (see footnote in Table 4). When implementing the cross-section tables and the lint5d interpolation routines, it is advised that the generality of the cross-section tables and interpolation routines should be maintained. Thus it should not be assumed that the state parameter sets of all materials are the same.

Table 6: Table with a range of variables (Example for fuel materials)

	Temperature		Buckling		
	T_f	T_m	Fast	Thermal	N(Xe)
1	300	300	-1.0E-04	-2.5E-03	1.0E-15
2	800	300	-1.0E-04	-2.5E-03	1.0E-15
3	1 400	300	-1.0E-04	-2.5E-03	1.0E-15
4	2 400	300	-1.0E-04	-2.5E-03	1.0E-15

	Temperature		Buckling		
	T_f	T_m	Fast	Thermal	N(Xe)
5	300	600	-1.0E-04	-2.5E-03	1.0E-15
6	800	600	-1.0E-04	-2.5E-03	1.0E-15
7	1 400	600	-1.0E-04	-2.5E-03	1.0E-15
8	2 400	600	-1.0E-04	-2.5E-03	1.0E-15
9	300	800	-1.0E-04	-2.5E-03	1.0E-15
10	800	800	-1.0E-04	-2.5E-03	1.0E-15
11	1 400	800	-1.0E-04	-2.5E-03	1.0E-15
12	2 400	800	-1.0E-04	-2.5E-03	1.0E-15
13	300	1 100	-1.0E-04	-2.5E-03	1.0E-15
14	800	1 100	-1.0E-04	-2.5E-03	1.0E-15
15	1 400	1 100	-1.0E-04	-2.5E-03	1.0E-15
16	2 400	1 100	-1.0E-04	-2.5E-03	1.0E-15
17	300	1 400	-1.0E-04	-2.5E-03	1.0E-15
18	800	1 400	-1.0E-04	-2.5E-03	1.0E-15
19	1 400	1 400	-1.0E-04	-2.5E-03	1.0E-15
20	2 400	1 400	-1.0E-04	-2.5E-03	1.0E-15
21	300	1 800	-1.0E-04	-2.5E-03	1.0E-15
22	800	1 800	-1.0E-04	-2.5E-03	1.0E-15
23	1 400	1 800	-1.0E-04	-2.5E-03	1.0E-15
24	2 400	1 800	-1.0E-04	-2.5E-03	1.0E-15
25	300	2 400	-1.0E-04	-2.5E-03	1.0E-15
26	800	2 400	-1.0E-04	-2.5E-03	1.0E-15
27	1 400	2 400	-1.0E-04	-2.5E-03	1.0E-15
28	2 400	2 400	-1.0E-04	-2.5E-03	1.0E-15
29	300	300	1.0E-04	-2.5E-03	1.0E-15
30	800	300	1.0E-04	-2.5E-03	1.0E-15
31	1 400	300	1.0E-04	-2.5E-03	1.0E-15
32	2 400	300	1.0E-04	-2.5E-03	1.0E-15
33	300	600	1.0E-04	-2.5E-03	1.0E-15
34	800	600	1.0E-04	-2.5E-03	1.0E-15
35	1 400	600	1.0E-04	-2.5E-03	1.0E-15
36	2 400	600	1.0E-04	-2.5E-03	1.0E-15
37	300	800	1.0E-04	-2.5E-03	1.0E-15
38	800	800	1.0E-04	-2.5E-03	1.0E-15
39	1 400	800	1.0E-04	-2.5E-03	1.0E-15
40	2 400	800	1.0E-04	-2.5E-03	1.0E-15
41	300	1 100	1.0E-04	-2.5E-03	1.0E-15
42	800	1 100	1.0E-04	-2.5E-03	1.0E-15
43	1 400	1 100	1.0E-04	-2.5E-03	1.0E-15
44	2 400	1 100	1.0E-04	-2.5E-03	1.0E-15
45	300	1 400	1.0E-04	-2.5E-03	1.0E-15
46	800	1 400	1.0E-04	-2.5E-03	1.0E-15
47	1 400	1 400	1.0E-04	-2.5E-03	1.0E-15
48	2 400	1 400	1.0E-04	-2.5E-03	1.0E-15

	Temperature		Buckling		
	T_f	T_m	Fast	Thermal	N(Xe)
49	300	1 800	1.0E-04	-2.5E-03	1.0E-15
50	800	1 800	1.0E-04	-2.5E-03	1.0E-15
51	1 400	1 800	1.0E-04	-2.5E-03	1.0E-15
52	2 400	1 800	1.0E-04	-2.5E-03	1.0E-15
53	300	2 400	1.0E-04	-2.5E-03	1.0E-15
54	800	2 400	1.0E-04	-2.5E-03	1.0E-15
55	1 400	2 400	1.0E-04	-2.5E-03	1.0E-15
56	2 400	2 400	1.0E-04	-2.5E-03	1.0E-15
57	300	300	4.0E-03	-2.5E-03	1.0E-15
58	800	300	4.0E-03	-2.5E-03	1.0E-15
59	1 400	300	4.0E-03	-2.5E-03	1.0E-15
60	2 400	300	4.0E-03	-2.5E-03	1.0E-15
61	300	600	4.0E-03	-2.5E-03	1.0E-15
62	800	600	4.0E-03	-2.5E-03	1.0E-15
63	1 400	600	4.0E-03	-2.5E-03	1.0E-15
64	2 400	600	4.0E-03	-2.5E-03	1.0E-15
65	300	800	4.0E-03	-2.5E-03	1.0E-15
66	800	800	4.0E-03	-2.5E-03	1.0E-15
67	1 400	800	4.0E-03	-2.5E-03	1.0E-15
68	2 400	800	4.0E-03	-2.5E-03	1.0E-15
69	300	1 100	4.0E-03	-2.5E-03	1.0E-15
70	800	1 100	4.0E-03	-2.5E-03	1.0E-15
71	1 400	1 100	4.0E-03	-2.5E-03	1.0E-15
72	2 400	1 100	4.0E-03	-2.5E-03	1.0E-15
73	300	1 400	4.0E-03	-2.5E-03	1.0E-15
74	800	1 400	4.0E-03	-2.5E-03	1.0E-15
75	1 400	1 400	4.0E-03	-2.5E-03	1.0E-15
76	2 400	1 400	4.0E-03	-2.5E-03	1.0E-15
77	300	1 800	4.0E-03	-2.5E-03	1.0E-15
78	800	1 800	4.0E-03	-2.5E-03	1.0E-15
79	1 400	1 800	4.0E-03	-2.5E-03	1.0E-15
80	2 400	1 800	4.0E-03	-2.5E-03	1.0E-15
81	300	2 400	4.0E-03	-2.5E-03	1.0E-15
82	800	2 400	4.0E-03	-2.5E-03	1.0E-15
83	1 400	2 400	4.0E-03	-2.5E-03	1.0E-15
84	2 400	2 400	4.0E-03	-2.5E-03	1.0E-15
85	300	300	-1.0E-04	-1.0E-05	1.0E-15
86	800	300	-1.0E-04	-1.0E-05	1.0E-15
87	1 400	300	-1.0E-04	-1.0E-05	1.0E-15
88	2 400	300	-1.0E-04	-1.0E-05	1.0E-15
89	300	600	-1.0E-04	-1.0E-05	1.0E-15
90	800	600	-1.0E-04	-1.0E-05	1.0E-15
91	1 400	600	-1.0E-04	-1.0E-05	1.0E-15
92	2 400	600	-1.0E-04	-1.0E-05	1.0E-15

	Temperature		Buckling		
	T_f	T_m	Fast	Thermal	N(Xe)
93	300	800	-1.0E-04	-1.0E-05	1.0E-15
94	800	800	-1.0E-04	-1.0E-05	1.0E-15
95	1 400	800	-1.0E-04	-1.0E-05	1.0E-15
96	2 400	800	-1.0E-04	-1.0E-05	1.0E-15
97	300	1 100	-1.0E-04	-1.0E-05	1.0E-15
98	800	1 100	-1.0E-04	-1.0E-05	1.0E-15
99	1 400	1 100	-1.0E-04	-1.0E-05	1.0E-15
100	2 400	1 100	-1.0E-04	-1.0E-05	1.0E-15
…	…	…	…	…	…
753	300	2 400	4.0E-03	5.0E-03	8.0E-10
754	800	2 400	4.0E-03	5.0E-03	8.0E-10
755	1 400	2 400	4.0E-03	5.0E-03	8.0E-10
756	2 400	2 400	4.0E-03	5.0E-03	8.0E-10

Two examples of the cross-section structure, for fuel and non-fuel are given in Appendix C.

Additional notes on the "OECD-PBMR400.XS" cross-section tables

- All macroscopic cross-sections are in units of cm^{-1}.
- The supplied cross-sections are macroscopic cross-sections, except for xenon absorption cross-sections, which are microscopic absorption cross sections (barns).
- The lines that start with an asterisk (*) are for information only (dummy read).
- The first records of the data in each table are the points or values of all the state parameters specified for the material. The order is thus very important. The first four values are fuel temperatures, the next seven values are moderator temperatures, the following three are the fast buckling, followed by three thermal buckling values, and the last three are the xenon number densities.
- The total macroscopic absorption cross-sections provided exclude the absorption effect of xenon that should be treated explicitly by the participants' codes. During the cross-section generation process the xenon absorption was subtracted from the macroscopic cross-section using the xenon microscopic cross-sections and the input xenon number densities.
- The diffusion coefficients were calculated from the transport cross-sections in the spectrum code.
- The delayed neutron decay constants are material-independent and given in Table 7.
- The β (delayed neutron fraction) and κ (energy release per fission) values are given per material per energy group. In the supplied benchmark library the two group values are the same even though the functionality exists to provide group-dependent values. This can be added in future work.

Interpolation and extrapolation

The programme (algorithm) for linear interpolation is called lint5d.f and is supplied with the benchmark specification as FORTRAN source code.

```
      subroutine lint5d(it,tb,x,f)
c
c     subroutine lint5d linearly interpolates and extrapolates
c     a function table with zero to five independent variables
c
c     subroutine argument parameter definitions:
c     it(i) = the number of table entries in the ith dimension
c     tb(j) = the table of independent variable entry values (it(1)
c             values for the first independent variable + it(2) values
c             for the second independent variable + it(3) values for
c             the third independent variable + it(4) values for the
c             fourth independent variable + it(5) values for the
c             fifth independent variable) followed by it(1)*it(2)*
c             it(3)*it(4)*it(5) dependent variable entry values for the
c             table's function. The order of variation is: it(1) is varied
c            first, then it(2)etc. See key in specification for explanation
c      x(i) = the input value of the table's ith dimension independent
c             variable where the table function is to be interpolated
c         f = the table's interpolated function value that is output
c
```

It should be noted that the arrays it(i) and tb(j) correspond to the format defined on the cross-section tables. Array it(i) is given once for each material, for example 4,7,3,3,3 for the fuel materials, while the array tb(j) is given for each cross-section or data set (34 of them) for each material. For the benchmark exercise the fuel temperature should be linearly interpolated between the square-root of the fuel temperatures. The fuel temperature values on the cross-section table are, however, given as the physical value (in Kelvin) and the translation to interpolation of the SQRT of the value must be done by the participant.

Other data

The delayed neutron decay constant (λ) values are given below and are not included in the cross-section library and should be treated as user input. A single set of decay constants was derived using the U^{235} data as the basis.

Table 7: Delayed neutron group values

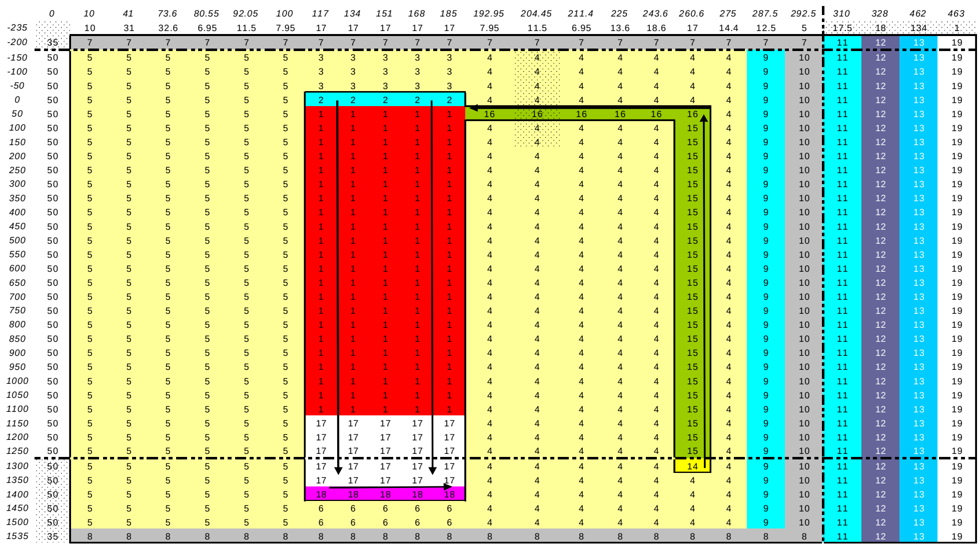
Group	λ [sec^{-1}]
1	3.870E+00
2	1.400E+00
3	3.110E-01
4	1.160E-01
5	3.174E-02
6	1.272E-02

6. Thermal-hydraulic data

The properties of helium, the temperature profile in the fuel elements, and the pressure drop over the reactor core are based on the safety technical rules of the German Nuclear Technical Committee (KTA rules 3102.1-3 [3], [4] and [5]). For completeness a summary is given in Appendix D.

Reactor thermal-hydraulic layout steady state

Figure 7: Thermal-hydraulic layout of PBMR core



THERMAL HYDRAULIC MATERIAL DEFINITIONS

1	REACTOR CORE; PEBBLE BED WITH 0.39 VOID FRACTION: DOWNWARD COOLANT FLOW
2	HELIUM FILLED WITH COOLANT FLOW
3	GRAPHITE: NO COOLANT GAS FLOW
4	GRAPHITE: NO COOLANT GAS FLOW
5	GRAPHITE: NO COOLANT GAS FLOW
6	GRAPHITE: NO COOLANT GAS FLOW
7	TOP BARREL PLATE: ADIABATIC BOUNDARY CONDITION: STEEL / IRON
8	BOTTOM BARREL PLATE: ADIABATIC BOUNDARY CONDITION: STEEL / IRON
9	STAGNANT HELIUM GAP BETWEEN SIDE REFLECTOR AND BARREL
10	BARREL : STEEL / IRON
11	STAGNANT HELIUM GAP BETWEEN BARREL AND REACTOR PRESSURE VESSEL
12	REACTOR PRESSURE VESSEL: STEEL / IRON
13	STAGNANT AIR OUTSIDE REACTOR PRESSURE VESSEL
14	INLET / BOTTOM INLET PLENUM OF COOL HELIUM GAS: GRAPHITE
15	RISER CHANNEL (UP FLOW) IN SIDE REFLECTOR: GRAPHITE WITH COOLANT FLOW
16	UPPER PLENUM (INWARDS FLOW) IN SIDE REFLECTOR: GRAPHITE WITH COOLANT FLOW
17	BOTTOM REFLECTOR: GRAPHITE WITH COOLANT FLOW
18	OUTLET / BOTTOM OUTLET PLENUM: GRAPHITE WITH COOLANT FLOW
19	REACTOR CAVITY COOLING SYSTEM: CONSTANT 20C TEMPERATURE BOUNDARY

The simplifications in the thermal-hydraulic definition of the PBMR 400 MW design for the benchmark were already discussed. In this section, the data to be utilised is described in detail. The layout of the core is shown in Figure 7.

The thermal-hydraulic model is larger than the neutronic region of importance and includes the top and bottom plate (adiabatic boundary conditions) in the axial direction while the reactor pressure vessel and the reactor cavity cooling system are also modelled in the radial direction.

Reactor main coolant flow specifications

The flow characteristics are summarised in Table 8. The inlet and outlet temperature were defined as indicated which result in the mass flow value also given. This value will of course differ depending on the heat losses through the RPV calculated in the analysis. These losses are typically small, around 1 MW, and are therefore not too important but could explain small variations that might be calculated for the outlet temperature.

Table 8: Main flow parameters

No.	Description	Unit	Value
1	Helium inlet temperature.	°C (K)	500 (773.15)
2	Helium outlet temperature (result of calculation).	°C (K)	~900 (1173.15)
3	Total inlet mass flow rate.	kg/s	192.7
4	Inlet pressure.	kPa	Calculated
5	Outlet pressure.	kPa	9 000
6	Coolant flow – flow is into inlet plenum (← 14), up into the helium flow skirt (↑ 15), into top plenum (← 16); through the core and void (↓ 1 ←2); through porous bottom reflector (↓ 17); into bottom/outlet plenum (→18).		
7	Bypass flow. No bypass flow or special coolant flow paths (all the mass flow through the pebble bed).		None

Stagnant helium and air are defined between the side reflector, barrel and RPV, and between the RPV and RCCS, respectively. No mass flow or convection should be calculated for these regions. This means that the only heat transfer mechanisms are thermal conduction and radiation across these two regions.

Material properties

The thermal properties of the materials are given in this section. This includes the emissivity given in Table 9, which was all set to 0.8 to simplify matters. The values do not differ too much from the actual material properties.

Table 9: Emissivity of materials

No.	Description	Unit	Value
1	The emissivity of the fuel and graphite spheres.		0.8
2	The emissivity of the graphite structures and carbon.		0.8
3	The emissivity of the core barrel: Type 316 Stainless Steel.		0.8
4	The emissivity of the RPV.		0.8

Table 10: Hydraulic diameters

No.	Description	Unit	Value
1	Risers channels: Side porous region.	cm	17.0
2	Top porous region.	cm	7.7
3	Bottom porous region.	cm	7.0
4	Top void area.	cm	170
5	Inlet (top and bottom) plenums.	cm	33.5
6	Outlet plenum.	cm	14.4

Adjustments must be made to the material densities where the helium flow areas are defined as porous graphite areas in the 2D model. A porosity of 20% is assumed in all these regions; that means that the density is 0.8 times the densities given for the reflector materials. Therefore, the specific heat capacity of these areas would be reduced by 20% more than for the rest of the graphite reflector regions. The "solid" reflector data is given in Table 11. The hydraulic diameters of the flow channels in these regions are given in Table 10. Since the geometry has been simplified to be two-dimensional, it implies that the riser channels can be modelled as a single vertical annulus with the same equivalent hydraulic diameter as provided.

Table 11: Specific heat capacity of materials

No.	Description	Unit	Value
1	Fuel and graphite spheres as well as reflector graphite or 3.02 $W.sec.cm^{-3}.K^{-1}$ for a density of 1.78 $g.cm^{-3}$.	$J.\ kg^{-1}\ K^{-1}$	1697
2	Reactor Pressure Vessel or 4.095 $W.sec.cm^{-3}.K^{-1}$ for a density of 7.8 $g.cm^{-3}$.	$J.\ kg^{-1}\ K^{-1}$	525
3	Core Barrel or 4.212 $W.sec.cm^{-3}.K^{-1}$ for a density of 7.8 $g.cm^{-3}$.	$J.\ kg^{-1}\ K^{-1}$	540
4	Specific heat capacity of helium for constant pressure.	$J.\ kg^{-1}\ K^{-1}$	5195
5	Specific heat capacity of air.	$J.\ kg^{-1}\ K^{-1}$	1006

The thermal conductivity of the materials in the pebble bed design is of course very important since the inherent safety of the design relies in many cases on the ability of the core structures to act as the heat removal path to the reactor cavity cooling system or to the building and surrounding environment. The thermal conductivity of graphite is dependent on neutron fast dose, irradiation temperatures and also the current temperature of the material. This normally requires complex models. In the benchmark this has been simplified to a representative constant value for all the graphite reflector regions. The thermal conductivity in the porous regions where helium flow is defined should be reduced according to the 20% porosity.

The effective thermal conductivity of a pebble bed is made up from many different heat transfer phenomena such as the radiation between pebbles and the thermal conductivity through touching pebbles. The problem has been well quantified and several correlations exist to describe these effects depending on the packing fraction, emissivity, thermal conductivity and heat capacity of the pebbles. The data to be used in the benchmark is listed in Table 12.

Table 12: Thermal conductivity of materials

No.	Description	Unit	Value
1	Pebble bed (effective). Simplified with constant thermal conductivity, heat capacity and with zero fast fluence dose.	W m^{-1} K^{-1}	Zehner-Schlünder correlation
2	Reflector, graphite spheres and fuel graphite (actual value is a function of temperature, fast fluence and irradiation temperature).	W m^{-1} K^{-1}	26.0
3	Reactor Pressure Vessel (SA 508) constant.	W m^{-1} K^{-1}	38.0
4	Core Barrel (Type 316 Stainless Steel) constant.	W m^{-1} K^{-1}	17.0
5	Helium (all areas; assumed at pressure (9 000 kPa) and inlet temperature (773.15 °K)).	W m^{-1} K^{-1}	0.33
6	Air (atmospheric conditions).	W m^{-1} K^{-1}	0.03
7	Fraction of contact area between spheres (*vs* total contact area).	%	1.6

Coated particle thermal material properties

The data for the coated particle thermal properties was introduced into the benchmark specification later (September 2005) with the focus on explicit coated particle models to be used in the transient Case 5. The volumetric coated particle packing fraction in the inner fuelled region of the fuel sphere is 9.3%.

Table 13: Volumetric heat capacity of TRISO particle

No.	Description	Unit	Assumed Density	Value
1	UO_2 kernel	J. cm^{-3} K^{-1}	Varying	$\rho c_p = 0.04058\left[\frac{C_1\theta^2 e^{\theta/T}}{T^2\left(e^{\theta/T}-1\right)^2} + 2C_2T + \frac{C_3E_a e^{-E_a/T}}{T^2}\right]$ *Where :* $C_1 = 81.613$ $C_2 = 2.285\cdot10^{-3}$ $C_3 = 2.360\cdot10^{7}$ $E_a = 1.85317\cdot10^{4}$ $\theta = 548.68$
2	Buffer layer	J. cm^{-3} K^{-1}	1.0 g/cm^3	For T ≤ 1 100 K: $\rho c_p = 9.063\ 10^{-3} + 3.244\ 10^{-3}\ T - 1.234\ 10^{4}\ T^{-2} - 1.448\ 10^{-6}\ T^{2}$ For T > 1 100 K: $\rho c_p = 2.036 + 3.625\ 10^{-5}\ T - 2.635\ 10^{5}\ T^{-2}$
3	Inner PyC	J. cm^{-3} K^{-1}	1.9 g/cm^3	For T ≤ 1100 K: $\rho c_p = 1.722\ 10^{-2} + 6.164\ 10^{-3}\ T - 2.345\ 10^{4}\ T^{-2} - 2.751\ 10^{-6}\ T^{2}$ For T > 1100 K: $\rho c_p = 3.868 + 6.888\ 10^{-5}\ T - 5.007\ 10^{5}\ T^{-2}$
4	SiC layer	J. cm^{-3} K^{-1}	3.238 g/cm^3	$\rho c_p = 4.104 + 1.576\ 10^{-4}\ T - 3.976\ 10^{5}\ T^{-2} + 6.63\ 10^{-7}\ T^{2}$
5	Outer PyC	J. cm^{-3} K^{-1}	1.9 g/cm^3	For T ≤ 1 100 K: $\rho c_p = 1.722\ 10^{-2} + 6.164\ 10^{-3}\ T - 2.345\ 10^{4}\ T^{-2} - 2.751\ 10^{-6}\ T^{2}$ For T > 1 100 K: $\rho c_p = 3.868 + 6.888\ 10^{-5}\ T - 5.007\ 10^{5}\ T^{-2}$

Table 14: Thermal conductivity of TRISO particle

No.	Description	Unit	Value
1	UO_2 kernel	W cm^{-1} K^{-1}	$0.01\left[\frac{1}{0.035 + 2.25\cdot10^{-4}T} + 8.30\cdot10^{-11}T^{3}\right]$
2	Buffer layer	W cm^{-1} K^{-1}	0.005
3	Inner PyC	W cm^{-1} K^{-1}	0.04
4	SiC layer	W cm^{-1} K^{-1}	0.16
5	Outer PyC	W cm^{-1} K^{-1}	0.04

Boundary conditions

The following thermal-hydraulic model boundary and boundary conditions apply to both steady-state and transient cases:

Table 15: Thermal-hydraulic model boundary conditions

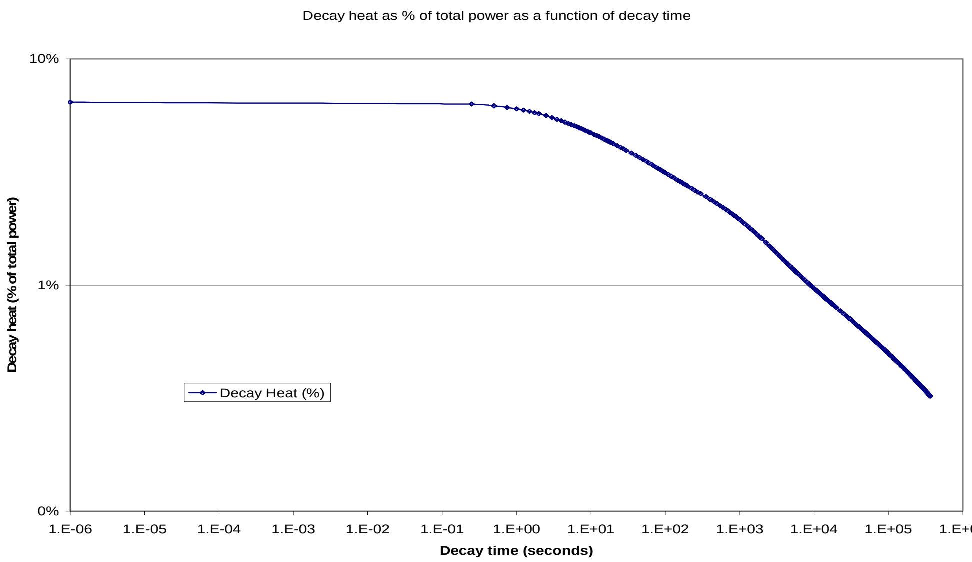
No.	Thermal-hydraulic Model Boundaries	Unit	Value
1	Radial.	m	4.62/4.63 *
2	Top (from top of fuel) *i.e.* top plate.	m	2.0
3	Bottom (from bottom of core) *i.e.* bottom plate.	m	4.0
	Thermal-hydraulic Boundary Conditions		
4	Radial (constant temperature). An isothermal boundary condition of 20 °C at a distance of one metre from the outer surface of the RPV.	°C (°K)	20 (293.15)
5	Top and Bottom. Adiabatic boundary condition at the top and bottom plate (an isothermal boundary condition can be considered after the implications for THERMIX (NRG) have been investigated).	-	Adiabatic

* Note that the constant temperature boundary condition is defined on the inner (facing the RPV) surface of the RCCS and simulates the cooling function of the RCCS. If a constant temperature surface is defined in the model, the radial dimensions of the model will only extend to 4.62 m. If a mesh needs to be defined to simulate the surface condition, a 1 cm mesh with isothermal conditions should be used. The thermal properties of the RCCS are therefore not needed.

Decay heat sources

For the benchmark problem the decay heat source is only of importance in certain transient cases, typically where the fission power is reduced to zero during the event. For the steady-state cases the decay heat is assumed to be part of the energy released per fission, which are assumed in this specification to be all deposited locally, i.e. where the fission took place.

Figure 8: Decay heat behaviour (% of Total Power)



The decay heat value for each material mesh in the core must be derived making use of the relative core average decay heat behaviour (values provided as determined from the DIN 25485 standard [6]) and the material mesh power. This implies that the decay heat is directly related to the steady-state power produced in the mesh prior to the start of the transient. No history effects or power excursions after the start of the transient (t = 0) should be taken into account. In the appropriate transient cases the time at which the decay heat start is indicated. Note that the decay heat contribution is ignored in certain transient cases.

The core average decay heat as calculated for the equilibrium core is shown in Figure 8 for a period of just over 100 hours (365 000 seconds). This decay heat should be distributed on the core mesh following the initial steady-state power distribution. In other words, the core average decay heat is scaled with the steady-state relative power of each mesh.

The data are available to participants in two forms. A detailed Excel spreadsheet table is provided as part of the data pack with all the calculated data points. As an alternative, a reduced set of data points is also provided to be used for interpolation and this will lead to an acceptable error. A linear interpolation of the log of time and log of the decay heat should be used and a sample FORTRAN subroutine is also available. The maximum error is -1.5%, but this only applies to the first half-second. After 100 seconds the time-integrated heat error is already smaller than -0.2% (underestimated), while over the 100-hour total period the error is only -0.026%. For the transient cases where this decay heat data is used, the effect of these errors will be insignificant. This is illustrated in Figure 9. The data points, 25 in total, are shown with the “LOG interpolated decay heat” data that falls on top of the reference “Decay Heat” set. The small differences are shown as the “LOG Interpolation error” and are also expressed as a percentage difference. The data points are given in Table 16.

Figure 9: Log interpolation data points and time step error estimation

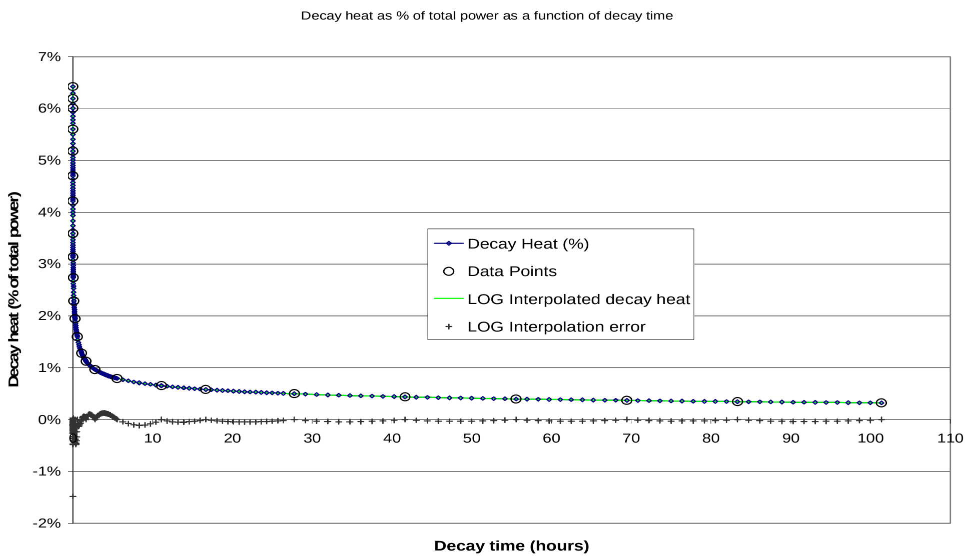


Table 16: Data points for log-log interpolation of decay heat

Seconds	Hours	Decay Heat [%]
0.000001	2.78E-10	6.426%
0.5	0.000139	6.193%
1	0.000278	6.008%
2.5	0.000694	5.603%
5	0.001389	5.180%
10	0.002778	4.704%
20	0.005556	4.216%
50	0.013889	3.592%
100	0.027778	3.137%
200	0.055556	2.739%
500	0.138889	2.287%
1 000	0.277778	1.945%
2 000	0.555556	1.599%
4 000	1.111111	1.281%
6 000	1.666667	1.127%
10 000	2.777778	0.966%
20 000	5.555556	0.795%
40 000	11.11111	0.655%
60 000	16.66667	0.582%
100 000	27.77778	0.499%
150 000	41.66667	0.438%
200 000	55.55556	0.399%
250 000	69.44444	0.369%
300 000	83.33333	0.347%
365 000	101.3889	0.323%

7. Phase I: Steady-state benchmark calculational cases

Case definitions

The cases are defined below. Note that the required results to be supplied are summarised in Section 9 and that three spreadsheets are supplied with the specification to be completed with the required results. These are "Template Steady State X.xls" with X being the case number 1 to 3.

Exercise 1: Neutronics solution with fixed cross-sections

Make use of the model description and the following conditions:

- use the simplified cross-section set with no state parameter dependence;
- no thermal-hydraulic solution required;
- report K_{eff}, power profile, two-group flux profile, core leakage;
- the calculational mesh is to be determined by each participant.

Exercise 2: Thermal-hydraulic solution with given power/heat sources

Make use of the thermal-hydraulic properties and model description and the following conditions:

- The provided power/heat source density given in Table 17 should be used. The values correspond to core regions 1 to 110 as used in Exercise 1 (see Figure 6);
- Calculate the temperature distribution, outlet temperature, pressure drop over the core, and heat loss to the constant temperature boundary;
- Assume fresh fuel Zehner-Schlünder pebble bed effective thermal conductivities (resultant values to be provided to be used as input if required);
- The calculational mesh is to be determined by each participant.

Table 17: Heat sources (W/cm3) for fuel meshes

No.	Region 1-22	Region 23-44	Region 45-66	Region 67-88	Region 89-110
1	2.570	2.040	1.753	1.529	1.371
2	4.320	3.449	2.968	2.590	2.328
3	6.266	5.113	4.512	4.080	3.841
4	8.221	6.911	6.337	6.123	6.517
5	9.721	8.353	7.806	7.716	8.390
6	10.491	9.155	8.612	8.541	9.234
7	10.547	9.330	8.808	8.732	9.350
8	10.075	9.022	8.542	8.458	8.967
9	9.275	8.398	7.970	7.881	8.280
10	8.318	7.600	7.227	7.138	7.441
11	7.304	6.729	6.411	6.325	6.546
12	6.315	5.860	5.592	5.512	5.669
13	5.400	5.041	4.817	4.744	4.854
14	4.581	4.298	4.112	4.046	4.122
15	3.859	3.636	3.482	3.425	3.475
16	3.232	3.056	2.929	2.879	2.912
17	2.690	2.552	2.448	2.404	2.425
18	2.222	2.113	2.029	1.992	2.004
19	1.815	1.730	1.662	1.631	1.638
20	1.457	1.391	1.336	1.311	1.314
21	1.136	1.087	1.045	1.024	1.023
22	0.872	0.855	0.827	0.799	0.775
Volumes of each region (all 22 axial regions the same height) given for the five rows					
	5.795E+05	6.703E+05	7.611E+05	8.518E+05	9.426E+05

Exercise 3: Coupled neutronics thermal-hydraulics calculation – starting condition for the transient cases

Make use of the neutronics model description and the following conditions:

- cross-section interpolation routines and provided tabulated cross-section data should be implemented in the codes and used;
- make use of state-parameter-dependent tabulated set of macroscopic cross-sections;
- equilibrium xenon distribution is to be calculated;
- calculate the temperatures distribution, outlet temperature, pressure drop over the core, and heat loss to the RCCS;
- a coupled neutronics–thermal-hydraulic calculation is done, with feedback;
- the calculational mesh is to be determined by each participant.

The following sub-cases are to be performed but limited results will be recorded as indicated:

- Subcase A: Determine the fuel (Doppler), moderator and reflector temperature coefficients.

Based on the results obtained from the coupled calculation the following analysis is performed:

  - Increase all the fuel (Doppler) temperatures by 50°C, keeping all other temperatures unchanged, and do not perform the coupled calculation with the thermal hydraulics. The change in k_{eff} is recorded.
  - Increase the entire moderator's temperature by 50°C, keeping all other temperatures unchanged, and do not perform the coupled calculation with the thermal-hydraulics. Note that the moderator temperature in this case refers to all graphite within the fuel spheres. The change in k_{eff} is recorded.
  - Increase the entire reflector's temperature by 50°C, keeping all other temperatures unchanged, and do not perform the coupled calculation with the thermal-hydraulics. Note that the reflector temperature in this case refers to all graphite outside the core and includes the central reflector, the side reflector, and the top and bottom reflector structures. The change in k_{eff} is recorded.

Sufficient significant numbers should be reported to be able to calculate the coefficients accurately, but it should also be consistent with the convergence criteria used.

- Subcase B: Determine the control rod worth for the control rods removed (ARO) and performing the coupled calculations again.
  - Rods are moved out to the ARO position (four meshes and 200 cm in total), i.e. to the bottom of the top reflector. Perform the coupled calculation (with thermal-hydraulics feedback) and the change in k_{eff} is recorded.

Convergence criteria

General guidelines are provided in Table 18 for convergence criteria. Each participant should ensure that a well-converged result is obtained by performing a sensitivity study on the input parameters, mesh sizes and acceleration parameters.

Table 18: Suggested convergence criteria

No.	Value	Unit	Criteria
1	K_{eff}		0.00001
2	Local fluxes		0.0001
3	Local temperature	°C	0.01
4	Local flows	m/s	0.1

8. Phase II: Transient benchmark

Exercise definitions

Six case studies, covering the range from slow to fast neutronic transients, as well as feedback effects from thermal-hydraulic parameters and fission products, are defined in this transient benchmark study.

The start of the transient is defined at t = 0 seconds, with a data output point specified at this point to capture the starting steady-state situation for each of the transient cases.

The six delayed neutron fractions β_i are dependent on the isotopic composition of the materials present. To ensure that all participants use a common set of kinetics data, the values will be provided as part of the cross-section data and therefore defined to be group-dependent and dependent on all state parameters to fit into the cross-section table philosophy.

The decay heat curves and interpolation tables provided should be used in Cases 1 to 3 and with the appropriate start of the decay time as indicated at time = 0. It is important to ensure that the total power produced is normalised correctly during steady-state and at the onset of the event.

Exercise 1: DLOFC without SCRAM

The event is a depressurised loss of forced cooling (DLOFC) without SCRAM. The effects of natural convection are to be excluded since a trickle flow is introduced, in this case for simplicity and also to ensure that re-criticality will occur within a reasonable time. It should be noted that no flow reversal will take place during the linear decrease of the mass flow. The sequence of events is listed in Table 19.

Apart from the output listed in Table 19, the transient history (from t = 0 to t = 100 hrs) must be indicated for the following parameters: maximum and average fuel temperatures, maximum and average moderator temperatures, and the heat lost from the system to the boundary. The values of the parameters must be indicated at least at the time points listed in the spreadsheet template attached, but since the times of re-criticality and maximum fuel temperature will most likely differ between the codes, the participants should include more detail data at the following two events:

- the time point when the maximum fuel temperature is reached;
- the time point when the reactor attains re-criticality.

The template also contains the output format for the spatial maps and single-parameter values.

Table 19: Exercise 1 - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady-state completed.	Equilibrium steady-state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
0	Assume t = 0 as the time zero for the decay heat. (Normalisation to total power during steady state to be kept in mind).	
0 – 13	A reduction in reactor inlet coolant *mass flow* from nominal (192.7 kg/s) to 0.2 kg/s over 13 seconds. The mass flow ramp is assumed linear. A trickle flow of 0.2 kg/s should then be assumed to remain after this step to continue flowing through the reactor with inlet temperature of 500°C.	None.
0 – 13	A reduction in reactor *helium outlet pressure* from nominal (90 bar) to 1 bar over 13 seconds. The pressure ramp is assumed linear. (Note that all pressures defined in this benchmark study are <u>absolute</u> pressure values, and not gauge values.)	None.
13	Depressurisation phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density and pebble bed effective thermal conductivity. Single-parameter value for axial power/heat offset.
13 – 360 000	No change in input parameters.	Just the defined time-dependent edits.
re-critical	Re-critical condition should be reached after some time (cool-down and xenon decay).	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power/heat density. Single-parameter value for core power, axial power offset, reactivity edit.
~ 360 000	Transient case completed. 100 hours or at least 10 hours after re-criticality.	Spatial maps of the maximum kernel and fuel temperature, moderator temperature, power density. Single-parameter value for axial power/heat offset.

Exercise 2: DLOFC with SCRAM

The event is a depressurised loss of forced cooling (DLOFC) with SCRAM. The effects of natural convection are included in this case and no external flow take place. It should be noted that no flow reversal will take place during the linear decrease of the mass flow.

The sequence of events is listed in Table 20.

Table 20: Exercise 2 - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady state completed.	Equilibrium steady state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
0	Assume t = 0 as the time zero for the decay heat. (Normalisation to total power during steady-state to be kept in mind).	
0 - 13	A reduction in reactor inlet coolant *mass flow* from nominal (192.7 kg/s) to 0.0 kg/s over 13 seconds. The mass flow ramp is assumed linear. There is no external flow after this step.	None.
0 - 13	A reduction in reactor *helium outlet pressure* from nominal (90 bar) to 1 bar over 13 seconds. The pressure ramp is assumed linear. (Note that all pressures defined in this benchmark study are <u>absolute</u> pressure values, and not gauge values).	None.
13	Depressurisation phase completed. Natural convection must be included that will lead to some internal mass flow. There is no external mass flow.	Transient output at this time point should be similar to the values in Exercise 1 (trickle flow the only difference), so a new output set will not be needed here.
13 – 16	All control rods are fully inserted over 3 seconds to SCRAM the reactor.	None.
16	Scram phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power/heat density. Single-parameter value for fission power and axial power/heat offset.
16 – 180 000	No change in input parameters.	None.
180 000	Transient case completed. 50 hours or at least 5 hours after maximum temperature has been reached	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power/heat density. Single-parameter value for axial power/heat offset.

Apart from the output listed in Table 20, the transient history (from t = 0 to t = 50 hrs) must be indicated for the following parameters: maximum and average fuel temperatures, maximum and average moderator temperatures and the heat loss from the system. The values of the parameters must be indicated at least at the time points listed in the spreadsheet template attached, but since the times of maximum fuel temperature will most likely differ between the codes, the participants should include more detail data at the time point when the maximum fuel temperature is reached. The template also contains the output format for the spatial maps and single-parameter values.

Exercise 3: PLOFC with SCRAM

The event is a pressurised loss of forced cooling (PLOFC) with SCRAM. The effects of natural convection are included in this case. Assume that no flow reversal will take place during the linear decrease of the mass flow. The sequence of events is listed in Table 21.

Table 21: Exercise 3 - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady state completed.	Equilibrium steady-state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
0	Assume t = 0 as the time zero for the decay heat. (Normalisation to total power during steady state to be kept in mind).	
0 - 13	A reduction in reactor inlet coolant *mass flow* from nominal (192.7 kg/s) to 0.0 kg/s over 13 seconds. The mass flow ramp is assumed linear.	None.
0 - 13	A reduction in reactor *helium outlet pressure* from nominal (90 bar) to 60 bar over 13 seconds. The pressure ramp is assumed linear.	None.
13	Pressure equalisation phase completed. Natural convection must be included that will lead to some internal mass flow. No external mass flow. The core helium inventory is to stay unchanged, thus pressure changes due to heat-up and cool-down are possible. Only helium volumes in the core to be included (no PCU). If needed, hand calculation estimates using the average helium temperature can be used to adjust the pressure linearly over time if this function does not exist in the core.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density, relative pressure, mass flow. Single-parameter value for axial power offset.
13 – 16	All control rods are fully inserted over 3 seconds to SCRAM the reactor.	None.
16	Scram phase completed.	None.
16 – 180 000	No change in input parameters.	None.
TBD	Maximum fuel temperature reached.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density relative pressure, mass flow. Single-parameter value for axial power offset.
180 000	Transient case completed. 50 hours or at least 5 hours after maximum temperature has been reached.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density relative pressure, mass flow. Single-parameter value for axial power offset.

The transient history (from t = 0 to t = 100 hrs) must be indicated for the following parameters: maximum and average fuel temperatures, maximum and average moderator temperatures, and reactivity (k_{eff}).

The values of these parameters must be indicated at least at the time points listed in the spreadsheet template attached, but since the times of maximum fuel temperature will most likely differ between the codes, the participants should include more detail data at the time point when the maximum fuel temperature is reached. The template also contains the output format for the spatial maps and single-parameter values.

Exercise 4: 100-40-100 load following

Two scenarios should be considered. In the first, no control rod movement is allowed, while in the second scenario the control rods are moved to maintain a critical core within a given reactivity band width. No decay heat effects will be taken into account during the transient so that the heat is only from fission. To assess the xenon behaviour, the xenon concentrations during these transients are included in the output.

The sequence of events is listed in Table 22.

Table 22: Exercise 4a - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady state completed.	Equilibrium steady-state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
0 - 360	A reduction in reactor inlet coolant *mass flow* from nominal (192.7 kg/s) to 77 kg/s (40% of nominal) over 6 minutes. The mass flow ramp is assumed linear. The reactor outlet pressure is decreased over the same time from nominal (90 bar) to 40% of the inventory.	None.
0 - 360	A reduction in reactor power level from nominal 400 MW (100%) to 160 MW (40%) over 6 minutes. The power ramp is assumed linear. The reactor total power is thus a fixed target condition.	None.
360	100-40% phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature, power density. Single-parameter value for axial power offset.
360 – 10 800 (3 hours)	No change in input parameters.	Spatial maps of the xenon concentration every two hours, at t = 3 600, 7 200 and 10 800 s. Also axial power offset values at these times.
10 800 – 11 160	An increase in reactor inlet coolant *mass flow* from 77 kg/s (40% of nominal) back to 192.7 kg/s, again over 6 minutes. The reactor outlet pressure is increased linearly back to nominal at the same time.	None.
10 800 - 11 160	An increase in reactor power level from 160 MW to 400 MW, again over 6 minutes. The reactor total power is thus a fixed target condition.	None.
11 160	40-100% phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature, power density, xenon concentration. Single-parameter value for axial power offset.
11 160 – 32 400	No change in input parameters.	Spatial maps of the xenon concentration every hours up to 9 hours. Also axial power offset values at these times.
32 400	Transient case completed.	Spatial maps of the maximum kernel and fuel temperature, maximum and average moderator temperature, power density, xenon concentration. Single-parameter value for axial power offset.
172 800	Optional. The xenon oscillation behaviour can be studied over a longer period.	Transient up to for 48 hours (at t = 43 200, 57 600, 72 000, 86 400, 100 800, 115 200, 129 600, 144 000, 158 400, and 172 800 s)

In Exercise 4a, the inlet mass flow rates, power and pressure are defined as input. This implies that the "external" reactivity required to keep the reactor artificially critical needs to be calculated (and added globally) during the load following. This reactivity will represent the effects of xenon concentration changes, power shape changes and temperature changes. Another way to describe it is:

- steady-state eigenvalue calculation for the neutronics calculation to obtain the flux (and the power) distribution and k_{eff};
- transient xenon calculation;

- transient T-H calculation.

Exercise 4b includes the control rod movement to keep the reactor critical and the reactor power is then calculated. The sequence of events is given in Table 23.

Table 23: Exercise 4b - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady state completed.	Equilibrium steady-state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
0 - 32400	Scenario 2: Activate controller moving control rods to keep the reactor critical. Control rods move at 1 $cm.s^{-1}$ and the reactivity bandwidth is 0.1% Δk.	
0 – 360	A reduction in inlet reactor coolant *mass flow* from nominal (192.7 kg/s) to 77 kg/s (40% of nominal) over 8 seconds. The mass flow ramp is assumed linear. The reactor outlet pressure is decreased over the same time from nominal (90 bar) to 40% of the inventory.	None.
0 – 360	The reactor fission power to be calculated. It should more or less follow the 400 MW (100%) to 160 MW (40%) ramp.	None.
360	100-40% phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density. Single-parameter value for axial power offset.
360 - 10800 (3 hours)	No change in input parameters.	Spatial maps of the xenon concentration every two hours, at t = 3 600, 7 200 and 10 800 s. Also axial power offset values at these times.
10800 – 11160	An increase in reactor inlet coolant *mass flow* from 77 kg/s (40% of nominal) back to 192.7 kg/s, again over 8 seconds. The reactor outlet pressure is increased linearly back to nominal at the same time.	None.
10800 - 11160	The reactor fission power to be calculated. It should more or less follow an increase from around 160 MW to 400 MW. The total power variation is still a boundary condition as in Exercise 4a.	None.
11160	40-100% phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density, xenon concentration. Single-parameter value for axial power offset.
11160 – 32400	No change in input parameters.	Spatial maps of the xenon concentration every hour up to 9 hours. Also axial power offset values at these times.
32400	Transient case completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solids temperature, power density, xenon concentration. Single-parameter value for axial power offset.
172800	Optional. The xenon oscillation behaviour can be studied over a longer period.	Transient up to for 48 hours (at t = 43 200, 57 600, 72 000, 86 400, 100 800, 115 200, 129 600, 144 000, 158 400, and 172 800 s)

The transient history in both cases must be indicated for the following parameters:

- maximum and average fuel temperatures;
- maximum and average moderator temperatures;
- fission power;
- reactivity (or K_{eff}) as appropriate;

- average xenon concentration in the entire spatial mesh;
- The xenon concentration in two meshes: one top mesh with co-ordinates (r = 134 - 151 cm, z = 150 – 200 cm), and one towards the bottom of the reactor with co-ordinates (r = 134 - 151 cm, z = 1000 – 1 050 cm);
- Control rod positions when applicable.

The values of these parameters must be indicated at the time points listed in the spreadsheet template attached.

Exercise 5: Reactivity insertions by CRW and CRE

This exercise concerns fast reactivity insertion by simulating different control rod withdrawal (CRW) and control rod ejection (CRE) scenarios at hot full power conditions. Four different cases are to be analysed. The sequence of events is listed in Table 24. Note that the decay heat does not need to be taken into account explicitly and that all energy from the fission event can be assumed to be delivered promptly. Since only the core is included in this specification, the changes in the inlet and outlet conditions due to the power conversion unit are not included and therefore the inlet mass flow rate, inlet temperature and outlet pressure should be kept constant at nominal conditions.

The calculation of this transient can suffer from a calculational phenomena called the "cusping effect" if simple volume-weighting is used to determine the cross-sections of the partially rodded axial meshes of the grey curtain. Notes on the cusping effect and an approximate solution that can be employed by participants who cannot treat this accurately by applying flux-volume-weighting are included in Appendix E.

The fast control rod transients also need special treatment to model the kernel explicitly in the thermal-hydraulic module so that the Doppler feedback temperatures are calculated accurately. The fuel coated particle thermal properties of the UO_2 kernel and the different coatings are to be applied to an explicit model if this is available in the participant's code system are given in Section 6. The reasons for the need of a coated particle thermal-hydraulic model for fast reactivity transients are further explained in Appendix E and an approximate method that may be used is also provided.

The transient history (from t = 0 to t = 60 seconds) must be indicated for the following parameters:

- maximum and average fuel temperatures;
- the peak kernel temperature (defined from a kernel model or approximate model) as the maximum of all fuel regions and for the kernel in the centre of the fuel sphere;
- maximum and average moderator temperatures;
- fission power;
- maximum power density;
- axial power offset;
- reactivity.

The values of these parameters must be indicated at the time points listed in the spreadsheet template attached. Comparisons with point kinetics calculations, where available, could be valuable.

Table 24: Case T-5 - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady state completed. Core is critical with CRs inserted to the specific positions.	Equilibrium steady-state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
Case T-5a	**TCRW: Total Control Rod Withdrawal**	
0 – 200	Withdrawal of all 24 control rods at the maximum speed of 1 cm.s^{-1}. This results in a total time of 200 seconds to complete the CR movement.	See below.
200	CRW phase completed.	See below.
200 – 600	Transient case completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature and power density at t = 10, 100, 200, 500 seconds.
Case T-5b	**TCRE: Total Control Rod Ejection of all 24 rods: Superprompt 2D Transient**	
0 – 0.1	Ejection of all 24 control rods over a 0.1 second duration.	See below.
0.1	CRW phase completed.	See below.
0.1 – 60	Transient case completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature and power density at t = 0.05, 0.1, 0.15, 0.2, 0.5, 1.0, 60 seconds.
Case T-5c	**SCRW: Single Control Rod Withdrawal: Subprompt 3D Transient**	
0 – 0.1	Ejection of a single control rod over a 0.1 second duration. This must be modelled by the change of the grey curtain to the graphite for $^1/_{24}$ of the azimuthal meshes of the grey curtain.	See below.
0.1	CRW phase completed.	See below.
0.1 – 60	Transient case completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature and power density at t = 0.05, 0.1, 0.15, 0.2, 0.5, 1.0, 60 seconds.
Case T-5d	**Prompt critical case with segment of CR ejection: Superprompt 3D Transient**	
0 – 0.1	Ejection of 6 control rods in one quarter of the core over a 0.1 second duration. This must be modelled by the change of the grey curtain to the graphite for ¼ of the azimuthal meshes of the grey curtain.	See below.
0.1	CRW phase completed.	See below.
0.1 – 60	Transient case completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature and power density at t = 0.05, 0.1, 0.15, 0.2, 0.5, 1.0, 60 seconds.

The transient history (from t = 0 to t = 60 seconds) must be indicated for the following parameters:

- maximum and average fuel temperatures;
- the peak kernel temperature (defined from a kernel model or approximate model) as the maximum of all fuel regions and for the kernel in the centre of the fuel sphere;
- maximum and average moderator temperatures;

- fission power;
- maximum power density;
- axial power offset;
- reactivity.

The values of these parameters must be indicated at the time points listed in the spreadsheet template attached. Comparisons with point kinetics calculations, where available, could be valuable.

Exercise 6: Cold helium inlet

This case simulates a bypass valve opening, with "cold" helium being injected into the core inlet plenum. A temperature ramp of 50°C (i.e. 10% of nominal inlet temperature) is applied over 10 seconds, without changing any other reactor parameters like mass flow, pressure or control rod positions. It is assumed that a reactor protection system would cause the valve to close again after 300 seconds, and the temperature would return to nominal value, again over 10 seconds. Note that no decay heat effects will be taken into account during the transient. The sequence of events is listed in Table 25.

Table 25: Exercise 6 - Sequence of events

Time (seconds)	Description	Time-specific Output Generated
0	Equilibrium steady state completed.	Equilibrium steady-state output at this time point should be identical to the values of Exercise 3 of steady state, so a new output set will not be needed here.
0 – 10	A reduction in reactor inlet temperature from nominal (500°C) to 450°C over 10 seconds. The temperature ramp is assumed linear.	None.
10	Temperature down-ramp phase completed.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature, gas temperature and power density. Single-parameter value for axial power offset.
10 – 300	No change in input parameters.	None.
300	Time just before inlet temperature is increased again.	Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature, gas temperature and power density. Single-parameter value for axial power offset.
300 – 310	An increase in the reactor inlet temperature from 450 C back to 500°C, over 10 seconds. The temperature ramp is assumed linear.	None.
310		Spatial maps of the maximum kernel and fuel temperature, moderator/solid temperature, gas temperature and power density. Single-parameter value for axial power offset.
310 – 3 600	No change in input parameters.	Single parameter value for axial power offset at t = 310 seconds.
3 600	Transient case completed.	Spatial maps of the maximum and average fuel temperature, maximum and average moderator temperature, gas temperature and power density. Single-parameter value for axial power offset.

The transient history (from t = 0 to t = 1 hour) must be provided for the following parameters:

- maximum and average fuel temperatures;
- maximum and average moderator temperatures;
- axial power off-set;
- fission power;
- reactivity.

Convergence criteria

Table 26 provides general guidelines for convergence criteria and proposed time step sizes. Each participant should ensure that a well-converged result is obtained by performing a sensitivity study on the optimal time-step width for all the transient cases.

Table 26: Suggested convergence criteria and step sizes for transient cases

No.	Value	Unit	Convergence Criteria
1	Temperature iterations	°C	0.2
2	Local fission sources		1.0E-04
	Step sizes		
3	Case 1 to 3 (during heat-up and cool-down)	sec	60
4	Recriticality phase of Case 1	sec	2
5	Case 5	sec	0.1

9. Requested output

Mesh definition for representation of results

The material definition given before is relatively simple in so far as the material type and properties are concerned. When macroscopic cross-sections are prepared for the equilibrium PBMR conditions, the isotopic concentration variations in the core (due to burn-up) and the temperature and spectrum variations throughout the core result in different cross-section sets for all these regions. Similarly, when the cross-sections, tabulated as a function of the state parameters, are to be used, a consistent set of spectrum regions, for which cross-sections will be determined, needs to be defined. For each of these spectrum regions the cross-sections would be interpolated from the multi-dimensional tables for the specific local state parameters.

A spectrum or macroscopic material regions are given in Figure 10 for the ex-core regions while each mesh in the core, 22 axial and 5 radial, has its own set of number densities and therefore its own set of cross-sections. The ex-core regions are only represented by a few sets of possible cross-sections, i.e. graphite in most regions, iron for the barrel, and definitions of control rods (grey curtain) and void. Note that the differences in region cross-sections are of course due to the differences in temperature and leakage spectrum (fast and thermal buckling).

Figure 10: Assigned spectrum/material regions for ex-core areas

		0	10	41	73.6	80.55	92.05	100	117	134	151	168	185	192.95	204.45	211.4	225	243.6	260.6	275	287.5	292.5	310	328	462	463
	-235		10	31	32.6	6.95	11.5	7.95	17	17	17	17	17	7.95	11.5	6.95	13.6	18.6	17	14.4	12.5	5	17.5	18	134	1
	-200	35	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	82	80	83	84
	-150	50	23	23	23	23	44	6	3	3	3	3	3	25	54	33	33	41	41	41	81	80	82	80	83	84
Control	-100	50	23	23	23	23	44	6	3	3	3	3	3	25	54	33	33	41	41	41	81	80	82	80	83	84
0	-50	50	23	23	23	23	44	6	2	2	2	2	2	25	54	33	33	41	41	41	81	80	82	80	83	84
50	0	50	23	23	23	23	44	6	1	1	1	1	1	25	55	33	33	41	41	41	81	80	82	80	83	84
100	50	50	24	24	24	15	46	7	0	0	0	0	0	25	56	34	34	42	42	42	81	80	82	80	83	84
150	100	50	24	24	24	15	46	7	0	0	0	0	0	25	57	34	34	42	42	42	81	80	82	80	83	84
200	150	50	24	24	24	16	47	8	0	0	0	0	0	26	58	35	35	42	42	42	81	80	82	80	83	84
250	200	50	24	24	24	16	47	8	0	0	0	0	0	26	59	35	35	42	42	42	81	80	82	80	83	84
300	250	50	24	24	24	16	47	8	0	0	0	0	0	26	60	35	35	42	42	42	81	80	82	80	83	84
350	300	50	24	24	24	17	48	9	0	0	0	0	0	27	61	36	36	42	42	42	81	80	82	80	83	84
400	350	50	24	24	24	17	48	9	0	0	0	0	0	27	62	36	36	42	42	42	81	80	82	80	83	84
450	400	50	24	24	24	17	48	9	0	0	0	0	0	27	63	36	36	42	42	42	81	80	82	80	83	84
500	450	50	24	24	24	17	48	9	0	0	0	0	0	27	64	36	36	42	42	42	81	80	82	80	83	84
550	500	50	24	24	24	18	49	10	0	0	0	0	0	28	65	37	37	42	42	42	81	80	82	80	83	84
600	550	50	24	24	24	18	49	10	0	0	0	0	0	28	66	37	37	42	42	42	81	80	82	80	83	84
650	600	50	24	24	24	18	49	10	0	0	0	0	0	28	67	37	37	42	42	42	81	80	82	80	83	84
700	650	50	24	24	24	18	49	10	0	0	0	0	0	28	68	37	37	42	42	42	81	80	82	80	83	84
750	700	50	24	24	24	19	50	11	0	0	0	0	0	29	69	38	38	42	42	42	81	80	82	80	83	84
800	750	50	24	24	24	19	50	11	0	0	0	0	0	29	70	38	38	42	42	42	81	80	82	80	83	84
850	800	50	24	24	24	19	50	11	0	0	0	0	0	29	71	38	38	42	42	42	81	80	82	80	83	84
900	850	50	24	24	24	19	50	11	0	0	0	0	0	29	72	38	38	42	42	42	81	80	82	80	83	84
950	900	50	24	24	24	20	51	12	0	0	0	0	0	30	73	39	39	42	42	42	81	80	82	80	83	84
1000	950	50	24	24	24	20	51	12	0	0	0	0	0	30	74	39	39	42	42	42	81	80	82	80	83	84
1050	1000	50	24	24	24	20	51	12	0	0	0	0	0	30	75	39	39	42	42	42	81	80	82	80	83	84
1100	1050	50	24	24	24	21	52	13	0	0	0	0	0	31	76	40	40	42	42	42	81	80	82	80	83	84
1150	1100	50	24	24	24	21	52	13	0	0	0	0	0	31	77	40	40	42	42	42	81	80	82	80	83	84
	1150	50	22	22	22	22	53	14	4	4	4	4	4	32	78	40	40	43	43	43	81	80	82	80	83	84
	1200	50	22	22	22	22	53	14	5	5	5	5	5	32	78	40	40	43	43	43	81	80	82	80	83	84
	1250	50	22	22	22	22	53	14	5	5	5	5	5	32	78	40	40	43	43	43	81	80	82	80	83	84
	1300	50	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	81	80	82	80	83	84
	1350	50	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	81	80	82	80	83	84
	1400	50	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	81	80	82	80	83	84
	1450	50	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	81	80	82	80	83	84
	1500	50	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	81	80	82	80	83	84
	1535	35	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	82	80	83	84

It is important to note that the material mesh given and the mesh in which results are requested correspond, but that it is not implied that this mesh should be used for the neutronics calculation. Each participant must ensure that spatially converged results applicable to the specific calculational method employed are reported. Therefore, the given mesh has to be refined for most applications (definitely in the case of finite-difference) to obtain a converged result. Also, the cases were defined to yield results with k_{eff} close to one, but this is not the reference answer and should thus not be assumed to be a critical core layout.

In order to ensure consistency in the comparisons, results have to be submitted on the mesh requested (one value for each mesh position defined in Figure 10, so several finer calculational meshes might need to be averaged to supply the required results.

Phase I: Steady-state output parameters

Detailed spreadsheets are supplied to participants to report their results. The following three files are available for the steady-state cases and contain all the fields listed below as appropriate for the neutronics and/or thermal-hydraulic results. They are:

- template steady-state 1.xls;
- template steady-state 2.xls;
- template steady-state 3.xls;

Every spreadsheet requests information on the name of the participant's organisation, the country or origin, and the code systems utilised in the study.

Neutronics results

- Global parameters:
  - K_{eff};
  - leakage from the core/fuel region and out of the system (neutronics domain);
  - maximum fast and thermal flux;
  - maximum power density;
  - convergence criteria used.
- Profiles (in the given mesh):
  - relative power profiles (reported for the 5 radial and 22 axial meshes);
  - two-group neutron flux distribution (reported for the neutronics domain; 20 radial and 29 axial meshes as defined in Figure 5);
  - details on the mesh subdivisions to confirm converged results have been achieved.

Thermal-hydraulics results

- Global parameters:
  - inlet/outlet pressure;
  - inlet/outlet temperatures;
  - total helium mass flow rate;
  - pressure drop over the core and model;
  - average fuel temperature;
  - average moderator temperature;

  - average helium temperature;
  - total heat loss from the system.
- Profiles (in the given mesh):
  - temperatures (Doppler, moderator (including reflector graphite temperatures), helium, pebble surface, maximum fuel);
  - pressure differences;
  - mass flows rate map (separated in radial and axial directions);
  - details on the mesh subdivisions to confirm converged results have been achieved;
  - pebble bed effective thermal conductivity (from Zehner-Schlünder).

The full thermal-hydraulic domain (24 radial x 36 axial meshes – see Figure 7) must be used to represent all the appropriate (2D) results.

The methodology for results comparisons will be provided with the results.

Phase II: Transient output parameters

Detailed spreadsheets are also supplied to participants to report these results. The following files are available for the transient cases and contain all the fields listed below as appropriate for the neutronics and thermal-hydraulic results. They are:

- Template Case 1.xls
- Template Case 2.xls
- Template Case 3.xls
- Template Case 4a.xls
- Template Case 4b.xls
- Template Case 5a.xls
- Template Case 5b.xls
- Template Case 5c.xls
- Template Case 5d.xls
- Template Case 6.xls

Every spreadsheet requests information on the name of the participant's organisation, the country or origin, and the code systems utilised in the study. In the transient cases the detail requested is more specific to each case as far as the requested time-dependent values and time step points are concerned. A list of these values is given below, but the specific spreadsheet should be consulted to get the specific requirements per case.

Neutronics results

- Global parameter time behaviour (single-value time histories):
  - maximum power density in the core;
  - axial power or heat production offset at given time points;
  - time of re-criticality (if appropriate);
  - fission power at given time points;

- reactivity at different time points;
- control rod positions at different time points;
- reactivity worth of control rods.

- Profiles on the given mesh (time snapshots at given times):
  - relative power profiles (reported for the 22 axial and 5 radial meshes) at given time points;
  - two-group neutron flux distribution (reported for the neutronics domain; 20 radial and 29 axial meshes as defined in Figure 5);
  - xenon concentrations (average and at specific mesh positions and maps).

Thermal-hydraulics results

- Global parameter time behaviour (single-value time histories):
  - inlet/outlet pressure;
  - inlet/outlet temperatures;
  - total helium mass flow rate;
  - pressure drop over the core and model;
  - average and maximum fuel temperature as a function of time;
  - average and maximum moderator temperature as a function of time;
  - time of maximum fuel temperature;
  - average helium temperature;
  - total heat loss from the system.
- Profiles on the given mesh (time snapshots at given times):
  - temperatures (Doppler, moderator (including reflector graphite and temperatures of other solids), helium, pebble surface, maximum fuel);
  - pressure differences;
  - mass flows rate map (separated in radial and axial directions);
  - pebble bed effective thermal conductivity (result from Zehner-Schlünder).

The full thermal-hydraulic domain (24 radial x 36 axial meshes – see Figure 7) must be used to represent the moderator/solid temperature data while all the other tables are restricted only to the core meshes.

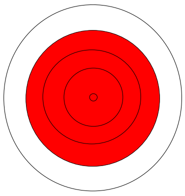
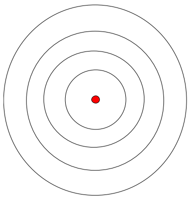
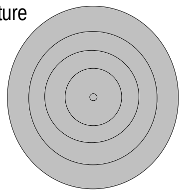
The methodology for results comparisons will be provided with the results.

Output parameters

Data output and reporting formats are included as MS Excel templates. These templates must be used for all reporting on transient data for the six cases. Transient output results are grouped into two sections: the time-history values of some important parameters (e.g. total power, maximum fuel temperature, power density, axial power offset, heat loss from the system), and “snapshot” information on the spatial values of these parameters at specific time points. The output required for each transient case is also well defined as part of the case description.

More detailed definitions of the output parameters are described in Table 27.

Table 27: Output parameter definition

Parameter	Description	Unit
Axial Power Offset	AO = $(FP_{top} - FP_{bottom})/(FP_{top} + FP_{bottom})$, where FP_{top} = fission power produced in the top half of the core, and FP_{bottom} = fission power produced in the bottom half of the core. The definition should be applied to the total heat sources when appropriate (sum of decay heat and fission power at recriticality).	None.
Average and Maximum Fuel Temperature 	The "fuel temperature" is defined as the average fuel *kernel* temperatures of all the fuel spheres present in a single mesh. (This value is calculated over the inner "rings" of pebble that contain the coated particles and is used for Doppler feedback calculations in each mesh point.) The maximum value that occurs in the 2D spatial map (the reported mesh) is defined as the "maximum fuel temperature", and the average of all the spatial moderator temperatures is defined as the "average fuel temperature". These are reported in the time-dependent results list.	°C
Maximum Kernel Temperature 	The maximum kernel temperature of a pebble refers to the maximum temperature seen by a single kernel, assumed in the centre of a fuel element (a region the size of a kernel). The core maximum kernel temperature (as is required in the time-dependent single-parameter edit for Case 5) is the highest of all the maximum kernel temperatures of pebbles that occur in the entire 2D spatial map. To exclude mesh effects these parameters are to be calculated in the reported mesh and not in the refined calculational mesh. Thus values calculated in a refined mesh should first be averaged per the reported mesh and then the maxima should be found.	°C
Average and Maximum Moderator Temperature 	The "moderator temperature" is defined as the average temperatures of all graphite in the fuel spheres present in a single mesh (*i.e.* in the fuel graphite matrix and the outer fuel-free graphite zone of a sphere). (This value is calculated over the whole pebble and is used for moderator temperature feedback calculations in each mesh point.) The maximum value that occurs in the 2D spatial map (the reported mesh) is defined as the "maximum moderator temperature", and the average of all the spatial moderator temperatures is defined as the "average moderator temperature". These are reported in the time-dependent results list.	°C
Helium Mass Flow Rate	Mass flow rate of helium coolant in the system, reported in directional components (radial and axial).	kg/s
Thermal Conductivity	Thermal conductivity value in each mesh point. Note that in the reflector regions this is a constant value, but in the core the Zehner-Schlünder correlation is dependent on the temperature of the graphite. The full Zehner-Schlünder correlation dependence on irradiation temperature and irradiation dose is not used for this benchmark, *i.e.* a fixed irradiation temperature of 850 °C and a zero fast-fluence factor is used.	W/m.K
Total Power	Total thermal power (*i.e.* fission power + decay heat). The steady-state value is by default 400 MW.	MW
Fission Power	Global fission power.	MW
Power Density	Power density that occurs in each of the 2D spatial meshes.	MW/m^3
Core Pressure Drop	Drop in helium pressure over the core (*i.e.* $P_{core\ inlet} - P_{core\ outlet}$). The pressure drop can also be calculated for each mesh, relative to the outlet pressure (*i.e.* a spatial map can be created indicating the pressure difference in each mesh point, relative to the outlet pressure).	kPa
Xenon Concentration	Xenon concentration that occurs in each of the 2D spatial meshes. Since the units for this parameter vary in the different codes, relative xenon concentration values, normalized to the steady-state xenon concentration levels in each of the 2D spatial meshes, will be used.	None (relative to steady-state).

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Appendix A: VSOP99 EQUILIBRIUM CYCLE: Additional information

The VSOP99 Code System

VSOP [7] is a suite of codes developed over many years at the Research Centre Jülich and used at the PBMR (Proprietary) Limited for fuel cycle analysis of PBMRs. VSOP consists of cross-section libraries and processing routines and neutron spectrum evaluation based upon the GAM and THERMOS codes, two-dimensional (2D) and three-dimensional (3D) diffusion, depletion routines, in-core and out-of-pile fuel management, fuel cycle cost analysis, and thermal-hydraulics for pebble bed reactors. The diffusion module is based on the CITATION finite-difference method and calculates the R-Z flux distribution in four energy groups. The VSOP code is used to generate the reference isotopic distribution at realistic equilibrium core conditions, i.e. temperatures and control rod positions.

Fuel specification

The fresh fuel specifications used in the VSOP model are given in Table A.1.

Table A.1: Fuel element characteristics

Description	Value
Fuel Pebble	
Fuel pebble outer radius	3.0 cm
Thickness of fuel free zone	0.5 cm
Total heavy metal loading per fuel pebble (equilibrium fuel)	9 g
Carbon content	189 g/fuel sphere
Coated Particle	
Fuel kernel diameter	500 micron
Kernel material type	UO_2
UO_2 density	10.4
Kernel coating material	C/C/SiC/C
Layer thickness	95/40/35/40 μm
Layer densities	1.05/1.90/3.18/1.90 g/cm^3

Structural material specifications

Table A.2: Structural material specifications and densities

No.	Description	Unit	Value
1	The reflector graphite density. Central column, top, bottom and side reflector.	$g.cm^{-3}$	1.78
2	The reflector graphite density used in the RSS, RCS, riser channel and inlet/outlet plenums.	$g.cm^{-3}$	1.78
3	Density of RPV: iron.	$g.cm^{-3}$	7.8
4	Density of core barrel: iron.	$g.cm^{-3}$	7.8

Control rod and shut-down system design

Table A.3: Control rod and shut-down specifications

No.	Description	Unit	Value
1	Thickness of grey-curtain region representing the control rods.	m	0.115
2	Distance between core outer diameter and inner diameter of control rod grey-curtain region.	m	0.0795
3	Homogenized number density of B-10 representing control system.	# $barn^{-1}$ cm^{-1}	6.0E-6
4	Density of graphite in the grey-curtain region.	$g.cm^{-3}$	1.78

Equilibrium core number densities

The equilibrium cycle was analysed with VSOP99. The exact geometrical and material definitions of the benchmark were used and an equilibrium cycle, with full thermal-hydraulics feedback, was performed. The resultant number densities are given in this section.

The graphite structures' graphite number density, the control rod' (grey curtain) number density, and core barrel data are given in Table A.4. These can of course be calculated directly from the given specifications.

Table A.4: Number densities for non-fuel regions

Isotope	Graphite (Reflector) all Regions	RCS/RSS	Core Barrel
C	8.925E-02	8.925E-02	0.0
B-10	1.0E-09	6.0E-06	0.0
Fe (Nat)	0.0	0.0	5.810E-02
Cu (Nat)	0.0	0.0	3.861E-04
Co-59	0.0	0.0	1.544E-04
Si	0.0	0.0	2.488E-04
Ni (Nat)	0.0	0.0	7.996E-03
Mo (Nat)	0.0	0.0	1.733E-03
Mn – 55	0.0	0.0	1.278E-03
Cr (Nat)	0.0	0.0	1.590E-02

Table A.5: Number-densities for fuel regions (Channel 1 – 5, Region 1 – 22)

Regions (Fuel1,1) – Fuel(1,11)

	(fuel1,1)	(fuel1,2)	(fuel1,3)	(fuel1,4)	(fuel1,5)	(fuel1,6)	(fuel1,7)	(fuel1,8)	(fuel1,9)	(fuel1,10)	(fuel1,11)
U-234	9.36E-08	9.34E-08	9.30E-08	9.25E-08	9.19E-08	9.11E-08	9.04E-08	8.96E-08	8.89E-08	8.83E-08	8.77E-08
U-235	5.81E-06	5.74E-06	5.65E-06	5.51E-06	5.35E-06	5.17E-06	4.99E-06	4.81E-06	4.64E-06	4.50E-06	4.37E-06
U-236	1.00E-06	1.01E-06	1.03E-06	1.05E-06	1.08E-06	1.10E-06	1.13E-06	1.16E-06	1.19E-06	1.21E-06	1.23E-06
U-237	3.71E-10	5.85E-10	9.30E-10	1.36E-09	1.81E-09	2.20E-09	2.48E-09	2.63E-09	2.65E-09	2.57E-09	2.42E-09
U-238	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04
U-239	4.58E-11	8.36E-11	1.25E-10	1.70E-10	2.07E-10	2.30E-10	2.37E-10	2.31E-10	2.17E-10	1.97E-10	1.76E-10
NP-237	4.08E-08	4.09E-08	4.11E-08	4.15E-08	4.20E-08	4.28E-08	4.37E-08	4.48E-08	4.60E-08	4.72E-08	4.83E-08
NP-238	5.94E-11	1.06E-10	1.64E-10	2.31E-10	2.96E-10	3.49E-10	3.82E-10	3.95E-10	3.91E-10	3.74E-10	3.48E-10
NP-239	5.39E-09	1.02E-08	1.60E-08	2.23E-08	2.80E-08	3.19E-08	3.36E-08	3.34E-08	3.18E-08	2.93E-08	2.63E-08
NP-240	4.17E-14	1.41E-13	3.25E-13	6.05E-13	9.16E-13	1.15E-12	1.24E-12	1.20E-12	1.07E-12	8.99E-13	7.19E-13
PU-238	1.30E-08	1.31E-08	1.33E-08	1.37E-08	1.42E-08	1.48E-08	1.54E-08	1.62E-08	1.69E-08	1.77E-08	1.84E-08
PU-239	4.42E-07	4.38E-07	4.33E-07	4.28E-07	4.24E-07	4.21E-07	4.19E-07	4.18E-07	4.18E-07	4.18E-07	4.18E-07
PU-240	2.41E-07	2.41E-07	2.42E-07	2.44E-07	2.46E-07	2.49E-07	2.52E-07	2.55E-07	2.58E-07	2.61E-07	2.63E-07
PU-241	1.58E-07	1.59E-07	1.61E-07	1.64E-07	1.67E-07	1.71E-07	1.75E-07	1.78E-07	1.81E-07	1.84E-07	1.86E-07
PU-242	1.01E-07	1.03E-07	1.05E-07	1.09E-07	1.14E-07	1.19E-07	1.25E-07	1.31E-07	1.37E-07	1.43E-07	1.48E-07
PU-243	1.37E-12	2.40E-12	3.61E-12	4.98E-12	6.27E-12	7.24E-12	7.81E-12	8.00E-12	7.86E-12	7.47E-12	6.91E-12
AM-241	3.04E-09	3.13E-09	3.16E-09	3.13E-09	3.06E-09	2.94E-09	2.82E-09	2.71E-09	2.62E-09	2.55E-09	2.52E-09
AM-242M	6.66E-11	6.71E-11	6.86E-11	7.11E-11	7.37E-11	7.56E-11	7.63E-11	7.60E-11	7.52E-11	7.44E-11	7.37E-11
AM-242	5.94E-12	1.06E-11	1.62E-11	2.23E-11	2.72E-11	2.99E-11	3.02E-11	2.89E-11	2.67E-11	2.41E-11	2.14E-11
AM-243	1.96E-09	1.99E-09	2.06E-09	2.14E-09	2.26E-09	2.40E-09	2.55E-09	2.71E-09	2.87E-09	3.03E-09	3.17E-09
AM-244	7.49E-13	1.31E-12	1.98E-12	2.76E-12	3.51E-12	4.11E-12	4.49E-12	4.65E-12	4.61E-12	4.43E-12	4.13E-12
CM-242	1.30E-09	1.31E-09	1.35E-09	1.43E-09	1.54E-09	1.68E-09	1.82E-09	1.96E-09	2.07E-09	2.17E-09	2.25E-09
CM-243	2.49E-11	2.52E-11	2.57E-11	2.64E-11	2.74E-11	2.87E-11	3.03E-11	3.20E-11	3.38E-11	3.55E-11	3.71E-11
CM-244	4.73E-10	4.86E-10	5.06E-10	5.35E-10	5.74E-10	6.21E-10	6.75E-10	7.33E-10	7.91E-10	8.49E-10	9.03E-10
XE-135	7.56E-11	8.67E-11	9.35E-11	9.81E-11	1.01E-10	1.02E-10	1.02E-10	1.01E-10	9.92E-11	9.72E-11	9.49E-11
XE-136	7.99E-07	8.07E-07	8.21E-07	8.40E-07	8.63E-07	8.90E-07	9.18E-07	9.45E-07	9.71E-07	9.94E-07	1.01E-06
KR-83	2.51E-08	2.54E-08	2.57E-08	2.62E-08	2.69E-08	2.75E-08	2.82E-08	2.88E-08	2.94E-08	2.99E-08	3.04E-08
ZR-95	4.72E-08	4.75E-08	5.01E-08	5.48E-08	6.11E-08	6.83E-08	7.53E-08	8.14E-08	8.62E-08	8.96E-08	9.15E-08
MO-95	3.48E-07	3.52E-07	3.56E-07	3.60E-07	3.64E-07	3.69E-07	3.75E-07	3.81E-07	3.88E-07	3.95E-07	4.02E-07
MO-97	3.89E-07	3.93E-07	4.00E-07	4.09E-07	4.20E-07	4.32E-07	4.45E-07	4.57E-07	4.69E-07	4.79E-07	4.89E-07
TC-99	3.85E-07	3.89E-07	3.95E-07	4.04E-07	4.15E-07	4.27E-07	4.39E-07	4.51E-07	4.62E-07	4.73E-07	4.82E-07

	(fuel1,1)	(fuel1,2)	(fuel1,3)	(fuel1,4)	(fuel1,5)	(fuel1,6)	(fuel1,7)	(fuel1,8)	(fuel1,9)	(fuel1,10)	(fuel1,11)
RU-101	3.46E-07	3.50E-07	3.55E-07	3.63E-07	3.73E-07	3.84E-07	3.96E-07	4.07E-07	4.17E-07	4.27E-07	4.36E-07
RU-103	1.73E-08	1.77E-08	1.97E-08	2.29E-08	2.71E-08	3.18E-08	3.62E-08	3.99E-08	4.27E-08	4.44E-08	4.51E-08
RH-103	1.77E-07	1.79E-07	1.79E-07	1.80E-07	1.80E-07	1.81E-07	1.82E-07	1.83E-07	1.85E-07	1.87E-07	1.90E-07
RH-105	2.79E-10	4.81E-10	7.03E-10	9.30E-10	1.12E-09	1.23E-09	1.27E-09	1.25E-09	1.19E-09	1.10E-09	9.96E-10
PD-105	1.25E-07	1.27E-07	1.29E-07	1.31E-07	1.35E-07	1.39E-07	1.43E-07	1.48E-07	1.52E-07	1.56E-07	1.60E-07
PD-108	4.28E-08	4.33E-08	4.41E-08	4.52E-08	4.67E-08	4.84E-08	5.02E-08	5.20E-08	5.38E-08	5.55E-08	5.70E-08
AG-109	2.29E-08	2.31E-08	2.36E-08	2.41E-08	2.49E-08	2.57E-08	2.67E-08	2.76E-08	2.85E-08	2.94E-08	3.01E-08
CD-113	2.52E-11	2.50E-11	2.50E-11	2.52E-11	2.54E-11	2.56E-11	2.57E-11	2.59E-11	2.60E-11	2.61E-11	2.62E-11
I-131	1.36E-09	2.34E-09	3.69E-09	5.28E-09	6.86E-09	8.17E-09	9.00E-09	9.30E-09	9.16E-09	8.68E-09	7.98E-09
XE-131	1.65E-07	1.65E-07	1.67E-07	1.69E-07	1.71E-07	1.75E-07	1.79E-07	1.84E-07	1.89E-07	1.93E-07	1.98E-07
XE-133	2.12E-09	3.99E-09	6.29E-09	8.81E-09	1.12E-08	1.29E-08	1.37E-08	1.38E-08	1.32E-08	1.22E-08	1.10E-08
CS-133	4.16E-07	4.18E-07	4.23E-07	4.30E-07	4.39E-07	4.50E-07	4.63E-07	4.75E-07	4.88E-07	5.00E-07	5.11E-07
CS-134	2.53E-08	2.55E-08	2.59E-08	2.66E-08	2.75E-08	2.86E-08	2.98E-08	3.11E-08	3.23E-08	3.34E-08	3.44E-08
PR-141	3.79E-07	3.83E-07	3.89E-07	3.98E-07	4.08E-07	4.20E-07	4.33E-07	4.45E-07	4.56E-07	4.66E-07	4.75E-07
PR-143	4.36E-09	6.31E-09	9.39E-09	1.33E-08	1.75E-08	2.13E-08	2.41E-08	2.57E-08	2.61E-08	2.55E-08	2.42E-08
ND-143	2.74E-07	2.75E-07	2.76E-07	2.77E-07	2.80E-07	2.83E-07	2.87E-07	2.92E-07	2.98E-07	3.04E-07	3.10E-07
ND-144	4.37E-07	4.42E-07	4.50E-07	4.61E-07	4.75E-07	4.90E-07	5.06E-07	5.22E-07	5.37E-07	5.51E-07	5.63E-07
ND-145	2.34E-07	2.36E-07	2.40E-07	2.45E-07	2.51E-07	2.59E-07	2.66E-07	2.73E-07	2.80E-07	2.86E-07	2.91E-07
ND-146	2.12E-07	2.14E-07	2.18E-07	2.23E-07	2.29E-07	2.36E-07	2.43E-07	2.50E-07	2.57E-07	2.63E-07	2.69E-07
PM-147	7.93E-08	8.00E-08	8.13E-08	8.31E-08	8.54E-08	8.80E-08	9.06E-08	9.31E-08	9.52E-08	9.71E-08	9.86E-08
PM-148M	2.56E-10	2.64E-10	2.86E-10	3.05E-10	3.21E-10	3.33E-10	3.44E-10	3.53E-10	3.60E-10	3.65E-10	3.67E-10
PM-148	1.15E-10	1.90E-10	2.82E-10	3.74E-10	4.50E-10	5.02E-10	5.29E-10	5.38E-10	5.32E-10	5.15E-10	4.91E-10
SM-147	2.22E-08	2.26E-08	2.30E-08	2.34E-08	2.37E-08	2.41E-08	2.44E-08	2.48E-08	2.51E-08	2.55E-08	2.59E-08
SM-148	2.20E-08	2.22E-08	2.26E-08	2.31E-08	2.37E-08	2.44E-08	2.51E-08	2.59E-08	2.67E-08	2.74E-08	2.81E-08
PM-149	2.46E-10	4.54E-10	7.01E-10	9.73E-10	1.22E-09	1.39E-09	1.46E-09	1.44E-09	1.37E-09	1.25E-09	1.12E-09
SM-149	6.45E-10	5.81E-10	6.15E-10	6.69E-10	7.25E-10	7.77E-10	8.19E-10	8.51E-10	8.73E-10	8.88E-10	8.97E-10
SM-150	8.72E-08	8.79E-08	8.90E-08	9.06E-08	9.27E-08	9.53E-08	9.82E-08	1.01E-07	1.04E-07	1.07E-07	1.09E-07
PM-151	5.56E-11	9.63E-11	1.42E-10	1.88E-10	2.26E-10	2.48E-10	2.53E-10	2.45E-10	2.28E-10	2.07E-10	1.83E-10
SM-151	4.14E-09	4.07E-09	4.02E-09	4.01E-09	4.04E-09	4.12E-09	4.21E-09	4.31E-09	4.39E-09	4.47E-09	4.53E-09
SM-152	4.09E-08	4.14E-08	4.22E-08	4.32E-08	4.45E-08	4.58E-08	4.72E-08	4.86E-08	4.98E-08	5.10E-08	5.21E-08
EU-153	2.98E-08	3.01E-08	3.06E-08	3.13E-08	3.22E-08	3.32E-08	3.44E-08	3.55E-08	3.66E-08	3.76E-08	3.86E-08
EU-154	5.28E-09	5.34E-09	5.45E-09	5.61E-09	5.80E-09	6.04E-09	6.29E-09	6.55E-09	6.80E-09	7.03E-09	7.25E-09
EU-155	1.63E-09	1.65E-09	1.68E-09	1.74E-09	1.80E-09	1.87E-09	1.95E-09	2.01E-09	2.08E-09	2.13E-09	2.18E-09
GD-155	5.94E-11	4.77E-11	3.31E-11	2.17E-11	1.54E-11	1.28E-11	1.21E-11	1.26E-11	1.36E-11	1.50E-11	1.69E-11

	(fuel1,1)	(fuel1,2)	(fuel1,3)	(fuel1,4)	(fuel1,5)	(fuel1,6)	(fuel1,7)	(fuel1,8)	(fuel1,9)	(fuel1,10)	(fuel1,11)
GD-156	9.89E-09	1.01E-08	1.03E-08	1.07E-08	1.11E-08	1.16E-08	1.22E-08	1.28E-08	1.33E-08	1.39E-08	1.44E-08
GD-157	1.36E-11	1.20E-11	1.22E-11	1.29E-11	1.37E-11	1.43E-11	1.49E-11	1.54E-11	1.59E-11	1.62E-11	1.65E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel1,12) – Fuel(1,22)

	(fuel1,12)	(fuel1,13)	(fuel1,14)	(fuel1,15)	(fuel1,16)	(fuel1,17)	(fuel1,18)	(fuel1,19)	(fuel1,20)	(fuel1,21)	(fuel1,22)
U-234	8.72E-08	8.68E-08	8.64E-08	8.61E-08	8.58E-08	8.56E-08	8.54E-08	8.52E-08	8.51E-08	8.50E-08	8.49E-08
U-235	4.26E-06	4.17E-06	4.09E-06	4.02E-06	3.96E-06	3.92E-06	3.88E-06	3.85E-06	3.82E-06	3.80E-06	3.79E-06
U-236	1.25E-06	1.26E-06	1.27E-06	1.28E-06	1.29E-06	1.30E-06	1.30E-06	1.31E-06	1.31E-06	1.32E-06	1.32E-06
U-237	2.21E-09	1.99E-09	1.75E-09	1.53E-09	1.32E-09	1.12E-09	9.51E-10	7.96E-10	6.58E-10	5.34E-10	4.13E-10
U-238	1.08E-04	1.08E-04	1.08E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04
U-239	1.54E-10	1.33E-10	1.13E-10	9.62E-11	8.10E-11	6.77E-11	5.61E-11	4.59E-11	3.69E-11	2.88E-11	2.01E-11
NP-237	4.93E-08	5.03E-08	5.12E-08	5.20E-08	5.26E-08	5.32E-08	5.37E-08	5.41E-08	5.45E-08	5.48E-08	5.50E-08
NP-238	3.17E-10	2.83E-10	2.49E-10	2.16E-10	1.86E-10	1.58E-10	1.33E-10	1.10E-10	9.01E-11	7.15E-11	5.54E-11
NP-239	2.32E-08	2.01E-08	1.73E-08	1.47E-08	1.24E-08	1.04E-08	8.66E-09	7.13E-09	5.77E-09	4.56E-09	3.32E-09
NP-240	5.54E-13	4.15E-13	3.05E-13	2.20E-13	1.57E-13	1.10E-13	7.58E-14	5.11E-14	3.33E-14	2.05E-14	1.08E-14
PU-238	1.91E-08	1.97E-08	2.03E-08	2.08E-08	2.12E-08	2.16E-08	2.19E-08	2.22E-08	2.25E-08	2.27E-08	2.29E-08
PU-239	4.18E-07	4.18E-07	4.18E-07	4.17E-07	4.17E-07	4.17E-07	4.17E-07	4.17E-07	4.17E-07	4.17E-07	4.17E-07
PU-240	2.65E-07	2.67E-07	2.69E-07	2.70E-07	2.71E-07	2.72E-07	2.73E-07	2.74E-07	2.74E-07	2.75E-07	2.75E-07
PU-241	1.88E-07	1.90E-07	1.91E-07	1.92E-07	1.93E-07	1.94E-07	1.94E-07	1.95E-07	1.95E-07	1.95E-07	1.95E-07
PU-242	1.53E-07	1.57E-07	1.61E-07	1.64E-07	1.66E-07	1.68E-07	1.70E-07	1.72E-07	1.73E-07	1.74E-07	1.75E-07
PU-243	6.25E-12	5.55E-12	4.87E-12	4.22E-12	3.61E-12	3.07E-12	2.57E-12	2.13E-12	1.73E-12	1.36E-12	1.03E-12
AM-241	2.51E-09	2.53E-09	2.58E-09	2.64E-09	2.73E-09	2.83E-09	2.94E-09	3.07E-09	3.21E-09	3.36E-09	3.52E-09
AM-242M	7.34E-11	7.34E-11	7.38E-11	7.45E-11	7.55E-11	7.67E-11	7.80E-11	7.94E-11	8.09E-11	8.23E-11	8.36E-11
AM-242	1.89E-11	1.66E-11	1.45E-11	1.27E-11	1.11E-11	9.66E-12	8.36E-12	7.16E-12	6.03E-12	4.94E-12	3.99E-12
AM-243	3.30E-09	3.42E-09	3.52E-09	3.61E-09	3.69E-09	3.76E-09	3.81E-09	3.86E-09	3.90E-09	3.93E-09	3.95E-09
AM-244	3.76E-12	3.36E-12	2.96E-12	2.57E-12	2.21E-12	1.88E-12	1.58E-12	1.31E-12	1.06E-12	8.36E-13	6.39E-13
CM-242	2.31E-09	2.35E-09	2.38E-09	2.39E-09	2.39E-09	2.38E-09	2.36E-09	2.33E-09	2.30E-09	2.26E-09	2.21E-09
CM-243	3.85E-11	3.97E-11	4.08E-11	4.17E-11	4.24E-11	4.30E-11	4.35E-11	4.39E-11	4.41E-11	4.44E-11	4.45E-11
CM-244	9.52E-10	9.97E-10	1.04E-09	1.07E-09	1.10E-09	1.13E-09	1.15E-09	1.16E-09	1.18E-09	1.19E-09	1.20E-09

	(fuel1,12)	(fuel1,13)	(fuel1,14)	(fuel1,15)	(fuel1,16)	(fuel1,17)	(fuel1,18)	(fuel1,19)	(fuel1,20)	(fuel1,21)	(fuel1,22)
XE-135	9.23E-11	8.94E-11	8.63E-11	8.29E-11	7.92E-11	7.52E-11	7.07E-11	6.58E-11	6.03E-11	5.38E-11	4.69E-11
XE-136	1.03E-06	1.05E-06	1.06E-06	1.07E-06	1.08E-06	1.09E-06	1.09E-06	1.10E-06	1.10E-06	1.10E-06	1.11E-06
KR-83	3.07E-08	3.11E-08	3.13E-08	3.15E-08	3.17E-08	3.19E-08	3.20E-08	3.21E-08	3.22E-08	3.22E-08	3.23E-08
ZR-95	9.20E-08	9.13E-08	8.97E-08	8.73E-08	8.43E-08	8.09E-08	7.71E-08	7.31E-08	6.91E-08	6.49E-08	6.08E-08
MO-95	4.09E-07	4.17E-07	4.24E-07	4.31E-07	4.38E-07	4.45E-07	4.52E-07	4.58E-07	4.64E-07	4.70E-07	4.75E-07
MO-97	4.97E-07	5.04E-07	5.10E-07	5.15E-07	5.19E-07	5.23E-07	5.26E-07	5.28E-07	5.30E-07	5.31E-07	5.33E-07
TC-99	4.89E-07	4.96E-07	5.02E-07	5.07E-07	5.11E-07	5.14E-07	5.17E-07	5.19E-07	5.21E-07	5.22E-07	5.24E-07
RU-101	4.43E-07	4.49E-07	4.55E-07	4.60E-07	4.63E-07	4.67E-07	4.69E-07	4.72E-07	4.73E-07	4.75E-07	4.76E-07
RU-103	4.49E-08	4.39E-08	4.24E-08	4.04E-08	3.82E-08	3.57E-08	3.32E-08	3.06E-08	2.80E-08	2.54E-08	2.30E-08
RH-103	1.94E-07	1.98E-07	2.01E-07	2.05E-07	2.09E-07	2.13E-07	2.16E-07	2.20E-07	2.23E-07	2.26E-07	2.29E-07
RH-105	8.86E-10	7.78E-10	6.75E-10	5.80E-10	4.94E-10	4.18E-10	3.50E-10	2.89E-10	2.35E-10	1.86E-10	1.44E-10
PD-105	1.63E-07	1.66E-07	1.69E-07	1.71E-07	1.73E-07	1.75E-07	1.76E-07	1.77E-07	1.78E-07	1.79E-07	1.79E-07
PD-108	5.84E-08	5.96E-08	6.06E-08	6.15E-08	6.22E-08	6.29E-08	6.34E-08	6.38E-08	6.42E-08	6.45E-08	6.47E-08
AG-109	3.08E-08	3.14E-08	3.19E-08	3.24E-08	3.28E-08	3.31E-08	3.33E-08	3.36E-08	3.37E-08	3.39E-08	3.40E-08
CD-113	2.62E-11	2.63E-11	2.63E-11	2.63E-11	2.63E-11	2.63E-11	2.63E-11	2.63E-11	2.63E-11	2.63E-11	2.62E-11
I-131	7.17E-09	6.32E-09	5.49E-09	4.72E-09	4.02E-09	3.39E-09	2.85E-09	2.37E-09	1.95E-09	1.58E-09	1.26E-09
XE-131	2.01E-07	2.05E-07	2.08E-07	2.11E-07	2.13E-07	2.15E-07	2.16E-07	2.18E-07	2.19E-07	2.20E-07	2.20E-07
XE-133	9.72E-09	8.44E-09	7.25E-09	6.17E-09	5.21E-09	4.37E-09	3.65E-09	3.01E-09	2.46E-09	1.97E-09	1.55E-09
CS-133	5.20E-07	5.29E-07	5.36E-07	5.42E-07	5.48E-07	5.52E-07	5.56E-07	5.59E-07	5.61E-07	5.63E-07	5.65E-07
CS-134	3.52E-08	3.60E-08	3.66E-08	3.70E-08	3.74E-08	3.76E-08	3.78E-08	3.79E-08	3.79E-08	3.79E-08	3.78E-08
PR-141	4.83E-07	4.90E-07	4.95E-07	5.00E-07	5.04E-07	5.08E-07	5.10E-07	5.13E-07	5.15E-07	5.16E-07	5.17E-07
PR-143	2.23E-08	2.02E-08	1.80E-08	1.59E-08	1.38E-08	1.19E-08	1.02E-08	8.60E-09	7.21E-09	5.98E-09	4.89E-09
ND-143	3.16E-07	3.21E-07	3.26E-07	3.30E-07	3.34E-07	3.38E-07	3.41E-07	3.43E-07	3.45E-07	3.47E-07	3.49E-07
ND-144	5.74E-07	5.83E-07	5.91E-07	5.98E-07	6.04E-07	6.09E-07	6.13E-07	6.16E-07	6.19E-07	6.21E-07	6.23E-07
ND-145	2.96E-07	2.99E-07	3.03E-07	3.06E-07	3.08E-07	3.10E-07	3.11E-07	3.13E-07	3.14E-07	3.15E-07	3.15E-07
ND-146	2.74E-07	2.78E-07	2.81E-07	2.84E-07	2.87E-07	2.89E-07	2.91E-07	2.92E-07	2.93E-07	2.94E-07	2.95E-07
PM-147	9.98E-08	1.01E-07	1.01E-07	1.02E-07	1.02E-07	1.02E-07	1.02E-07	1.02E-07	1.02E-07	1.02E-07	1.01E-07
PM-148M	3.69E-10	3.68E-10	3.66E-10	3.62E-10	3.57E-10	3.50E-10	3.43E-10	3.33E-10	3.23E-10	3.10E-10	2.93E-10
PM-148	4.60E-10	4.25E-10	3.88E-10	3.50E-10	3.13E-10	2.76E-10	2.41E-10	2.07E-10	1.76E-10	1.45E-10	1.15E-10
SM-147	2.64E-08	2.68E-08	2.73E-08	2.78E-08	2.83E-08	2.89E-08	2.94E-08	2.99E-08	3.05E-08	3.11E-08	3.16E-08
SM-148	2.88E-08	2.94E-08	3.00E-08	3.05E-08	3.10E-08	3.14E-08	3.18E-08	3.21E-08	3.24E-08	3.26E-08	3.28E-08
PM-149	9.76E-10	8.39E-10	7.12E-10	5.99E-10	4.99E-10	4.13E-10	3.38E-10	2.74E-10	2.19E-10	1.70E-10	1.29E-10
SM-149	9.00E-10	8.99E-10	8.94E-10	8.87E-10	8.78E-10	8.68E-10	8.58E-10	8.49E-10	8.41E-10	8.35E-10	8.28E-10
SM-150	1.11E-07	1.13E-07	1.15E-07	1.16E-07	1.17E-07	1.18E-07	1.19E-07	1.19E-07	1.20E-07	1.20E-07	1.20E-07

	(fuel1,12)	(fuel1,13)	(fuel1,14)	(fuel1,15)	(fuel1,16)	(fuel1,17)	(fuel1,18)	(fuel1,19)	(fuel1,20)	(fuel1,21)	(fuel1,22)
PM-151	1.60E-10	1.37E-10	1.17E-10	9.92E-11	8.34E-11	6.96E-11	5.77E-11	4.73E-11	3.81E-11	2.98E-11	2.30E-11
SM-151	4.58E-09	4.63E-09	4.66E-09	4.69E-09	4.71E-09	4.72E-09	4.74E-09	4.75E-09	4.76E-09	4.76E-09	4.77E-09
SM-152	5.30E-08	5.38E-08	5.45E-08	5.50E-08	5.55E-08	5.59E-08	5.63E-08	5.65E-08	5.68E-08	5.69E-08	5.71E-08
EU-153	3.94E-08	4.01E-08	4.07E-08	4.13E-08	4.17E-08	4.21E-08	4.24E-08	4.27E-08	4.29E-08	4.31E-08	4.32E-08
EU-154	7.44E-09	7.61E-09	7.75E-09	7.87E-09	7.98E-09	8.07E-09	8.14E-09	8.20E-09	8.24E-09	8.28E-09	8.30E-09
EU-155	2.22E-09	2.25E-09	2.27E-09	2.29E-09	2.31E-09	2.32E-09	2.32E-09	2.32E-09	2.32E-09	2.31E-09	2.31E-09
GD-155	1.93E-11	2.21E-11	2.53E-11	2.91E-11	3.34E-11	3.84E-11	4.40E-11	5.04E-11	5.77E-11	6.60E-11	7.55E-11
GD-156	1.48E-08	1.52E-08	1.56E-08	1.59E-08	1.61E-08	1.63E-08	1.65E-08	1.67E-08	1.68E-08	1.69E-08	1.70E-08
GD-157	1.67E-11	1.69E-11	1.70E-11	1.71E-11	1.72E-11	1.72E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.72E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel2,1) – Fuel(2,11)

	(fuel2,1)	(fuel2,2)	(fuel2,3)	(fuel2,4)	(fuel2,5)	(fuel2,6)	(fuel2,7)	(fuel2,8)	(fuel2,9)	(fuel2,10)	(fuel2,11)
U-234	9.36E-08	9.34E-08	9.30E-08	9.25E-08	9.18E-08	9.11E-08	9.03E-08	8.96E-08	8.88E-08	8.82E-08	8.76E-08
U-235	5.81E-06	5.76E-06	5.68E-06	5.57E-06	5.43E-06	5.28E-06	5.12E-06	4.97E-06	4.83E-06	4.70E-06	4.59E-06
U-236	1.00E-06	1.01E-06	1.02E-06	1.04E-06	1.06E-06	1.09E-06	1.11E-06	1.14E-06	1.16E-06	1.18E-06	1.20E-06
U-237	4.16E-10	7.19E-10	1.18E-09	1.74E-09	2.32E-09	2.83E-09	3.19E-09	3.37E-09	3.38E-09	3.26E-09	3.05E-09
U-238	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04
U-239	5.46E-11	1.00E-10	1.52E-10	2.08E-10	2.56E-10	2.83E-10	2.91E-10	2.84E-10	2.66E-10	2.42E-10	2.15E-10
NP-237	4.08E-08	4.11E-08	4.15E-08	4.22E-08	4.32E-08	4.45E-08	4.61E-08	4.79E-08	4.98E-08	5.16E-08	5.33E-08
NP-238	5.05E-11	8.75E-11	1.37E-10	1.98E-10	2.59E-10	3.09E-10	3.43E-10	3.59E-10	3.59E-10	3.48E-10	3.27E-10
NP-239	6.26E-09	1.22E-08	1.93E-08	2.72E-08	3.44E-08	3.93E-08	4.14E-08	4.11E-08	3.91E-08	3.60E-08	3.23E-08
NP-240	5.13E-14	1.80E-13	4.25E-13	8.13E-13	1.25E-12	1.57E-12	1.69E-12	1.63E-12	1.45E-12	1.21E-12	9.65E-13
PU-238	1.30E-08	1.31E-08	1.33E-08	1.36E-08	1.40E-08	1.46E-08	1.52E-08	1.59E-08	1.66E-08	1.74E-08	1.81E-08
PU-239	4.45E-07	4.48E-07	4.56E-07	4.68E-07	4.83E-07	5.01E-07	5.19E-07	5.36E-07	5.50E-07	5.62E-07	5.71E-07
PU-240	2.41E-07	2.41E-07	2.42E-07	2.44E-07	2.48E-07	2.53E-07	2.59E-07	2.66E-07	2.73E-07	2.80E-07	2.86E-07
PU-241	1.58E-07	1.59E-07	1.60E-07	1.62E-07	1.66E-07	1.69E-07	1.74E-07	1.78E-07	1.83E-07	1.87E-07	1.91E-07
PU-242	1.01E-07	1.03E-07	1.04E-07	1.07E-07	1.11E-07	1.15E-07	1.20E-07	1.25E-07	1.30E-07	1.35E-07	1.39E-07

	(fuel2,1)	(fuel2,2)	(fuel2,3)	(fuel2,4)	(fuel2,5)	(fuel2,6)	(fuel2,7)	(fuel2,8)	(fuel2,9)	(fuel2,10)	(fuel2,11)
PU-243	1.21E-12	2.13E-12	3.24E-12	4.52E-12	5.69E-12	6.53E-12	6.99E-12	7.09E-12	6.91E-12	6.52E-12	5.99E-12
AM-241	3.05E-09	3.15E-09	3.21E-09	3.22E-09	3.18E-09	3.11E-09	3.03E-09	2.95E-09	2.90E-09	2.86E-09	2.85E-09
AM-242M	6.66E-11	6.70E-11	6.84E-11	7.08E-11	7.39E-11	7.67E-11	7.87E-11	7.98E-11	8.04E-11	8.08E-11	8.11E-11
AM-242	4.66E-12	8.31E-12	1.30E-11	1.84E-11	2.30E-11	2.56E-11	2.63E-11	2.55E-11	2.39E-11	2.18E-11	1.96E-11
AM-243	1.95E-09	1.99E-09	2.04E-09	2.13E-09	2.23E-09	2.36E-09	2.50E-09	2.64E-09	2.78E-09	2.92E-09	3.04E-09
AM-244	6.18E-13	1.08E-12	1.67E-12	2.38E-12	3.06E-12	3.60E-12	3.94E-12	4.09E-12	4.06E-12	3.90E-12	3.63E-12
CM-242	1.30E-09	1.30E-09	1.32E-09	1.38E-09	1.46E-09	1.57E-09	1.69E-09	1.81E-09	1.91E-09	2.00E-09	2.07E-09
CM-243	2.50E-11	2.54E-11	2.60E-11	2.69E-11	2.81E-11	2.96E-11	3.14E-11	3.33E-11	3.52E-11	3.71E-11	3.88E-11
CM-244	4.73E-10	4.82E-10	4.99E-10	5.23E-10	5.56E-10	5.97E-10	6.43E-10	6.93E-10	7.44E-10	7.93E-10	8.40E-10
XE-135	7.08E-11	8.37E-11	9.24E-11	9.88E-11	1.03E-10	1.06E-10	1.08E-10	1.08E-10	1.08E-10	1.07E-10	1.05E-10
XE-136	7.98E-07	8.05E-07	8.15E-07	8.31E-07	8.51E-07	8.73E-07	8.98E-07	9.22E-07	9.45E-07	9.66E-07	9.84E-07
KR-83	2.51E-08	2.53E-08	2.56E-08	2.60E-08	2.65E-08	2.71E-08	2.77E-08	2.83E-08	2.88E-08	2.93E-08	2.97E-08
ZR-95	4.68E-08	4.64E-08	4.78E-08	5.12E-08	5.62E-08	6.21E-08	6.80E-08	7.33E-08	7.76E-08	8.06E-08	8.24E-08
MO-95	3.48E-07	3.52E-07	3.56E-07	3.59E-07	3.64E-07	3.68E-07	3.73E-07	3.78E-07	3.84E-07	3.90E-07	3.97E-07
MO-97	3.89E-07	3.92E-07	3.98E-07	4.05E-07	4.14E-07	4.25E-07	4.36E-07	4.47E-07	4.57E-07	4.67E-07	4.76E-07
TC-99	3.84E-07	3.88E-07	3.93E-07	4.00E-07	4.08E-07	4.18E-07	4.29E-07	4.39E-07	4.49E-07	4.58E-07	4.66E-07
RU-101	3.46E-07	3.48E-07	3.53E-07	3.60E-07	3.68E-07	3.77E-07	3.87E-07	3.97E-07	4.07E-07	4.16E-07	4.23E-07
RU-103	1.70E-08	1.70E-08	1.82E-08	2.06E-08	2.41E-08	2.82E-08	3.21E-08	3.56E-08	3.84E-08	4.02E-08	4.11E-08
RH-103	1.77E-07	1.79E-07	1.80E-07	1.81E-07	1.81E-07	1.82E-07	1.83E-07	1.84E-07	1.86E-07	1.89E-07	1.91E-07
RH-105	2.24E-10	3.85E-10	5.79E-10	7.97E-10	9.89E-10	1.12E-09	1.19E-09	1.19E-09	1.15E-09	1.08E-09	9.90E-10
PD-105	1.25E-07	1.26E-07	1.28E-07	1.30E-07	1.33E-07	1.37E-07	1.41E-07	1.45E-07	1.49E-07	1.53E-07	1.57E-07
PD-108	4.27E-08	4.31E-08	4.38E-08	4.47E-08	4.59E-08	4.74E-08	4.90E-08	5.07E-08	5.24E-08	5.40E-08	5.55E-08
AG-109	2.29E-08	2.30E-08	2.33E-08	2.38E-08	2.44E-08	2.51E-08	2.59E-08	2.68E-08	2.76E-08	2.85E-08	2.92E-08
CD-113	2.53E-11	2.54E-11	2.57E-11	2.62E-11	2.70E-11	2.78E-11	2.87E-11	2.94E-11	3.01E-11	3.08E-11	3.13E-11
I-131	1.21E-09	1.93E-09	3.00E-09	4.36E-09	5.79E-09	7.02E-09	7.86E-09	8.25E-09	8.23E-09	7.89E-09	7.33E-09
XE-131	1.65E-07	1.65E-07	1.66E-07	1.67E-07	1.69E-07	1.72E-07	1.75E-07	1.79E-07	1.83E-07	1.87E-07	1.91E-07
XE-133	1.82E-09	3.23E-09	5.10E-09	7.29E-09	9.44E-09	1.11E-08	1.20E-08	1.22E-08	1.19E-08	1.11E-08	1.01E-08
CS-133	4.16E-07	4.18E-07	4.21E-07	4.27E-07	4.34E-07	4.43E-07	4.53E-07	4.64E-07	4.75E-07	4.86E-07	4.95E-07
CS-134	2.53E-08	2.56E-08	2.61E-08	2.69E-08	2.80E-08	2.93E-08	3.07E-08	3.21E-08	3.34E-08	3.47E-08	3.58E-08
PR-141	3.79E-07	3.82E-07	3.87E-07	3.94E-07	4.03E-07	4.13E-07	4.24E-07	4.35E-07	4.45E-07	4.54E-07	4.62E-07
PR-143	4.08E-09	5.43E-09	7.82E-09	1.10E-08	1.47E-08	1.81E-08	2.07E-08	2.23E-08	2.29E-08	2.26E-08	2.16E-08

	(fuel2,1)	(fuel2,2)	(fuel2,3)	(fuel2,4)	(fuel2,5)	(fuel2,6)	(fuel2,7)	(fuel2,8)	(fuel2,9)	(fuel2,10)	(fuel2,11)
ND-143	2.74E-07	2.75E-07	2.76E-07	2.77E-07	2.79E-07	2.82E-07	2.86E-07	2.91E-07	2.96E-07	3.02E-07	3.07E-07
ND-144	4.37E-07	4.41E-07	4.47E-07	4.56E-07	4.68E-07	4.81E-07	4.94E-07	5.08E-07	5.21E-07	5.33E-07	5.44E-07
ND-145	2.33E-07	2.35E-07	2.38E-07	2.43E-07	2.48E-07	2.54E-07	2.60E-07	2.66E-07	2.72E-07	2.78E-07	2.82E-07
ND-146	2.12E-07	2.14E-07	2.17E-07	2.21E-07	2.26E-07	2.32E-07	2.39E-07	2.45E-07	2.51E-07	2.57E-07	2.62E-07
PM-147	7.92E-08	7.95E-08	8.02E-08	8.14E-08	8.30E-08	8.48E-08	8.67E-08	8.85E-08	9.01E-08	9.15E-08	9.27E-08
PM-148M	2.74E-10	3.16E-10	3.66E-10	4.02E-10	4.23E-10	4.37E-10	4.48E-10	4.56E-10	4.62E-10	4.66E-10	4.68E-10
PM-148	1.21E-10	2.08E-10	3.18E-10	4.30E-10	5.23E-10	5.84E-10	6.14E-10	6.19E-10	6.07E-10	5.82E-10	5.49E-10
SM-147	2.22E-08	2.26E-08	2.30E-08	2.33E-08	2.37E-08	2.40E-08	2.43E-08	2.46E-08	2.49E-08	2.52E-08	2.56E-08
SM-148	2.20E-08	2.23E-08	2.27E-08	2.32E-08	2.39E-08	2.47E-08	2.56E-08	2.65E-08	2.74E-08	2.82E-08	2.90E-08
PM-149	2.01E-10	3.71E-10	5.95E-10	8.59E-10	1.11E-09	1.28E-09	1.36E-09	1.36E-09	1.29E-09	1.19E-09	1.06E-09
SM-149	6.85E-10	6.18E-10	6.49E-10	7.18E-10	7.97E-10	8.69E-10	9.30E-10	9.77E-10	1.01E-09	1.04E-09	1.05E-09
SM-150	8.72E-08	8.77E-08	8.86E-08	8.99E-08	9.18E-08	9.41E-08	9.68E-08	9.95E-08	1.02E-07	1.05E-07	1.07E-07
PM-151	4.44E-11	7.67E-11	1.15E-10	1.58E-10	1.95E-10	2.18E-10	2.26E-10	2.22E-10	2.10E-10	1.92E-10	1.72E-10
SM-151	4.16E-09	4.13E-09	4.11E-09	4.13E-09	4.20E-09	4.31E-09	4.45E-09	4.60E-09	4.74E-09	4.86E-09	4.97E-09
SM-152	4.08E-08	4.12E-08	4.17E-08	4.23E-08	4.31E-08	4.40E-08	4.50E-08	4.60E-08	4.70E-08	4.79E-08	4.87E-08
EU-153	2.98E-08	3.01E-08	3.06E-08	3.13E-08	3.23E-08	3.34E-08	3.46E-08	3.57E-08	3.69E-08	3.80E-08	3.89E-08
EU-154	5.28E-09	5.35E-09	5.47E-09	5.64E-09	5.86E-09	6.12E-09	6.39E-09	6.68E-09	6.95E-09	7.21E-09	7.44E-09
EU-155	1.63E-09	1.64E-09	1.68E-09	1.73E-09	1.80E-09	1.89E-09	1.98E-09	2.07E-09	2.15E-09	2.23E-09	2.29E-09
GD-155	6.16E-11	5.37E-11	4.09E-11	2.86E-11	2.03E-11	1.64E-11	1.52E-11	1.56E-11	1.68E-11	1.88E-11	2.12E-11
GD-156	9.88E-09	1.00E-08	1.02E-08	1.05E-08	1.09E-08	1.13E-08	1.18E-08	1.23E-08	1.28E-08	1.32E-08	1.37E-08
GD-157	1.43E-11	1.28E-11	1.30E-11	1.39E-11	1.50E-11	1.61E-11	1.72E-11	1.81E-11	1.90E-11	1.97E-11	2.03E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel2,12) – Fuel(2,22)

	(fuel2,12)	(fuel2,13)	(fuel2,14)	(fuel2,15)	(fuel2,16)	(fuel2,17)	(fuel2,18)	(fuel2,19)	(fuel2,20)	(fuel2,21)	(fuel2,22)
U-234	8.71E-08	8.66E-08	8.62E-08	8.59E-08	8.56E-08	8.54E-08	8.52E-08	8.51E-08	8.50E-08	8.49E-08	8.48E-08
U-235	4.49E-06	4.41E-06	4.34E-06	4.28E-06	4.23E-06	4.19E-06	4.16E-06	4.13E-06	4.11E-06	4.09E-06	4.08E-06
U-236	1.21E-06	1.22E-06	1.23E-06	1.24E-06	1.25E-06	1.26E-06	1.26E-06	1.27E-06	1.27E-06	1.27E-06	1.27E-06
U-237	2.78E-09	2.49E-09	2.19E-09	1.90E-09	1.64E-09	1.40E-09	1.18E-09	9.85E-10	8.13E-10	6.59E-10	5.09E-10
U-238	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04
U-239	1.88E-10	1.62E-10	1.39E-10	1.17E-10	9.87E-11	8.25E-11	6.84E-11	5.60E-11	4.50E-11	3.51E-11	2.43E-11
NP-237	5.49E-08	5.64E-08	5.77E-08	5.88E-08	5.98E-08	6.06E-08	6.13E-08	6.19E-08	6.24E-08	6.29E-08	6.32E-08
NP-238	2.99E-10	2.69E-10	2.38E-10	2.08E-10	1.80E-10	1.53E-10	1.30E-10	1.08E-10	8.83E-11	7.03E-11	5.52E-11
NP-239	2.84E-08	2.46E-08	2.11E-08	1.80E-08	1.52E-08	1.27E-08	1.06E-08	8.69E-09	7.03E-09	5.55E-09	4.03E-09
NP-240	7.42E-13	5.55E-13	4.06E-13	2.93E-13	2.08E-13	1.46E-13	1.00E-13	6.77E-14	4.41E-14	2.71E-14	1.42E-14
PU-238	1.88E-08	1.94E-08	1.99E-08	2.04E-08	2.09E-08	2.13E-08	2.16E-08	2.19E-08	2.22E-08	2.24E-08	2.26E-08
PU-239	5.78E-07	5.84E-07	5.88E-07	5.92E-07	5.94E-07	5.96E-07	5.98E-07	5.99E-07	6.00E-07	6.01E-07	6.02E-07
PU-240	2.92E-07	2.96E-07	3.01E-07	3.04E-07	3.07E-07	3.10E-07	3.12E-07	3.13E-07	3.15E-07	3.16E-07	3.17E-07
PU-241	1.95E-07	1.99E-07	2.02E-07	2.04E-07	2.06E-07	2.08E-07	2.10E-07	2.11E-07	2.12E-07	2.12E-07	2.13E-07
PU-242	1.43E-07	1.47E-07	1.50E-07	1.52E-07	1.55E-07	1.56E-07	1.58E-07	1.59E-07	1.61E-07	1.61E-07	1.62E-07
PU-243	5.40E-12	4.78E-12	4.18E-12	3.61E-12	3.09E-12	2.62E-12	2.19E-12	1.81E-12	1.47E-12	1.16E-12	8.80E-13
AM-241	2.87E-09	2.91E-09	2.98E-09	3.06E-09	3.17E-09	3.29E-09	3.42E-09	3.57E-09	3.73E-09	3.90E-09	4.09E-09
AM-242M	8.16E-11	8.24E-11	8.34E-11	8.45E-11	8.59E-11	8.74E-11	8.90E-11	9.07E-11	9.23E-11	9.38E-11	9.52E-11
AM-242	1.74E-11	1.54E-11	1.36E-11	1.19E-11	1.04E-11	9.09E-12	7.87E-12	6.75E-12	5.69E-12	4.67E-12	3.86E-12
AM-243	3.16E-09	3.26E-09	3.34E-09	3.42E-09	3.49E-09	3.54E-09	3.59E-09	3.63E-09	3.66E-09	3.69E-09	3.71E-09
AM-244	3.31E-12	2.96E-12	2.60E-12	2.26E-12	1.94E-12	1.65E-12	1.39E-12	1.15E-12	9.34E-13	7.34E-13	5.72E-13
CM-242	2.12E-09	2.16E-09	2.18E-09	2.19E-09	2.20E-09	2.19E-09	2.17E-09	2.15E-09	2.12E-09	2.08E-09	2.04E-09
CM-243	4.03E-11	4.17E-11	4.28E-11	4.37E-11	4.45E-11	4.52E-11	4.57E-11	4.61E-11	4.64E-11	4.67E-11	4.68E-11
CM-244	8.83E-10	9.21E-10	9.56E-10	9.85E-10	1.01E-09	1.03E-09	1.05E-09	1.07E-09	1.08E-09	1.09E-09	1.10E-09
XE-135	1.03E-10	1.00E-10	9.70E-11	9.31E-11	8.88E-11	8.39E-11	7.85E-11	7.25E-11	6.57E-11	5.81E-11	5.06E-11
XE-136	1.00E-06	1.01E-06	1.03E-06	1.04E-06	1.04E-06	1.05E-06	1.06E-06	1.06E-06	1.06E-06	1.07E-06	1.07E-06
KR-83	3.01E-08	3.04E-08	3.06E-08	3.09E-08	3.10E-08	3.12E-08	3.13E-08	3.14E-08	3.15E-08	3.16E-08	3.16E-08
ZR-95	8.30E-08	8.25E-08	8.12E-08	7.91E-08	7.65E-08	7.35E-08	7.02E-08	6.67E-08	6.30E-08	5.93E-08	5.55E-08

	(fuel2,12)	(fuel2,13)	(fuel2,14)	(fuel2,15)	(fuel2,16)	(fuel2,17)	(fuel2,18)	(fuel2,19)	(fuel2,20)	(fuel2,21)	(fuel2,22)
MO-95	4.03E-07	4.10E-07	4.17E-07	4.23E-07	4.30E-07	4.36E-07	4.42E-07	4.47E-07	4.53E-07	4.58E-07	4.63E-07
MO-97	4.83E-07	4.90E-07	4.95E-07	5.00E-07	5.04E-07	5.07E-07	5.10E-07	5.12E-07	5.14E-07	5.16E-07	5.17E-07
TC-99	4.74E-07	4.80E-07	4.85E-07	4.89E-07	4.93E-07	4.96E-07	4.99E-07	5.01E-07	5.03E-07	5.04E-07	5.05E-07
RU-101	4.30E-07	4.36E-07	4.41E-07	4.46E-07	4.49E-07	4.52E-07	4.55E-07	4.57E-07	4.59E-07	4.60E-07	4.61E-07
RU-103	4.12E-08	4.06E-08	3.94E-08	3.77E-08	3.58E-08	3.36E-08	3.13E-08	2.89E-08	2.65E-08	2.42E-08	2.19E-08
RH-103	1.95E-07	1.98E-07	2.02E-07	2.06E-07	2.09E-07	2.13E-07	2.16E-07	2.20E-07	2.23E-07	2.26E-07	2.29E-07
RH-105	8.88E-10	7.84E-10	6.84E-10	5.90E-10	5.05E-10	4.28E-10	3.59E-10	2.97E-10	2.42E-10	1.91E-10	1.51E-10
PD-105	1.60E-07	1.63E-07	1.66E-07	1.68E-07	1.70E-07	1.72E-07	1.73E-07	1.74E-07	1.75E-07	1.76E-07	1.77E-07
PD-108	5.68E-08	5.80E-08	5.90E-08	5.99E-08	6.07E-08	6.13E-08	6.18E-08	6.23E-08	6.27E-08	6.29E-08	6.32E-08
AG-109	2.99E-08	3.05E-08	3.10E-08	3.14E-08	3.18E-08	3.21E-08	3.24E-08	3.26E-08	3.28E-08	3.30E-08	3.31E-08
CD-113	3.17E-11	3.20E-11	3.23E-11	3.26E-11	3.27E-11	3.29E-11	3.30E-11	3.31E-11	3.32E-11	3.32E-11	3.32E-11
I-131	6.64E-09	5.90E-09	5.17E-09	4.47E-09	3.82E-09	3.24E-09	2.73E-09	2.28E-09	1.88E-09	1.53E-09	1.22E-09
XE-131	1.94E-07	1.97E-07	2.00E-07	2.02E-07	2.04E-07	2.06E-07	2.08E-07	2.09E-07	2.10E-07	2.11E-07	2.12E-07
XE-133	8.97E-09	7.85E-09	6.78E-09	5.80E-09	4.92E-09	4.14E-09	3.46E-09	2.87E-09	2.35E-09	1.88E-09	1.49E-09
CS-133	5.04E-07	5.12E-07	5.18E-07	5.24E-07	5.29E-07	5.33E-07	5.36E-07	5.39E-07	5.42E-07	5.44E-07	5.45E-07
CS-134	3.68E-08	3.76E-08	3.82E-08	3.88E-08	3.92E-08	3.95E-08	3.97E-08	3.98E-08	3.98E-08	3.98E-08	3.97E-08
PR-141	4.70E-07	4.76E-07	4.81E-07	4.86E-07	4.90E-07	4.93E-07	4.95E-07	4.98E-07	4.99E-07	5.01E-07	5.02E-07
PR-143	2.01E-08	1.83E-08	1.64E-08	1.45E-08	1.27E-08	1.10E-08	9.42E-09	8.00E-09	6.73E-09	5.59E-09	4.60E-09
ND-143	3.13E-07	3.18E-07	3.23E-07	3.27E-07	3.31E-07	3.34E-07	3.37E-07	3.40E-07	3.42E-07	3.44E-07	3.45E-07
ND-144	5.53E-07	5.62E-07	5.69E-07	5.75E-07	5.80E-07	5.84E-07	5.88E-07	5.91E-07	5.93E-07	5.95E-07	5.97E-07
ND-145	2.87E-07	2.90E-07	2.93E-07	2.96E-07	2.98E-07	3.00E-07	3.01E-07	3.03E-07	3.04E-07	3.04E-07	3.05E-07
ND-146	2.66E-07	2.70E-07	2.74E-07	2.76E-07	2.79E-07	2.81E-07	2.82E-07	2.84E-07	2.85E-07	2.86E-07	2.86E-07
PM-147	9.36E-08	9.43E-08	9.49E-08	9.52E-08	9.54E-08	9.55E-08	9.54E-08	9.53E-08	9.51E-08	9.48E-08	9.45E-08
PM-148M	4.67E-10	4.65E-10	4.60E-10	4.54E-10	4.46E-10	4.36E-10	4.25E-10	4.11E-10	3.96E-10	3.79E-10	3.56E-10
PM-148	5.10E-10	4.67E-10	4.23E-10	3.79E-10	3.35E-10	2.94E-10	2.55E-10	2.18E-10	1.84E-10	1.52E-10	1.19E-10
SM-147	2.60E-08	2.64E-08	2.68E-08	2.73E-08	2.78E-08	2.82E-08	2.87E-08	2.92E-08	2.98E-08	3.03E-08	3.08E-08
SM-148	2.98E-08	3.05E-08	3.11E-08	3.17E-08	3.22E-08	3.26E-08	3.30E-08	3.34E-08	3.37E-08	3.39E-08	3.42E-08
PM-149	9.32E-10	8.03E-10	6.83E-10	5.75E-10	4.80E-10	3.97E-10	3.25E-10	2.64E-10	2.10E-10	1.63E-10	1.26E-10
SM-149	1.06E-09	1.07E-09	1.06E-09	1.06E-09	1.05E-09	1.04E-09	1.03E-09	1.02E-09	1.02E-09	1.01E-09	9.99E-10
SM-150	1.09E-07	1.11E-07	1.12E-07	1.14E-07	1.15E-07	1.16E-07	1.16E-07	1.17E-07	1.17E-07	1.18E-07	1.18E-07

	(fuel2,12)	(fuel2,13)	(fuel2,14)	(fuel2,15)	(fuel2,16)	(fuel2,17)	(fuel2,18)	(fuel2,19)	(fuel2,20)	(fuel2,21)	(fuel2,22)
PM-151	1.51E-10	1.31E-10	1.13E-10	9.58E-11	8.09E-11	6.78E-11	5.64E-11	4.63E-11	3.74E-11	2.94E-11	2.31E-11
SM-151	5.06E-09	5.14E-09	5.20E-09	5.25E-09	5.30E-09	5.33E-09	5.36E-09	5.38E-09	5.40E-09	5.42E-09	5.43E-09
SM-152	4.94E-08	5.00E-08	5.06E-08	5.11E-08	5.15E-08	5.18E-08	5.21E-08	5.23E-08	5.25E-08	5.27E-08	5.28E-08
EU-153	3.98E-08	4.06E-08	4.12E-08	4.18E-08	4.22E-08	4.26E-08	4.30E-08	4.32E-08	4.35E-08	4.36E-08	4.38E-08
EU-154	7.65E-09	7.83E-09	7.99E-09	8.12E-09	8.23E-09	8.33E-09	8.40E-09	8.47E-09	8.51E-09	8.55E-09	8.58E-09
EU-155	2.35E-09	2.40E-09	2.43E-09	2.46E-09	2.49E-09	2.50E-09	2.51E-09	2.52E-09	2.52E-09	2.51E-09	2.51E-09
GD-155	2.43E-11	2.79E-11	3.21E-11	3.69E-11	4.24E-11	4.86E-11	5.56E-11	6.35E-11	7.24E-11	8.24E-11	9.35E-11
GD-156	1.41E-08	1.44E-08	1.47E-08	1.50E-08	1.52E-08	1.54E-08	1.56E-08	1.57E-08	1.58E-08	1.59E-08	1.60E-08
GD-157	2.09E-11	2.13E-11	2.16E-11	2.19E-11	2.21E-11	2.23E-11	2.24E-11	2.26E-11	2.26E-11	2.27E-11	2.26E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel3,1) – Fuel(3,11)

	(fuel3,1)	(fuel3,2)	(fuel3,3)	(fuel3,4)	(fuel3,5)	(fuel3,6)	(fuel3,7)	(fuel3,8)	(fuel3,9)	(fuel3,10)	(fuel3,11)
U-234	9.36E-08	9.34E-08	9.31E-08	9.26E-08	9.19E-08	9.12E-08	9.04E-08	8.97E-08	8.90E-08	8.83E-08	8.77E-08
U-235	5.82E-06	5.77E-06	5.70E-06	5.60E-06	5.47E-06	5.33E-06	5.18E-06	5.03E-06	4.90E-06	4.78E-06	4.67E-06
U-236	1.00E-06	1.01E-06	1.02E-06	1.04E-06	1.06E-06	1.08E-06	1.10E-06	1.13E-06	1.15E-06	1.17E-06	1.18E-06
U-237	4.10E-10	7.02E-10	1.15E-09	1.73E-09	2.34E-09	2.88E-09	3.25E-09	3.43E-09	3.45E-09	3.33E-09	3.11E-09
U-238	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04
U-239	5.22E-11	9.61E-11	1.48E-10	2.08E-10	2.58E-10	2.87E-10	2.96E-10	2.89E-10	2.71E-10	2.46E-10	2.19E-10
NP-237	4.08E-08	4.11E-08	4.15E-08	4.23E-08	4.33E-08	4.47E-08	4.64E-08	4.83E-08	5.03E-08	5.22E-08	5.41E-08
NP-238	4.50E-11	7.60E-11	1.21E-10	1.80E-10	2.40E-10	2.89E-10	3.21E-10	3.37E-10	3.38E-10	3.27E-10	3.08E-10
NP-239	6.02E-09	1.17E-08	1.88E-08	2.70E-08	3.46E-08	3.98E-08	4.21E-08	4.18E-08	3.98E-08	3.66E-08	3.28E-08
NP-240	4.60E-14	1.62E-13	3.94E-13	7.90E-13	1.25E-12	1.58E-12	1.71E-12	1.65E-12	1.47E-12	1.23E-12	9.80E-13
PU-238	1.30E-08	1.31E-08	1.33E-08	1.35E-08	1.39E-08	1.44E-08	1.50E-08	1.57E-08	1.64E-08	1.71E-08	1.78E-08
PU-239	4.45E-07	4.50E-07	4.61E-07	4.76E-07	4.95E-07	5.18E-07	5.41E-07	5.63E-07	5.81E-07	5.97E-07	6.09E-07
PU-240	2.41E-07	2.41E-07	2.42E-07	2.44E-07	2.47E-07	2.52E-07	2.59E-07	2.66E-07	2.74E-07	2.81E-07	2.88E-07
PU-241	1.57E-07	1.58E-07	1.60E-07	1.62E-07	1.65E-07	1.68E-07	1.72E-07	1.77E-07	1.81E-07	1.86E-07	1.90E-07

	(fuel3,1)	(fuel3,2)	(fuel3,3)	(fuel3,4)	(fuel3,5)	(fuel3,6)	(fuel3,7)	(fuel3,8)	(fuel3,9)	(fuel3,10)	(fuel3,11)
PU-242	1.01E-07	1.02E-07	1.04E-07	1.06E-07	1.10E-07	1.14E-07	1.18E-07	1.23E-07	1.27E-07	1.32E-07	1.36E-07
PU-243	1.08E-12	1.89E-12	2.93E-12	4.22E-12	5.37E-12	6.17E-12	6.58E-12	6.66E-12	6.47E-12	6.09E-12	5.59E-12
AM-241	3.05E-09	3.16E-09	3.24E-09	3.26E-09	3.24E-09	3.19E-09	3.12E-09	3.05E-09	3.01E-09	2.98E-09	2.98E-09
AM-242M	6.66E-11	6.69E-11	6.81E-11	7.05E-11	7.36E-11	7.67E-11	7.91E-11	8.07E-11	8.18E-11	8.25E-11	8.32E-11
AM-242	3.98E-12	7.08E-12	1.14E-11	1.68E-11	2.14E-11	2.41E-11	2.49E-11	2.42E-11	2.27E-11	2.08E-11	1.88E-11
AM-243	1.95E-09	1.98E-09	2.03E-09	2.11E-09	2.21E-09	2.33E-09	2.46E-09	2.60E-09	2.73E-09	2.86E-09	2.97E-09
AM-244	5.37E-13	9.41E-13	1.48E-12	2.18E-12	2.85E-12	3.36E-12	3.68E-12	3.81E-12	3.78E-12	3.62E-12	3.37E-12
CM-242	1.30E-09	1.29E-09	1.30E-09	1.35E-09	1.43E-09	1.53E-09	1.64E-09	1.74E-09	1.84E-09	1.92E-09	1.99E-09
CM-243	2.50E-11	2.53E-11	2.59E-11	2.68E-11	2.81E-11	2.96E-11	3.13E-11	3.32E-11	3.50E-11	3.69E-11	3.85E-11
CM-244	4.72E-10	4.81E-10	4.95E-10	5.16E-10	5.47E-10	5.84E-10	6.28E-10	6.74E-10	7.21E-10	7.66E-10	8.09E-10
XE-135	6.71E-11	8.06E-11	9.04E-11	9.80E-11	1.03E-10	1.06E-10	1.08E-10	1.09E-10	1.10E-10	1.09E-10	1.07E-10
XE-136	7.98E-07	8.03E-07	8.13E-07	8.26E-07	8.44E-07	8.66E-07	8.89E-07	9.11E-07	9.33E-07	9.53E-07	9.70E-07
KR-83	2.51E-08	2.53E-08	2.55E-08	2.59E-08	2.64E-08	2.69E-08	2.75E-08	2.80E-08	2.85E-08	2.90E-08	2.94E-08
ZR-95	4.67E-08	4.57E-08	4.66E-08	4.93E-08	5.38E-08	5.93E-08	6.48E-08	6.98E-08	7.38E-08	7.67E-08	7.84E-08
MO-95	3.48E-07	3.52E-07	3.56E-07	3.59E-07	3.63E-07	3.67E-07	3.72E-07	3.77E-07	3.83E-07	3.89E-07	3.95E-07
MO-97	3.89E-07	3.92E-07	3.96E-07	4.03E-07	4.11E-07	4.21E-07	4.32E-07	4.42E-07	4.52E-07	4.61E-07	4.69E-07
TC-99	3.84E-07	3.87E-07	3.91E-07	3.97E-07	4.06E-07	4.15E-07	4.25E-07	4.35E-07	4.44E-07	4.52E-07	4.60E-07
RU-101	3.45E-07	3.48E-07	3.52E-07	3.58E-07	3.65E-07	3.74E-07	3.84E-07	3.93E-07	4.02E-07	4.10E-07	4.18E-07
RU-103	1.69E-08	1.66E-08	1.74E-08	1.95E-08	2.27E-08	2.64E-08	3.02E-08	3.36E-08	3.62E-08	3.80E-08	3.89E-08
RH-103	1.77E-07	1.79E-07	1.80E-07	1.81E-07	1.81E-07	1.82E-07	1.83E-07	1.84E-07	1.86E-07	1.89E-07	1.91E-07
RH-105	1.95E-10	3.32E-10	5.11E-10	7.30E-10	9.27E-10	1.06E-09	1.13E-09	1.14E-09	1.11E-09	1.04E-09	9.55E-10
PD-105	1.25E-07	1.26E-07	1.27E-07	1.30E-07	1.32E-07	1.36E-07	1.40E-07	1.44E-07	1.48E-07	1.51E-07	1.55E-07
PD-108	4.27E-08	4.31E-08	4.36E-08	4.44E-08	4.55E-08	4.69E-08	4.84E-08	5.00E-08	5.16E-08	5.32E-08	5.46E-08
AG-109	2.28E-08	2.30E-08	2.33E-08	2.36E-08	2.42E-08	2.49E-08	2.56E-08	2.64E-08	2.72E-08	2.80E-08	2.87E-08
CD-113	2.53E-11	2.55E-11	2.58E-11	2.64E-11	2.73E-11	2.82E-11	2.92E-11	3.01E-11	3.10E-11	3.17E-11	3.24E-11
I-131	1.14E-09	1.70E-09	2.64E-09	3.90E-09	5.30E-09	6.52E-09	7.36E-09	7.77E-09	7.78E-09	7.48E-09	6.97E-09
XE-131	1.65E-07	1.65E-07	1.66E-07	1.67E-07	1.69E-07	1.71E-07	1.74E-07	1.77E-07	1.81E-07	1.85E-07	1.88E-07
XE-133	1.66E-09	2.81E-09	4.46E-09	6.56E-09	8.69E-09	1.04E-08	1.13E-08	1.15E-08	1.12E-08	1.05E-08	9.59E-09
CS-133	4.16E-07	4.18E-07	4.20E-07	4.25E-07	4.32E-07	4.40E-07	4.50E-07	4.60E-07	4.70E-07	4.80E-07	4.89E-07
CS-134	2.53E-08	2.55E-08	2.60E-08	2.68E-08	2.79E-08	2.92E-08	3.06E-08	3.20E-08	3.33E-08	3.46E-08	3.57E-08
PR-141	3.79E-07	3.81E-07	3.86E-07	3.92E-07	4.00E-07	4.10E-07	4.20E-07	4.30E-07	4.40E-07	4.49E-07	4.57E-07

	(fuel3,1)	(fuel3,2)	(fuel3,3)	(fuel3,4)	(fuel3,5)	(fuel3,6)	(fuel3,7)	(fuel3,8)	(fuel3,9)	(fuel3,10)	(fuel3,11)
PR-143	3.93E-09	4.95E-09	6.97E-09	9.93E-09	1.34E-08	1.67E-08	1.93E-08	2.09E-08	2.16E-08	2.13E-08	2.04E-08
ND-143	2.74E-07	2.75E-07	2.76E-07	2.77E-07	2.79E-07	2.82E-07	2.85E-07	2.90E-07	2.95E-07	3.00E-07	3.06E-07
ND-144	4.37E-07	4.40E-07	4.46E-07	4.54E-07	4.64E-07	4.76E-07	4.89E-07	5.02E-07	5.14E-07	5.26E-07	5.36E-07
ND-145	2.33E-07	2.35E-07	2.38E-07	2.41E-07	2.46E-07	2.52E-07	2.58E-07	2.64E-07	2.69E-07	2.74E-07	2.79E-07
ND-146	2.12E-07	2.13E-07	2.16E-07	2.20E-07	2.25E-07	2.30E-07	2.37E-07	2.43E-07	2.48E-07	2.54E-07	2.59E-07
PM-147	7.91E-08	7.93E-08	7.98E-08	8.07E-08	8.21E-08	8.37E-08	8.54E-08	8.70E-08	8.84E-08	8.97E-08	9.07E-08
PM-148M	2.76E-10	3.24E-10	3.83E-10	4.26E-10	4.50E-10	4.64E-10	4.75E-10	4.83E-10	4.89E-10	4.93E-10	4.94E-10
PM-148	1.17E-10	1.99E-10	3.08E-10	4.25E-10	5.26E-10	5.92E-10	6.24E-10	6.29E-10	6.16E-10	5.90E-10	5.55E-10
SM-147	2.22E-08	2.26E-08	2.30E-08	2.34E-08	2.37E-08	2.40E-08	2.42E-08	2.45E-08	2.49E-08	2.52E-08	2.55E-08
SM-148	2.20E-08	2.23E-08	2.26E-08	2.32E-08	2.39E-08	2.47E-08	2.56E-08	2.65E-08	2.74E-08	2.82E-08	2.91E-08
PM-149	1.77E-10	3.20E-10	5.24E-10	7.88E-10	1.04E-09	1.21E-09	1.29E-09	1.29E-09	1.23E-09	1.14E-09	1.02E-09
SM-149	7.06E-10	6.35E-10	6.51E-10	7.16E-10	8.03E-10	8.85E-10	9.51E-10	1.00E-09	1.04E-09	1.07E-09	1.09E-09
SM-150	8.71E-08	8.76E-08	8.84E-08	8.96E-08	9.13E-08	9.34E-08	9.59E-08	9.86E-08	1.01E-07	1.04E-07	1.06E-07
PM-151	3.83E-11	6.59E-11	1.01E-10	1.44E-10	1.82E-10	2.05E-10	2.13E-10	2.10E-10	1.99E-10	1.83E-10	1.64E-10
SM-151	4.17E-09	4.14E-09	4.14E-09	4.15E-09	4.22E-09	4.34E-09	4.48E-09	4.64E-09	4.79E-09	4.92E-09	5.04E-09
SM-152	4.08E-08	4.11E-08	4.14E-08	4.20E-08	4.27E-08	4.35E-08	4.43E-08	4.52E-08	4.61E-08	4.69E-08	4.76E-08
EU-153	2.98E-08	3.01E-08	3.05E-08	3.12E-08	3.22E-08	3.32E-08	3.44E-08	3.56E-08	3.67E-08	3.77E-08	3.87E-08
EU-154	5.28E-09	5.34E-09	5.45E-09	5.62E-09	5.84E-09	6.09E-09	6.37E-09	6.65E-09	6.93E-09	7.18E-09	7.41E-09
EU-155	1.63E-09	1.64E-09	1.67E-09	1.72E-09	1.79E-09	1.87E-09	1.96E-09	2.05E-09	2.14E-09	2.22E-09	2.29E-09
GD-155	6.27E-11	5.71E-11	4.56E-11	3.27E-11	2.31E-11	1.82E-11	1.65E-11	1.67E-11	1.80E-11	2.00E-11	2.26E-11
GD-156	9.87E-09	9.99E-09	1.02E-08	1.04E-08	1.08E-08	1.12E-08	1.16E-08	1.21E-08	1.25E-08	1.30E-08	1.34E-08
GD-157	1.45E-11	1.31E-11	1.32E-11	1.41E-11	1.52E-11	1.64E-11	1.75E-11	1.86E-11	1.95E-11	2.04E-11	2.11E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel3,12) – Fuel(3,22)

	(fuel3,12)	(fuel3,13)	(fuel3,14)	(fuel3,15)	(fuel3,16)	(fuel3,17)	(fuel3,18)	(fuel3,19)	(fuel3,20)	(fuel3,21)	(fuel3,22)
U-234	8.72E-08	8.68E-08	8.64E-08	8.61E-08	8.58E-08	8.56E-08	8.54E-08	8.53E-08	8.52E-08	8.51E-08	8.50E-08
U-235	4.58E-06	4.50E-06	4.44E-06	4.38E-06	4.34E-06	4.30E-06	4.27E-06	4.24E-06	4.22E-06	4.20E-06	4.19E-06
U-236	1.20E-06	1.21E-06	1.22E-06	1.23E-06	1.23E-06	1.24E-06	1.25E-06	1.25E-06	1.25E-06	1.25E-06	1.26E-06
U-237	2.84E-09	2.54E-09	2.23E-09	1.94E-09	1.67E-09	1.42E-09	1.20E-09	1.00E-09	8.28E-10	6.71E-10	5.18E-10
U-238	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04
U-239	1.91E-10	1.65E-10	1.41E-10	1.20E-10	1.01E-10	8.41E-11	6.97E-11	5.71E-11	4.59E-11	3.57E-11	2.47E-11
NP-237	5.58E-08	5.73E-08	5.87E-08	5.99E-08	6.09E-08	6.18E-08	6.25E-08	6.32E-08	6.37E-08	6.41E-08	6.45E-08
NP-238	2.82E-10	2.54E-10	2.25E-10	1.97E-10	1.70E-10	1.45E-10	1.23E-10	1.02E-10	8.38E-11	6.67E-11	5.25E-11
NP-239	2.89E-08	2.51E-08	2.15E-08	1.83E-08	1.54E-08	1.29E-08	1.08E-08	8.86E-09	7.17E-09	5.66E-09	4.11E-09
NP-240	7.54E-13	5.64E-13	4.13E-13	2.98E-13	2.12E-13	1.48E-13	1.02E-13	6.88E-14	4.48E-14	2.76E-14	1.43E-14
PU-238	1.84E-08	1.90E-08	1.96E-08	2.00E-08	2.05E-08	2.09E-08	2.12E-08	2.15E-08	2.17E-08	2.19E-08	2.21E-08
PU-239	6.19E-07	6.27E-07	6.34E-07	6.38E-07	6.42E-07	6.45E-07	6.48E-07	6.50E-07	6.51E-07	6.53E-07	6.54E-07
PU-240	2.94E-07	3.00E-07	3.04E-07	3.08E-07	3.12E-07	3.15E-07	3.17E-07	3.19E-07	3.20E-07	3.22E-07	3.23E-07
PU-241	1.94E-07	1.98E-07	2.01E-07	2.04E-07	2.06E-07	2.08E-07	2.09E-07	2.11E-07	2.12E-07	2.12E-07	2.13E-07
PU-242	1.39E-07	1.42E-07	1.45E-07	1.48E-07	1.50E-07	1.51E-07	1.53E-07	1.54E-07	1.55E-07	1.56E-07	1.57E-07
PU-243	5.02E-12	4.44E-12	3.87E-12	3.34E-12	2.86E-12	2.42E-12	2.03E-12	1.68E-12	1.36E-12	1.07E-12	8.13E-13
AM-241	3.00E-09	3.05E-09	3.12E-09	3.21E-09	3.32E-09	3.45E-09	3.58E-09	3.74E-09	3.90E-09	4.07E-09	4.26E-09
AM-242M	8.40E-11	8.50E-11	8.61E-11	8.74E-11	8.89E-11	9.05E-11	9.21E-11	9.37E-11	9.53E-11	9.68E-11	9.82E-11
AM-242	1.67E-11	1.48E-11	1.30E-11	1.14E-11	1.00E-11	8.72E-12	7.55E-12	6.47E-12	5.44E-12	4.46E-12	3.70E-12
AM-243	3.08E-09	3.17E-09	3.25E-09	3.32E-09	3.39E-09	3.44E-09	3.48E-09	3.52E-09	3.55E-09	3.57E-09	3.59E-09
AM-244	3.07E-12	2.74E-12	2.41E-12	2.09E-12	1.80E-12	1.53E-12	1.28E-12	1.06E-12	8.63E-13	6.79E-13	5.31E-13
CM-242	2.04E-09	2.08E-09	2.10E-09	2.11E-09	2.11E-09	2.10E-09	2.09E-09	2.07E-09	2.04E-09	2.00E-09	1.96E-09
CM-243	4.00E-11	4.13E-11	4.24E-11	4.34E-11	4.42E-11	4.48E-11	4.53E-11	4.57E-11	4.60E-11	4.62E-11	4.64E-11
CM-244	8.49E-10	8.85E-10	9.16E-10	9.44E-10	9.67E-10	9.87E-10	1.00E-09	1.02E-09	1.03E-09	1.04E-09	1.04E-09
XE-135	1.05E-10	1.02E-10	9.87E-11	9.47E-11	9.01E-11	8.50E-11	7.94E-11	7.31E-11	6.60E-11	5.80E-11	5.05E-11
XE-136	9.86E-07	9.99E-07	1.01E-06	1.02E-06	1.03E-06	1.03E-06	1.04E-06	1.04E-06	1.05E-06	1.05E-06	1.05E-06
KR-83	2.98E-08	3.01E-08	3.03E-08	3.05E-08	3.07E-08	3.08E-08	3.10E-08	3.11E-08	3.11E-08	3.12E-08	3.13E-08
ZR-95	7.89E-08	7.85E-08	7.73E-08	7.53E-08	7.29E-08	7.00E-08	6.69E-08	6.35E-08	6.00E-08	5.65E-08	5.29E-08
MO-95	4.01E-07	4.07E-07	4.14E-07	4.20E-07	4.26E-07	4.32E-07	4.37E-07	4.43E-07	4.48E-07	4.53E-07	4.58E-07
MO-97	4.77E-07	4.83E-07	4.88E-07	4.93E-07	4.97E-07	5.00E-07	5.02E-07	5.05E-07	5.06E-07	5.08E-07	5.09E-07

	(fuel3,12)	(fuel3,13)	(fuel3,14)	(fuel3,15)	(fuel3,16)	(fuel3,17)	(fuel3,18)	(fuel3,19)	(fuel3,20)	(fuel3,21)	(fuel3,22)
TC-99	4.67E-07	4.73E-07	4.78E-07	4.82E-07	4.85E-07	4.88E-07	4.91E-07	4.93E-07	4.95E-07	4.96E-07	4.97E-07
RU-101	4.24E-07	4.30E-07	4.35E-07	4.39E-07	4.42E-07	4.45E-07	4.48E-07	4.50E-07	4.52E-07	4.53E-07	4.54E-07
RU-103	3.91E-08	3.86E-08	3.75E-08	3.59E-08	3.41E-08	3.21E-08	2.99E-08	2.76E-08	2.54E-08	2.31E-08	2.10E-08
RH-103	1.95E-07	1.98E-07	2.02E-07	2.05E-07	2.09E-07	2.12E-07	2.15E-07	2.19E-07	2.22E-07	2.25E-07	2.27E-07
RH-105	8.58E-10	7.58E-10	6.62E-10	5.72E-10	4.89E-10	4.15E-10	3.48E-10	2.88E-10	2.35E-10	1.86E-10	1.48E-10
PD-105	1.58E-07	1.61E-07	1.64E-07	1.66E-07	1.68E-07	1.69E-07	1.71E-07	1.72E-07	1.73E-07	1.74E-07	1.74E-07
PD-108	5.58E-08	5.70E-08	5.80E-08	5.88E-08	5.95E-08	6.01E-08	6.07E-08	6.11E-08	6.14E-08	6.17E-08	6.19E-08
AG-109	2.93E-08	2.99E-08	3.04E-08	3.08E-08	3.12E-08	3.15E-08	3.17E-08	3.20E-08	3.21E-08	3.23E-08	3.24E-08
CD-113	3.29E-11	3.33E-11	3.37E-11	3.40E-11	3.42E-11	3.44E-11	3.46E-11	3.47E-11	3.48E-11	3.48E-11	3.49E-11
I-131	6.33E-09	5.64E-09	4.94E-09	4.28E-09	3.66E-09	3.11E-09	2.62E-09	2.19E-09	1.81E-09	1.47E-09	1.18E-09
XE-131	1.91E-07	1.94E-07	1.97E-07	1.99E-07	2.01E-07	2.03E-07	2.04E-07	2.06E-07	2.07E-07	2.07E-07	2.08E-07
XE-133	8.55E-09	7.49E-09	6.48E-09	5.55E-09	4.71E-09	3.97E-09	3.32E-09	2.75E-09	2.26E-09	1.81E-09	1.44E-09
CS-133	4.97E-07	5.04E-07	5.11E-07	5.16E-07	5.21E-07	5.25E-07	5.28E-07	5.31E-07	5.33E-07	5.35E-07	5.36E-07
CS-134	3.67E-08	3.75E-08	3.81E-08	3.86E-08	3.90E-08	3.93E-08	3.95E-08	3.97E-08	3.97E-08	3.97E-08	3.96E-08
PR-141	4.63E-07	4.69E-07	4.75E-07	4.79E-07	4.83E-07	4.86E-07	4.88E-07	4.90E-07	4.92E-07	4.93E-07	4.95E-07
PR-143	1.91E-08	1.74E-08	1.56E-08	1.38E-08	1.21E-08	1.05E-08	9.00E-09	7.65E-09	6.44E-09	5.36E-09	4.40E-09
ND-143	3.11E-07	3.16E-07	3.20E-07	3.25E-07	3.28E-07	3.31E-07	3.34E-07	3.37E-07	3.39E-07	3.41E-07	3.42E-07
ND-144	5.45E-07	5.52E-07	5.59E-07	5.65E-07	5.70E-07	5.74E-07	5.77E-07	5.80E-07	5.82E-07	5.84E-07	5.86E-07
ND-145	2.83E-07	2.86E-07	2.89E-07	2.91E-07	2.94E-07	2.95E-07	2.97E-07	2.98E-07	2.99E-07	3.00E-07	3.00E-07
ND-146	2.63E-07	2.67E-07	2.70E-07	2.72E-07	2.75E-07	2.77E-07	2.78E-07	2.79E-07	2.80E-07	2.81E-07	2.82E-07
PM-147	9.16E-08	9.22E-08	9.27E-08	9.30E-08	9.31E-08	9.32E-08	9.31E-08	9.30E-08	9.28E-08	9.25E-08	9.22E-08
PM-148M	4.93E-10	4.90E-10	4.85E-10	4.78E-10	4.69E-10	4.58E-10	4.45E-10	4.31E-10	4.15E-10	3.96E-10	3.71E-10
PM-148	5.14E-10	4.69E-10	4.24E-10	3.78E-10	3.34E-10	2.92E-10	2.53E-10	2.16E-10	1.82E-10	1.50E-10	1.17E-10
SM-147	2.59E-08	2.63E-08	2.68E-08	2.72E-08	2.76E-08	2.81E-08	2.86E-08	2.91E-08	2.96E-08	3.01E-08	3.06E-08
SM-148	2.98E-08	3.05E-08	3.12E-08	3.17E-08	3.22E-08	3.27E-08	3.31E-08	3.34E-08	3.37E-08	3.40E-08	3.42E-08
PM-149	8.92E-10	7.69E-10	6.54E-10	5.50E-10	4.59E-10	3.80E-10	3.12E-10	2.53E-10	2.02E-10	1.57E-10	1.21E-10
SM-149	1.10E-09	1.10E-09	1.10E-09	1.10E-09	1.09E-09	1.08E-09	1.07E-09	1.07E-09	1.06E-09	1.05E-09	1.04E-09
SM-150	1.08E-07	1.09E-07	1.11E-07	1.12E-07	1.13E-07	1.14E-07	1.15E-07	1.15E-07	1.16E-07	1.16E-07	1.16E-07
PM-151	1.45E-10	1.26E-10	1.08E-10	9.20E-11	7.78E-11	6.53E-11	5.43E-11	4.46E-11	3.60E-11	2.83E-11	2.24E-11
SM-151	5.14E-09	5.22E-09	5.29E-09	5.35E-09	5.40E-09	5.44E-09	5.47E-09	5.50E-09	5.52E-09	5.54E-09	5.55E-09
SM-152	4.83E-08	4.88E-08	4.93E-08	4.98E-08	5.01E-08	5.04E-08	5.07E-08	5.09E-08	5.11E-08	5.12E-08	5.13E-08

	(fuel3,12)	(fuel3,13)	(fuel3,14)	(fuel3,15)	(fuel3,16)	(fuel3,17)	(fuel3,18)	(fuel3,19)	(fuel3,20)	(fuel3,21)	(fuel3,22)
EU-153	3.95E-08	4.03E-08	4.09E-08	4.14E-08	4.19E-08	4.23E-08	4.26E-08	4.29E-08	4.31E-08	4.33E-08	4.34E-08
EU-154	7.62E-09	7.80E-09	7.95E-09	8.09E-09	8.20E-09	8.29E-09	8.36E-09	8.43E-09	8.47E-09	8.51E-09	8.54E-09
EU-155	2.35E-09	2.40E-09	2.44E-09	2.47E-09	2.49E-09	2.51E-09	2.52E-09	2.53E-09	2.53E-09	2.52E-09	2.52E-09
GD-155	2.58E-11	2.97E-11	3.41E-11	3.92E-11	4.51E-11	5.16E-11	5.90E-11	6.72E-11	7.65E-11	8.69E-11	9.83E-11
GD-156	1.37E-08	1.41E-08	1.43E-08	1.46E-08	1.48E-08	1.50E-08	1.52E-08	1.53E-08	1.54E-08	1.55E-08	1.56E-08
GD-157	2.16E-11	2.21E-11	2.25E-11	2.29E-11	2.31E-11	2.34E-11	2.35E-11	2.37E-11	2.38E-11	2.39E-11	2.38E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel4,1) – Fuel(4,11)

	(fuel4,1)	(fuel4,2)	(fuel4,3)	(fuel4,4)	(fuel4,5)	(fuel4,6)	(fuel4,7)	(fuel4,8)	(fuel4,9)	(fuel4,10)	(fuel4,11)
U-234	9.36E-08	9.34E-08	9.31E-08	9.27E-08	9.21E-08	9.14E-08	9.07E-08	9.00E-08	8.93E-08	8.87E-08	8.81E-08
U-235	5.82E-06	5.78E-06	5.72E-06	5.62E-06	5.50E-06	5.35E-06	5.20E-06	5.06E-06	4.92E-06	4.80E-06	4.69E-06
U-236	1.00E-06	1.01E-06	1.02E-06	1.03E-06	1.05E-06	1.08E-06	1.10E-06	1.12E-06	1.14E-06	1.16E-06	1.18E-06
U-237	3.77E-10	6.06E-10	9.88E-10	1.50E-09	2.06E-09	2.55E-09	2.89E-09	3.06E-09	3.07E-09	2.97E-09	2.78E-09
U-238	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04
U-239	4.40E-11	8.12E-11	1.27E-10	1.85E-10	2.33E-10	2.60E-10	2.68E-10	2.61E-10	2.45E-10	2.23E-10	1.98E-10
NP-237	4.08E-08	4.11E-08	4.14E-08	4.20E-08	4.29E-08	4.41E-08	4.56E-08	4.72E-08	4.89E-08	5.05E-08	5.21E-08
NP-238	4.02E-11	6.59E-11	1.08E-10	1.69E-10	2.32E-10	2.80E-10	3.11E-10	3.25E-10	3.25E-10	3.13E-10	2.94E-10
NP-239	5.22E-09	9.93E-09	1.61E-08	2.38E-08	3.11E-08	3.59E-08	3.80E-08	3.78E-08	3.60E-08	3.31E-08	2.97E-08
NP-240	3.40E-14	1.17E-13	2.95E-13	6.32E-13	1.03E-12	1.32E-12	1.43E-12	1.39E-12	1.23E-12	1.03E-12	8.21E-13
PU-238	1.29E-08	1.31E-08	1.32E-08	1.35E-08	1.39E-08	1.43E-08	1.49E-08	1.56E-08	1.62E-08	1.69E-08	1.75E-08
PU-239	4.46E-07	4.49E-07	4.57E-07	4.68E-07	4.82E-07	4.98E-07	5.15E-07	5.31E-07	5.44E-07	5.55E-07	5.64E-07
PU-240	2.41E-07	2.41E-07	2.42E-07	2.43E-07	2.46E-07	2.51E-07	2.56E-07	2.62E-07	2.69E-07	2.75E-07	2.81E-07
PU-241	1.57E-07	1.58E-07	1.59E-07	1.61E-07	1.64E-07	1.68E-07	1.71E-07	1.76E-07	1.80E-07	1.84E-07	1.88E-07
PU-242	1.01E-07	1.02E-07	1.04E-07	1.06E-07	1.09E-07	1.13E-07	1.18E-07	1.22E-07	1.27E-07	1.31E-07	1.35E-07
PU-243	9.28E-13	1.63E-12	2.60E-12	3.95E-12	5.13E-12	5.92E-12	6.34E-12	6.42E-12	6.24E-12	5.88E-12	5.40E-12
AM-241	3.05E-09	3.17E-09	3.26E-09	3.29E-09	3.27E-09	3.21E-09	3.14E-09	3.08E-09	3.02E-09	2.99E-09	2.99E-09

	(fuel4,1)	(fuel4,2)	(fuel4,3)	(fuel4,4)	(fuel4,5)	(fuel4,6)	(fuel4,7)	(fuel4,8)	(fuel4,9)	(fuel4,10)	(fuel4,11)
AM-242M	6.65E-11	6.68E-11	6.79E-11	7.02E-11	7.35E-11	7.68E-11	7.93E-11	8.09E-11	8.19E-11	8.26E-11	8.32E-11
AM-242	3.46E-12	6.16E-12	1.03E-11	1.63E-11	2.14E-11	2.42E-11	2.51E-11	2.45E-11	2.30E-11	2.10E-11	1.89E-11
AM-243	1.95E-09	1.98E-09	2.02E-09	2.09E-09	2.18E-09	2.30E-09	2.43E-09	2.56E-09	2.69E-09	2.81E-09	2.92E-09
AM-244	4.66E-13	8.13E-13	1.32E-12	2.06E-12	2.75E-12	3.25E-12	3.55E-12	3.67E-12	3.64E-12	3.48E-12	3.24E-12
CM-242	1.30E-09	1.28E-09	1.29E-09	1.33E-09	1.41E-09	1.51E-09	1.62E-09	1.73E-09	1.83E-09	1.92E-09	1.98E-09
CM-243	2.49E-11	2.53E-11	2.58E-11	2.65E-11	2.76E-11	2.89E-11	3.05E-11	3.21E-11	3.38E-11	3.55E-11	3.70E-11
CM-244	4.72E-10	4.79E-10	4.91E-10	5.11E-10	5.41E-10	5.77E-10	6.19E-10	6.64E-10	7.09E-10	7.54E-10	7.95E-10
XE-135	6.32E-11	7.71E-11	8.79E-11	9.66E-11	1.02E-10	1.05E-10	1.07E-10	1.07E-10	1.07E-10	1.06E-10	1.04E-10
XE-136	7.98E-07	8.02E-07	8.10E-07	8.23E-07	8.41E-07	8.62E-07	8.85E-07	9.07E-07	9.29E-07	9.48E-07	9.66E-07
KR-83	2.51E-08	2.52E-08	2.55E-08	2.58E-08	2.63E-08	2.68E-08	2.74E-08	2.79E-08	2.85E-08	2.89E-08	2.93E-08
ZR-95	4.65E-08	4.52E-08	4.56E-08	4.81E-08	5.25E-08	5.80E-08	6.35E-08	6.86E-08	7.26E-08	7.55E-08	7.72E-08
MO-95	3.48E-07	3.52E-07	3.56E-07	3.59E-07	3.63E-07	3.67E-07	3.72E-07	3.77E-07	3.82E-07	3.88E-07	3.94E-07
MO-97	3.89E-07	3.91E-07	3.95E-07	4.01E-07	4.10E-07	4.20E-07	4.30E-07	4.40E-07	4.50E-07	4.59E-07	4.67E-07
TC-99	3.84E-07	3.87E-07	3.90E-07	3.96E-07	4.04E-07	4.14E-07	4.24E-07	4.33E-07	4.43E-07	4.51E-07	4.59E-07
RU-101	3.45E-07	3.47E-07	3.51E-07	3.57E-07	3.64E-07	3.73E-07	3.82E-07	3.92E-07	4.00E-07	4.09E-07	4.16E-07
RU-103	1.68E-08	1.62E-08	1.68E-08	1.87E-08	2.18E-08	2.56E-08	2.94E-08	3.28E-08	3.54E-08	3.71E-08	3.80E-08
RH-103	1.77E-07	1.79E-07	1.80E-07	1.81E-07	1.81E-07	1.82E-07	1.83E-07	1.84E-07	1.86E-07	1.88E-07	1.91E-07
RH-105	1.73E-10	2.90E-10	4.61E-10	6.99E-10	9.08E-10	1.04E-09	1.10E-09	1.11E-09	1.07E-09	1.01E-09	9.20E-10
PD-105	1.25E-07	1.26E-07	1.27E-07	1.29E-07	1.32E-07	1.35E-07	1.39E-07	1.43E-07	1.47E-07	1.50E-07	1.54E-07
PD-108	4.27E-08	4.30E-08	4.35E-08	4.42E-08	4.53E-08	4.67E-08	4.82E-08	4.97E-08	5.13E-08	5.28E-08	5.41E-08
AG-109	2.28E-08	2.30E-08	2.32E-08	2.36E-08	2.41E-08	2.48E-08	2.55E-08	2.63E-08	2.71E-08	2.78E-08	2.85E-08
CD-113	2.53E-11	2.54E-11	2.57E-11	2.61E-11	2.68E-11	2.76E-11	2.84E-11	2.91E-11	2.98E-11	3.03E-11	3.08E-11
I-131	1.08E-09	1.53E-09	2.36E-09	3.62E-09	5.09E-09	6.37E-09	7.24E-09	7.66E-09	7.67E-09	7.37E-09	6.86E-09
XE-131	1.65E-07	1.65E-07	1.66E-07	1.67E-07	1.68E-07	1.71E-07	1.74E-07	1.77E-07	1.81E-07	1.85E-07	1.88E-07
XE-133	1.54E-09	2.48E-09	3.98E-09	6.13E-09	8.43E-09	1.02E-08	1.12E-08	1.14E-08	1.11E-08	1.04E-08	9.47E-09
CS-133	4.16E-07	4.17E-07	4.20E-07	4.24E-07	4.30E-07	4.39E-07	4.48E-07	4.59E-07	4.69E-07	4.79E-07	4.88E-07
CS-134	2.53E-08	2.55E-08	2.59E-08	2.65E-08	2.75E-08	2.86E-08	2.99E-08	3.12E-08	3.24E-08	3.35E-08	3.45E-08
PR-141	3.78E-07	3.81E-07	3.85E-07	3.91E-07	3.99E-07	4.08E-07	4.19E-07	4.29E-07	4.38E-07	4.47E-07	4.55E-07
PR-143	3.81E-09	4.57E-09	6.33E-09	9.21E-09	1.28E-08	1.63E-08	1.90E-08	2.07E-08	2.13E-08	2.11E-08	2.02E-08
ND-143	2.75E-07	2.75E-07	2.76E-07	2.77E-07	2.79E-07	2.81E-07	2.84E-07	2.89E-07	2.94E-07	2.99E-07	3.04E-07
ND-144	4.36E-07	4.40E-07	4.45E-07	4.52E-07	4.62E-07	4.74E-07	4.87E-07	5.00E-07	5.12E-07	5.23E-07	5.33E-07

	(fuel4,1)	(fuel4,2)	(fuel4,3)	(fuel4,4)	(fuel4,5)	(fuel4,6)	(fuel4,7)	(fuel4,8)	(fuel4,9)	(fuel4,10)	(fuel4,11)
ND-145	2.33E-07	2.35E-07	2.37E-07	2.41E-07	2.45E-07	2.51E-07	2.57E-07	2.63E-07	2.68E-07	2.73E-07	2.78E-07
ND-146	2.12E-07	2.13E-07	2.15E-07	2.19E-07	2.24E-07	2.29E-07	2.35E-07	2.41E-07	2.47E-07	2.52E-07	2.57E-07
PM-147	7.91E-08	7.92E-08	7.96E-08	8.05E-08	8.20E-08	8.37E-08	8.54E-08	8.72E-08	8.87E-08	9.01E-08	9.12E-08
PM-148M	2.71E-10	3.09E-10	3.60E-10	3.96E-10	4.15E-10	4.26E-10	4.36E-10	4.43E-10	4.49E-10	4.52E-10	4.53E-10
PM-148	1.07E-10	1.73E-10	2.70E-10	3.82E-10	4.80E-10	5.44E-10	5.76E-10	5.82E-10	5.71E-10	5.48E-10	5.16E-10
SM-147	2.22E-08	2.26E-08	2.30E-08	2.34E-08	2.37E-08	2.40E-08	2.43E-08	2.46E-08	2.50E-08	2.53E-08	2.57E-08
SM-148	2.20E-08	2.22E-08	2.26E-08	2.30E-08	2.37E-08	2.44E-08	2.52E-08	2.61E-08	2.69E-08	2.77E-08	2.85E-08
PM-149	1.57E-10	2.76E-10	4.63E-10	7.35E-10	9.97E-10	1.17E-09	1.25E-09	1.25E-09	1.19E-09	1.10E-09	9.81E-10
SM-149	7.22E-10	6.44E-10	6.36E-10	6.81E-10	7.67E-10	8.49E-10	9.11E-10	9.57E-10	9.91E-10	1.02E-09	1.03E-09
SM-150	8.71E-08	8.76E-08	8.82E-08	8.93E-08	9.09E-08	9.30E-08	9.54E-08	9.80E-08	1.00E-07	1.03E-07	1.05E-07
PM-151	3.37E-11	5.75E-11	9.14E-11	1.39E-10	1.79E-10	2.02E-10	2.10E-10	2.07E-10	1.96E-10	1.80E-10	1.61E-10
SM-151	4.17E-09	4.15E-09	4.13E-09	4.13E-09	4.18E-09	4.27E-09	4.40E-09	4.53E-09	4.66E-09	4.78E-09	4.88E-09
SM-152	4.08E-08	4.10E-08	4.14E-08	4.19E-08	4.27E-08	4.36E-08	4.45E-08	4.54E-08	4.63E-08	4.72E-08	4.80E-08
EU-153	2.98E-08	3.00E-08	3.04E-08	3.10E-08	3.19E-08	3.29E-08	3.40E-08	3.51E-08	3.61E-08	3.71E-08	3.80E-08
EU-154	5.27E-09	5.33E-09	5.42E-09	5.57E-09	5.77E-09	6.00E-09	6.26E-09	6.52E-09	6.77E-09	7.00E-09	7.21E-09
EU-155	1.62E-09	1.63E-09	1.66E-09	1.70E-09	1.77E-09	1.85E-09	1.93E-09	2.01E-09	2.09E-09	2.16E-09	2.22E-09
GD-155	6.36E-11	5.98E-11	4.92E-11	3.54E-11	2.43E-11	1.85E-11	1.64E-11	1.63E-11	1.74E-11	1.93E-11	2.17E-11
GD-156	9.87E-09	9.97E-09	1.01E-08	1.04E-08	1.07E-08	1.11E-08	1.15E-08	1.20E-08	1.24E-08	1.29E-08	1.33E-08
GD-157	1.46E-11	1.30E-11	1.29E-11	1.37E-11	1.47E-11	1.57E-11	1.67E-11	1.76E-11	1.84E-11	1.91E-11	1.96E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel4,12) – Fuel(4,22)

	(fuel4,12)	(fuel4,13)	(fuel4,14)	(fuel4,15)	(fuel4,16)	(fuel4,17)	(fuel4,18)	(fuel4,19)	(fuel4,20)	(fuel4,21)	(fuel4,22)
U-234	8.77E-08	8.72E-08	8.69E-08	8.66E-08	8.63E-08	8.61E-08	8.60E-08	8.58E-08	8.57E-08	8.56E-08	8.55E-08
U-235	4.60E-06	4.52E-06	4.46E-06	4.40E-06	4.35E-06	4.31E-06	4.28E-06	4.26E-06	4.23E-06	4.22E-06	4.20E-06
U-236	1.19E-06	1.21E-06	1.22E-06	1.22E-06	1.23E-06	1.24E-06	1.24E-06	1.25E-06	1.25E-06	1.25E-06	1.25E-06
U-237	2.53E-09	2.26E-09	1.99E-09	1.73E-09	1.49E-09	1.27E-09	1.07E-09	8.95E-10	7.39E-10	5.98E-10	4.62E-10
U-238	1.08E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04	1.07E-04
U-239	1.73E-10	1.49E-10	1.27E-10	1.08E-10	9.09E-11	7.59E-11	6.29E-11	5.15E-11	4.14E-11	3.22E-11	2.23E-11
NP-237	5.36E-08	5.49E-08	5.61E-08	5.71E-08	5.80E-08	5.88E-08	5.95E-08	6.00E-08	6.05E-08	6.08E-08	6.12E-08
NP-238	2.69E-10	2.41E-10	2.13E-10	1.86E-10	1.60E-10	1.37E-10	1.16E-10	9.62E-11	7.87E-11	6.26E-11	4.89E-11
NP-239	2.61E-08	2.27E-08	1.94E-08	1.65E-08	1.39E-08	1.17E-08	9.72E-09	7.99E-09	6.47E-09	5.10E-09	3.70E-09
NP-240	6.31E-13	4.72E-13	3.46E-13	2.50E-13	1.77E-13	1.24E-13	8.56E-14	5.77E-14	3.76E-14	2.31E-14	1.20E-14
PU-238	1.81E-08	1.87E-08	1.92E-08	1.97E-08	2.01E-08	2.04E-08	2.07E-08	2.10E-08	2.12E-08	2.14E-08	2.16E-08
PU-239	5.71E-07	5.77E-07	5.81E-07	5.84E-07	5.87E-07	5.89E-07	5.91E-07	5.92E-07	5.93E-07	5.94E-07	5.95E-07
PU-240	2.86E-07	2.91E-07	2.94E-07	2.98E-07	3.01E-07	3.03E-07	3.05E-07	3.07E-07	3.08E-07	3.09E-07	3.10E-07
PU-241	1.91E-07	1.94E-07	1.97E-07	1.99E-07	2.01E-07	2.03E-07	2.04E-07	2.05E-07	2.06E-07	2.06E-07	2.07E-07
PU-242	1.39E-07	1.42E-07	1.44E-07	1.47E-07	1.49E-07	1.51E-07	1.52E-07	1.53E-07	1.54E-07	1.55E-07	1.56E-07
PU-243	4.86E-12	4.29E-12	3.75E-12	3.24E-12	2.77E-12	2.34E-12	1.96E-12	1.62E-12	1.31E-12	1.03E-12	7.82E-13
AM-241	3.01E-09	3.05E-09	3.12E-09	3.20E-09	3.31E-09	3.42E-09	3.56E-09	3.70E-09	3.86E-09	4.03E-09	4.21E-09
AM-242M	8.38E-11	8.47E-11	8.57E-11	8.69E-11	8.82E-11	8.97E-11	9.12E-11	9.27E-11	9.42E-11	9.57E-11	9.70E-11
AM-242	1.68E-11	1.49E-11	1.31E-11	1.15E-11	1.00E-11	8.73E-12	7.55E-12	6.46E-12	5.43E-12	4.44E-12	3.63E-12
AM-243	3.02E-09	3.12E-09	3.20E-09	3.26E-09	3.32E-09	3.37E-09	3.42E-09	3.45E-09	3.48E-09	3.50E-09	3.52E-09
AM-244	2.94E-12	2.63E-12	2.31E-12	2.00E-12	1.72E-12	1.46E-12	1.23E-12	1.02E-12	8.24E-13	6.48E-13	5.01E-13
CM-242	2.04E-09	2.07E-09	2.10E-09	2.11E-09	2.11E-09	2.10E-09	2.09E-09	2.06E-09	2.04E-09	2.00E-09	1.96E-09
CM-243	3.83E-11	3.95E-11	4.05E-11	4.14E-11	4.21E-11	4.27E-11	4.32E-11	4.35E-11	4.38E-11	4.40E-11	4.42E-11
CM-244	8.34E-10	8.68E-10	8.98E-10	9.25E-10	9.47E-10	9.66E-10	9.83E-10	9.96E-10	1.01E-09	1.02E-09	1.02E-09
XE-135	1.02E-10	9.87E-11	9.52E-11	9.13E-11	8.68E-11	8.19E-11	7.65E-11	7.05E-11	6.37E-11	5.60E-11	4.85E-11
XE-136	9.81E-07	9.94E-07	1.00E-06	1.01E-06	1.02E-06	1.03E-06	1.03E-06	1.04E-06	1.04E-06	1.04E-06	1.04E-06
KR-83	2.97E-08	3.00E-08	3.02E-08	3.04E-08	3.06E-08	3.07E-08	3.09E-08	3.10E-08	3.10E-08	3.11E-08	3.11E-08

	(fuel4,12)	(fuel4,13)	(fuel4,14)	(fuel4,15)	(fuel4,16)	(fuel4,17)	(fuel4,18)	(fuel4,19)	(fuel4,20)	(fuel4,21)	(fuel4,22)
ZR-95	7.78E-08	7.74E-08	7.62E-08	7.43E-08	7.19E-08	6.91E-08	6.60E-08	6.27E-08	5.92E-08	5.57E-08	5.22E-08
MO-95	4.00E-07	4.07E-07	4.13E-07	4.19E-07	4.25E-07	4.31E-07	4.36E-07	4.42E-07	4.47E-07	4.52E-07	4.56E-07
MO-97	4.75E-07	4.81E-07	4.86E-07	4.90E-07	4.94E-07	4.97E-07	5.00E-07	5.02E-07	5.04E-07	5.05E-07	5.06E-07
TC-99	4.66E-07	4.71E-07	4.76E-07	4.80E-07	4.84E-07	4.87E-07	4.89E-07	4.91E-07	4.93E-07	4.94E-07	4.95E-07
RU-101	4.22E-07	4.28E-07	4.33E-07	4.37E-07	4.40E-07	4.43E-07	4.46E-07	4.48E-07	4.49E-07	4.50E-07	4.51E-07
RU-103	3.82E-08	3.76E-08	3.66E-08	3.51E-08	3.33E-08	3.12E-08	2.91E-08	2.69E-08	2.47E-08	2.25E-08	2.04E-08
RH-103	1.94E-07	1.97E-07	2.01E-07	2.04E-07	2.08E-07	2.11E-07	2.14E-07	2.17E-07	2.20E-07	2.23E-07	2.26E-07
RH-105	8.25E-10	7.28E-10	6.34E-10	5.47E-10	4.67E-10	3.96E-10	3.32E-10	2.75E-10	2.24E-10	1.77E-10	1.39E-10
PD-105	1.57E-07	1.60E-07	1.62E-07	1.64E-07	1.66E-07	1.68E-07	1.69E-07	1.70E-07	1.71E-07	1.72E-07	1.72E-07
PD-108	5.53E-08	5.64E-08	5.74E-08	5.82E-08	5.89E-08	5.95E-08	5.99E-08	6.04E-08	6.07E-08	6.10E-08	6.12E-08
AG-109	2.91E-08	2.97E-08	3.02E-08	3.06E-08	3.09E-08	3.12E-08	3.15E-08	3.17E-08	3.18E-08	3.20E-08	3.21E-08
CD-113	3.12E-11	3.15E-11	3.18E-11	3.20E-11	3.22E-11	3.23E-11	3.24E-11	3.25E-11	3.25E-11	3.26E-11	3.26E-11
I-131	6.22E-09	5.53E-09	4.84E-09	4.19E-09	3.59E-09	3.05E-09	2.56E-09	2.14E-09	1.77E-09	1.43E-09	1.15E-09
XE-131	1.91E-07	1.94E-07	1.97E-07	1.99E-07	2.01E-07	2.03E-07	2.04E-07	2.06E-07	2.07E-07	2.07E-07	2.08E-07
XE-133	8.43E-09	7.38E-09	6.38E-09	5.46E-09	4.63E-09	3.90E-09	3.26E-09	2.70E-09	2.21E-09	1.78E-09	1.40E-09
CS-133	4.96E-07	5.03E-07	5.10E-07	5.15E-07	5.20E-07	5.23E-07	5.27E-07	5.29E-07	5.32E-07	5.34E-07	5.35E-07
CS-134	3.54E-08	3.61E-08	3.67E-08	3.72E-08	3.75E-08	3.78E-08	3.80E-08	3.81E-08	3.81E-08	3.81E-08	3.80E-08
PR-141	4.61E-07	4.67E-07	4.72E-07	4.77E-07	4.80E-07	4.83E-07	4.86E-07	4.88E-07	4.90E-07	4.91E-07	4.92E-07
PR-143	1.89E-08	1.72E-08	1.55E-08	1.37E-08	1.20E-08	1.04E-08	8.89E-09	7.56E-09	6.36E-09	5.29E-09	4.34E-09
ND-143	3.09E-07	3.14E-07	3.19E-07	3.23E-07	3.27E-07	3.30E-07	3.33E-07	3.35E-07	3.37E-07	3.39E-07	3.40E-07
ND-144	5.42E-07	5.50E-07	5.57E-07	5.63E-07	5.67E-07	5.71E-07	5.75E-07	5.78E-07	5.80E-07	5.82E-07	5.83E-07
ND-145	2.82E-07	2.85E-07	2.88E-07	2.91E-07	2.93E-07	2.94E-07	2.96E-07	2.97E-07	2.98E-07	2.99E-07	2.99E-07
ND-146	2.61E-07	2.65E-07	2.68E-07	2.71E-07	2.73E-07	2.75E-07	2.76E-07	2.78E-07	2.79E-07	2.79E-07	2.80E-07
PM-147	9.21E-08	9.28E-08	9.33E-08	9.36E-08	9.38E-08	9.39E-08	9.38E-08	9.37E-08	9.35E-08	9.32E-08	9.29E-08
PM-148M	4.52E-10	4.49E-10	4.44E-10	4.38E-10	4.29E-10	4.20E-10	4.08E-10	3.95E-10	3.80E-10	3.64E-10	3.41E-10
PM-148	4.78E-10	4.37E-10	3.95E-10	3.53E-10	3.12E-10	2.73E-10	2.36E-10	2.02E-10	1.70E-10	1.40E-10	1.10E-10
SM-147	2.61E-08	2.65E-08	2.69E-08	2.74E-08	2.78E-08	2.83E-08	2.88E-08	2.93E-08	2.98E-08	3.03E-08	3.09E-08
SM-148	2.92E-08	2.98E-08	3.04E-08	3.10E-08	3.14E-08	3.18E-08	3.22E-08	3.25E-08	3.28E-08	3.31E-08	3.33E-08
PM-149	8.60E-10	7.41E-10	6.30E-10	5.31E-10	4.43E-10	3.67E-10	3.01E-10	2.44E-10	1.95E-10	1.51E-10	1.16E-10
SM-149	1.04E-09	1.04E-09	1.04E-09	1.04E-09	1.03E-09	1.02E-09	1.01E-09	1.00E-09	9.95E-10	9.89E-10	9.81E-10
SM-150	1.07E-07	1.08E-07	1.10E-07	1.11E-07	1.12E-07	1.13E-07	1.14E-07	1.14E-07	1.15E-07	1.15E-07	1.15E-07

	(fuel4,12)	(fuel4,13)	(fuel4,14)	(fuel4,15)	(fuel4,16)	(fuel4,17)	(fuel4,18)	(fuel4,19)	(fuel4,20)	(fuel4,21)	(fuel4,22)
PM-151	1.41E-10	1.23E-10	1.05E-10	8.95E-11	7.56E-11	6.34E-11	5.27E-11	4.33E-11	3.49E-11	2.74E-11	2.14E-11
SM-151	4.97E-09	5.04E-09	5.10E-09	5.15E-09	5.19E-09	5.22E-09	5.25E-09	5.27E-09	5.29E-09	5.30E-09	5.31E-09
SM-152	4.86E-08	4.92E-08	4.98E-08	5.02E-08	5.06E-08	5.09E-08	5.12E-08	5.14E-08	5.16E-08	5.17E-08	5.18E-08
EU-153	3.88E-08	3.95E-08	4.01E-08	4.06E-08	4.10E-08	4.14E-08	4.17E-08	4.20E-08	4.22E-08	4.23E-08	4.25E-08
EU-154	7.40E-09	7.57E-09	7.71E-09	7.83E-09	7.93E-09	8.02E-09	8.09E-09	8.14E-09	8.19E-09	8.22E-09	8.24E-09
EU-155	2.27E-09	2.32E-09	2.35E-09	2.38E-09	2.40E-09	2.41E-09	2.42E-09	2.42E-09	2.42E-09	2.42E-09	2.41E-09
GD-155	2.47E-11	2.83E-11	3.25E-11	3.73E-11	4.27E-11	4.89E-11	5.58E-11	6.36E-11	7.23E-11	8.21E-11	9.31E-11
GD-156	1.36E-08	1.39E-08	1.42E-08	1.45E-08	1.47E-08	1.49E-08	1.50E-08	1.51E-08	1.52E-08	1.53E-08	1.54E-08
GD-157	2.01E-11	2.05E-11	2.08E-11	2.11E-11	2.13E-11	2.15E-11	2.16E-11	2.17E-11	2.18E-11	2.18E-11	2.18E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel5,1) – Fuel(5,11)

	(fuel5,1)	(fuel5,2)	(fuel5,3)	(fuel5,4)	(fuel5,5)	(fuel5,6)	(fuel5,7)	(fuel5,8)	(fuel5,9)	(fuel5,10)	(fuel5,11)
U-234	9.36E-08	9.35E-08	9.33E-08	9.29E-08	9.24E-08	9.18E-08	9.11E-08	9.05E-08	8.98E-08	8.93E-08	8.88E-08
U-235	5.82E-06	5.79E-06	5.73E-06	5.63E-06	5.50E-06	5.34E-06	5.17E-06	5.01E-06	4.86E-06	4.73E-06	4.61E-06
U-236	1.00E-06	1.01E-06	1.02E-06	1.03E-06	1.05E-06	1.08E-06	1.10E-06	1.13E-06	1.15E-06	1.17E-06	1.19E-06
U-237	3.21E-10	4.38E-10	6.84E-10	1.03E-09	1.43E-09	1.78E-09	2.03E-09	2.16E-09	2.17E-09	2.11E-09	1.98E-09
U-238	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04
U-239	3.08E-11	5.66E-11	9.02E-11	1.34E-10	1.71E-10	1.92E-10	1.98E-10	1.94E-10	1.82E-10	1.66E-10	1.48E-10
NP-237	4.08E-08	4.10E-08	4.12E-08	4.15E-08	4.19E-08	4.25E-08	4.32E-08	4.41E-08	4.51E-08	4.60E-08	4.69E-08
NP-238	3.60E-11	5.73E-11	9.67E-11	1.68E-10	2.40E-10	2.90E-10	3.19E-10	3.29E-10	3.24E-10	3.08E-10	2.86E-10
NP-239	3.90E-09	6.95E-09	1.14E-08	1.72E-08	2.28E-08	2.65E-08	2.82E-08	2.81E-08	2.67E-08	2.46E-08	2.21E-08
NP-240	1.90E-14	6.06E-14	1.59E-13	3.70E-13	6.25E-13	8.11E-13	8.85E-13	8.59E-13	7.67E-13	6.44E-13	5.15E-13
PU-238	1.29E-08	1.31E-08	1.32E-08	1.34E-08	1.38E-08	1.43E-08	1.49E-08	1.55E-08	1.61E-08	1.67E-08	1.73E-08
PU-239	4.45E-07	4.46E-07	4.46E-07	4.44E-07	4.39E-07	4.34E-07	4.30E-07	4.27E-07	4.25E-07	4.23E-07	4.22E-07
PU-240	2.41E-07	2.41E-07	2.41E-07	2.43E-07	2.45E-07	2.47E-07	2.50E-07	2.53E-07	2.56E-07	2.58E-07	2.60E-07
PU-241	1.57E-07	1.58E-07	1.59E-07	1.61E-07	1.64E-07	1.68E-07	1.71E-07	1.75E-07	1.78E-07	1.80E-07	1.82E-07

	(fuel5,1)	(fuel5,2)	(fuel5,3)	(fuel5,4)	(fuel5,5)	(fuel5,6)	(fuel5,7)	(fuel5,8)	(fuel5,9)	(fuel5,10)	(fuel5,11)
PU-242	1.01E-07	1.02E-07	1.03E-07	1.06E-07	1.09E-07	1.14E-07	1.19E-07	1.24E-07	1.29E-07	1.34E-07	1.38E-07
PU-243	7.73E-13	1.35E-12	2.25E-12	3.79E-12	5.08E-12	5.92E-12	6.38E-12	6.51E-12	6.37E-12	6.03E-12	5.56E-12
AM-241	3.06E-09	3.18E-09	3.27E-09	3.30E-09	3.26E-09	3.17E-09	3.08E-09	2.98E-09	2.90E-09	2.85E-09	2.83E-09
AM-242M	6.65E-11	6.67E-11	6.76E-11	7.00E-11	7.35E-11	7.67E-11	7.87E-11	7.95E-11	7.97E-11	7.95E-11	7.93E-11
AM-242	3.12E-12	5.57E-12	9.77E-12	1.77E-11	2.39E-11	2.70E-11	2.78E-11	2.69E-11	2.50E-11	2.27E-11	2.03E-11
AM-243	1.95E-09	1.97E-09	2.01E-09	2.07E-09	2.16E-09	2.27E-09	2.40E-09	2.53E-09	2.67E-09	2.79E-09	2.91E-09
AM-244	4.05E-13	7.05E-13	1.19E-12	2.09E-12	2.85E-12	3.36E-12	3.66E-12	3.76E-12	3.71E-12	3.54E-12	3.29E-12
CM-242	1.29E-09	1.28E-09	1.28E-09	1.33E-09	1.42E-09	1.54E-09	1.67E-09	1.79E-09	1.90E-09	2.00E-09	2.08E-09
CM-243	2.49E-11	2.51E-11	2.54E-11	2.59E-11	2.66E-11	2.76E-11	2.87E-11	3.00E-11	3.14E-11	3.27E-11	3.39E-11
CM-244	4.71E-10	4.78E-10	4.89E-10	5.09E-10	5.39E-10	5.78E-10	6.22E-10	6.69E-10	7.16E-10	7.62E-10	8.05E-10
XE-135	5.97E-11	7.36E-11	8.51E-11	9.50E-11	9.95E-11	1.01E-10	1.01E-10	1.00E-10	9.86E-11	9.66E-11	9.42E-11
XE-136	7.98E-07	8.02E-07	8.09E-07	8.22E-07	8.41E-07	8.65E-07	8.89E-07	9.13E-07	9.36E-07	9.56E-07	9.75E-07
KR-83	2.51E-08	2.52E-08	2.54E-08	2.58E-08	2.63E-08	2.69E-08	2.75E-08	2.81E-08	2.86E-08	2.91E-08	2.95E-08
ZR-95	4.64E-08	4.49E-08	4.50E-08	4.76E-08	5.28E-08	5.91E-08	6.54E-08	7.10E-08	7.54E-08	7.86E-08	8.05E-08
MO-95	3.48E-07	3.52E-07	3.56E-07	3.59E-07	3.63E-07	3.67E-07	3.72E-07	3.78E-07	3.83E-07	3.89E-07	3.96E-07
MO-97	3.89E-07	3.91E-07	3.95E-07	4.01E-07	4.10E-07	4.21E-07	4.32E-07	4.43E-07	4.53E-07	4.63E-07	4.71E-07
TC-99	3.84E-07	3.86E-07	3.90E-07	3.96E-07	4.05E-07	4.15E-07	4.26E-07	4.37E-07	4.47E-07	4.57E-07	4.65E-07
RU-101	3.45E-07	3.47E-07	3.51E-07	3.56E-07	3.64E-07	3.74E-07	3.84E-07	3.94E-07	4.04E-07	4.12E-07	4.20E-07
RU-103	1.68E-08	1.60E-08	1.64E-08	1.84E-08	2.20E-08	2.63E-08	3.04E-08	3.39E-08	3.65E-08	3.82E-08	3.90E-08
RH-103	1.77E-07	1.79E-07	1.80E-07	1.81E-07	1.81E-07	1.81E-07	1.82E-07	1.83E-07	1.85E-07	1.87E-07	1.90E-07
RH-105	1.57E-10	2.61E-10	4.32E-10	7.27E-10	9.61E-10	1.08E-09	1.13E-09	1.11E-09	1.05E-09	9.74E-10	8.80E-10
PD-105	1.25E-07	1.26E-07	1.27E-07	1.29E-07	1.32E-07	1.35E-07	1.39E-07	1.43E-07	1.47E-07	1.51E-07	1.54E-07
PD-108	4.27E-08	4.30E-08	4.34E-08	4.42E-08	4.54E-08	4.68E-08	4.84E-08	5.00E-08	5.15E-08	5.30E-08	5.43E-08
AG-109	2.28E-08	2.30E-08	2.32E-08	2.36E-08	2.42E-08	2.49E-08	2.58E-08	2.66E-08	2.74E-08	2.81E-08	2.88E-08
CD-113	2.53E-11	2.52E-11	2.52E-11	2.54E-11	2.56E-11	2.57E-11	2.58E-11	2.59E-11	2.60E-11	2.60E-11	2.61E-11
I-131	1.03E-09	1.41E-09	2.18E-09	3.59E-09	5.33E-09	6.79E-09	7.73E-09	8.13E-09	8.07E-09	7.69E-09	7.09E-09
XE-131	1.65E-07	1.65E-07	1.66E-07	1.67E-07	1.69E-07	1.72E-07	1.75E-07	1.79E-07	1.84E-07	1.88E-07	1.92E-07
XE-133	1.45E-09	2.25E-09	3.69E-09	6.18E-09	8.95E-09	1.10E-08	1.20E-08	1.22E-08	1.18E-08	1.09E-08	9.86E-09
CS-133	4.16E-07	4.17E-07	4.20E-07	4.24E-07	4.31E-07	4.40E-07	4.51E-07	4.62E-07	4.74E-07	4.84E-07	4.94E-07
CS-134	2.53E-08	2.53E-08	2.56E-08	2.60E-08	2.67E-08	2.76E-08	2.86E-08	2.96E-08	3.05E-08	3.14E-08	3.22E-08
PR-141	3.78E-07	3.80E-07	3.84E-07	3.90E-07	3.99E-07	4.09E-07	4.20E-07	4.31E-07	4.41E-07	4.50E-07	4.58E-07

	(fuel5,1)	(fuel5,2)	(fuel5,3)	(fuel5,4)	(fuel5,5)	(fuel5,6)	(fuel5,7)	(fuel5,8)	(fuel5,9)	(fuel5,10)	(fuel5,11)
PR-143	3.73E-09	4.31E-09	5.92E-09	9.05E-09	1.33E-08	1.73E-08	2.03E-08	2.21E-08	2.28E-08	2.25E-08	2.14E-08
ND-143	2.75E-07	2.75E-07	2.76E-07	2.77E-07	2.78E-07	2.80E-07	2.84E-07	2.88E-07	2.93E-07	2.99E-07	3.04E-07
ND-144	4.36E-07	4.39E-07	4.44E-07	4.51E-07	4.63E-07	4.76E-07	4.90E-07	5.04E-07	5.17E-07	5.29E-07	5.40E-07
ND-145	2.33E-07	2.34E-07	2.37E-07	2.40E-07	2.46E-07	2.52E-07	2.59E-07	2.65E-07	2.71E-07	2.76E-07	2.81E-07
ND-146	2.12E-07	2.13E-07	2.15E-07	2.19E-07	2.24E-07	2.30E-07	2.36E-07	2.42E-07	2.48E-07	2.54E-07	2.59E-07
PM-147	7.91E-08	7.92E-08	7.97E-08	8.09E-08	8.28E-08	8.51E-08	8.75E-08	8.97E-08	9.18E-08	9.35E-08	9.49E-08
PM-148M	2.58E-10	2.69E-10	2.94E-10	3.05E-10	3.08E-10	3.15E-10	3.23E-10	3.31E-10	3.37E-10	3.41E-10	3.43E-10
PM-148	9.20E-11	1.33E-10	2.05E-10	2.96E-10	3.79E-10	4.35E-10	4.63E-10	4.73E-10	4.68E-10	4.54E-10	4.31E-10
SM-147	2.22E-08	2.27E-08	2.31E-08	2.34E-08	2.38E-08	2.41E-08	2.45E-08	2.49E-08	2.52E-08	2.56E-08	2.60E-08
SM-148	2.20E-08	2.22E-08	2.24E-08	2.28E-08	2.33E-08	2.39E-08	2.46E-08	2.52E-08	2.59E-08	2.66E-08	2.72E-08
PM-149	1.43E-10	2.43E-10	4.14E-10	7.21E-10	1.00E-09	1.18E-09	1.25E-09	1.24E-09	1.17E-09	1.08E-09	9.60E-10
SM-149	7.31E-10	6.44E-10	6.04E-10	6.07E-10	6.84E-10	7.52E-10	7.97E-10	8.28E-10	8.49E-10	8.63E-10	8.71E-10
SM-150	8.71E-08	8.75E-08	8.82E-08	8.92E-08	9.08E-08	9.30E-08	9.54E-08	9.80E-08	1.00E-07	1.03E-07	1.05E-07
PM-151	3.04E-11	5.17E-11	8.58E-11	1.46E-10	1.93E-10	2.17E-10	2.23E-10	2.16E-10	2.02E-10	1.83E-10	1.62E-10
SM-151	4.17E-09	4.13E-09	4.09E-09	4.04E-09	4.04E-09	4.09E-09	4.16E-09	4.24E-09	4.32E-09	4.38E-09	4.44E-09
SM-152	4.08E-08	4.11E-08	4.15E-08	4.22E-08	4.32E-08	4.45E-08	4.57E-08	4.70E-08	4.82E-08	4.92E-08	5.02E-08
EU-153	2.97E-08	2.99E-08	3.02E-08	3.08E-08	3.15E-08	3.24E-08	3.33E-08	3.43E-08	3.52E-08	3.61E-08	3.68E-08
EU-154	5.27E-09	5.31E-09	5.38E-09	5.49E-09	5.65E-09	5.84E-09	6.05E-09	6.27E-09	6.47E-09	6.67E-09	6.84E-09
EU-155	1.62E-09	1.63E-09	1.65E-09	1.69E-09	1.74E-09	1.81E-09	1.87E-09	1.94E-09	1.99E-09	2.04E-09	2.08E-09
GD-155	6.41E-11	6.15E-11	5.14E-11	3.55E-11	2.24E-11	1.61E-11	1.40E-11	1.39E-11	1.47E-11	1.61E-11	1.80E-11
GD-156	9.86E-09	9.96E-09	1.01E-08	1.04E-08	1.07E-08	1.12E-08	1.16E-08	1.21E-08	1.26E-08	1.30E-08	1.35E-08
GD-157	1.45E-11	1.26E-11	1.22E-11	1.26E-11	1.33E-11	1.39E-11	1.45E-11	1.49E-11	1.52E-11	1.55E-11	1.57E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	: 2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Regions (Fuel5,12) – Fuel(5,22)

	(fuel5,12)	(fuel5,13)	(fuel5,14)	(fuel5,15)	(fuel5,16)	(fuel5,17)	(fuel5,18)	(fuel5,19)	(fuel5,20)	(fuel5,21)	(fuel5,22)
U-234	8.83E-08	8.80E-08	8.76E-08	8.74E-08	8.71E-08	8.69E-08	8.68E-08	8.66E-08	8.65E-08	8.64E-08	8.64E-08
U-235	4.51E-06	4.42E-06	4.35E-06	4.29E-06	4.24E-06	4.20E-06	4.16E-06	4.13E-06	4.11E-06	4.09E-06	4.07E-06
U-236	1.21E-06	1.22E-06	1.23E-06	1.24E-06	1.25E-06	1.26E-06	1.26E-06	1.27E-06	1.27E-06	1.27E-06	1.27E-06
U-237	1.81E-09	1.62E-09	1.43E-09	1.25E-09	1.08E-09	9.18E-10	7.76E-10	6.50E-10	5.37E-10	4.35E-10	3.36E-10
U-238	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04
U-239	1.29E-10	1.12E-10	9.54E-11	8.09E-11	6.81E-11	5.69E-11	4.72E-11	3.87E-11	3.11E-11	2.42E-11	1.68E-11
NP-237	4.78E-08	4.86E-08	4.93E-08	5.00E-08	5.05E-08	5.10E-08	5.14E-08	5.17E-08	5.20E-08	5.23E-08	5.25E-08
NP-238	2.59E-10	2.30E-10	2.02E-10	1.75E-10	1.50E-10	1.28E-10	1.07E-10	8.92E-11	7.27E-11	5.76E-11	4.42E-11
NP-239	1.95E-08	1.69E-08	1.45E-08	1.24E-08	1.05E-08	8.76E-09	7.29E-09	6.00E-09	4.86E-09	3.83E-09	2.79E-09
NP-240	3.97E-13	2.98E-13	2.19E-13	1.58E-13	1.13E-13	7.90E-14	5.45E-14	3.68E-14	2.39E-14	1.47E-14	7.67E-15
PU-238	1.79E-08	1.84E-08	1.89E-08	1.93E-08	1.97E-08	2.00E-08	2.03E-08	2.05E-08	2.07E-08	2.09E-08	2.11E-08
PU-239	4.20E-07	4.20E-07	4.19E-07	4.18E-07	4.18E-07	4.17E-07	4.17E-07	4.16E-07	4.16E-07	4.16E-07	4.16E-07
PU-240	2.62E-07	2.64E-07	2.65E-07	2.67E-07	2.68E-07	2.68E-07	2.69E-07	2.70E-07	2.70E-07	2.71E-07	2.71E-07
PU-241	1.84E-07	1.86E-07	1.87E-07	1.88E-07	1.89E-07	1.89E-07	1.90E-07	1.90E-07	1.90E-07	1.90E-07	1.90E-07
PU-242	1.42E-07	1.46E-07	1.49E-07	1.52E-07	1.54E-07	1.56E-07	1.57E-07	1.59E-07	1.60E-07	1.60E-07	1.61E-07
PU-243	5.02E-12	4.45E-12	3.89E-12	3.37E-12	2.88E-12	2.44E-12	2.05E-12	1.69E-12	1.37E-12	1.08E-12	8.04E-13
AM-241	2.83E-09	2.85E-09	2.90E-09	2.97E-09	3.05E-09	3.15E-09	3.27E-09	3.40E-09	3.53E-09	3.68E-09	3.84E-09
AM-242M	7.93E-11	7.96E-11	8.01E-11	8.08E-11	8.18E-11	8.30E-11	8.42E-11	8.55E-11	8.69E-11	8.82E-11	8.93E-11
AM-242	1.80E-11	1.58E-11	1.38E-11	1.21E-11	1.05E-11	9.13E-12	7.87E-12	6.72E-12	5.64E-12	4.59E-12	3.65E-12
AM-243	3.02E-09	3.11E-09	3.20E-09	3.27E-09	3.33E-09	3.38E-09	3.43E-09	3.47E-09	3.50E-09	3.52E-09	3.54E-09
AM-244	2.98E-12	2.66E-12	2.33E-12	2.02E-12	1.73E-12	1.47E-12	1.24E-12	1.02E-12	8.28E-13	6.49E-13	4.91E-13
CM-242	2.13E-09	2.18E-09	2.20E-09	2.21E-09	2.22E-09	2.21E-09	2.19E-09	2.17E-09	2.14E-09	2.10E-09	2.06E-09
CM-243	3.50E-11	3.60E-11	3.69E-11	3.76E-11	3.82E-11	3.86E-11	3.90E-11	3.93E-11	3.96E-11	3.97E-11	3.99E-11
CM-244	8.45E-10	8.80E-10	9.11E-10	9.38E-10	9.61E-10	9.81E-10	9.98E-10	1.01E-09	1.02E-09	1.03E-09	1.04E-09
XE-135	9.15E-11	8.85E-11	8.53E-11	8.17E-11	7.78E-11	7.36E-11	6.90E-11	6.39E-11	5.81E-11	5.15E-11	4.42E-11
XE-136	9.90E-07	1.00E-06	1.02E-06	1.02E-06	1.03E-06	1.04E-06	1.04E-06	1.05E-06	1.05E-06	1.05E-06	1.06E-06
KR-83	2.99E-08	3.02E-08	3.05E-08	3.07E-08	3.08E-08	3.10E-08	3.11E-08	3.12E-08	3.13E-08	3.13E-08	3.14E-08
ZR-95	8.11E-08	8.07E-08	7.94E-08	7.73E-08	7.48E-08	7.18E-08	6.85E-08	6.50E-08	6.14E-08	5.78E-08	5.41E-08
MO-95	4.02E-07	4.09E-07	4.16E-07	4.22E-07	4.28E-07	4.34E-07	4.40E-07	4.46E-07	4.51E-07	4.56E-07	4.61E-07

	(fuel5,12)	(fuel5,13)	(fuel5,14)	(fuel5,15)	(fuel5,16)	(fuel5,17)	(fuel5,18)	(fuel5,19)	(fuel5,20)	(fuel5,21)	(fuel5,22)
MO-97	4.79E-07	4.85E-07	4.90E-07	4.95E-07	4.99E-07	5.02E-07	5.05E-07	5.07E-07	5.08E-07	5.10E-07	5.11E-07
TC-99	4.72E-07	4.78E-07	4.83E-07	4.88E-07	4.91E-07	4.94E-07	4.97E-07	4.99E-07	5.01E-07	5.02E-07	5.03E-07
RU-101	4.26E-07	4.32E-07	4.37E-07	4.41E-07	4.45E-07	4.48E-07	4.50E-07	4.52E-07	4.54E-07	4.55E-07	4.56E-07
RU-103	3.90E-08	3.83E-08	3.70E-08	3.54E-08	3.34E-08	3.13E-08	2.91E-08	2.68E-08	2.46E-08	2.24E-08	2.02E-08
RH-103	1.93E-07	1.96E-07	1.99E-07	2.02E-07	2.06E-07	2.09E-07	2.12E-07	2.15E-07	2.18E-07	2.21E-07	2.24E-07
RH-105	7.82E-10	6.85E-10	5.93E-10	5.09E-10	4.33E-10	3.66E-10	3.06E-10	2.53E-10	2.05E-10	1.62E-10	1.24E-10
PD-105	1.57E-07	1.60E-07	1.62E-07	1.64E-07	1.66E-07	1.67E-07	1.68E-07	1.69E-07	1.70E-07	1.71E-07	1.71E-07
PD-108	5.55E-08	5.65E-08	5.74E-08	5.81E-08	5.88E-08	5.93E-08	5.97E-08	6.01E-08	6.04E-08	6.07E-08	6.09E-08
AG-109	2.94E-08	2.99E-08	3.03E-08	3.07E-08	3.10E-08	3.13E-08	3.15E-08	3.17E-08	3.19E-08	3.20E-08	3.21E-08
CD-113	2.61E-11	2.61E-11	2.61E-11	2.61E-11	2.61E-11	2.61E-11	2.61E-11	2.61E-11	2.60E-11	2.60E-11	2.60E-11
I-131	6.39E-09	5.64E-09	4.91E-09	4.22E-09	3.60E-09	3.04E-09	2.55E-09	2.12E-09	1.75E-09	1.42E-09	1.12E-09
XE-131	1.95E-07	1.98E-07	2.01E-07	2.04E-07	2.06E-07	2.07E-07	2.09E-07	2.10E-07	2.11E-07	2.12E-07	2.13E-07
XE-133	8.72E-09	7.59E-09	6.52E-09	5.56E-09	4.70E-09	3.94E-09	3.29E-09	2.72E-09	2.22E-09	1.78E-09	1.39E-09
CS-133	5.03E-07	5.11E-07	5.17E-07	5.23E-07	5.28E-07	5.32E-07	5.35E-07	5.38E-07	5.40E-07	5.42E-07	5.44E-07
CS-134	3.29E-08	3.35E-08	3.39E-08	3.43E-08	3.46E-08	3.48E-08	3.49E-08	3.49E-08	3.49E-08	3.49E-08	3.48E-08
PR-141	4.65E-07	4.71E-07	4.77E-07	4.81E-07	4.85E-07	4.88E-07	4.90E-07	4.92E-07	4.94E-07	4.95E-07	4.96E-07
PR-143	1.99E-08	1.81E-08	1.62E-08	1.43E-08	1.24E-08	1.07E-08	9.18E-09	7.78E-09	6.53E-09	5.42E-09	4.43E-09
ND-143	3.09E-07	3.14E-07	3.19E-07	3.23E-07	3.26E-07	3.30E-07	3.32E-07	3.35E-07	3.37E-07	3.38E-07	3.40E-07
ND-144	5.50E-07	5.58E-07	5.65E-07	5.71E-07	5.76E-07	5.81E-07	5.84E-07	5.87E-07	5.90E-07	5.92E-07	5.93E-07
ND-145	2.85E-07	2.89E-07	2.92E-07	2.94E-07	2.97E-07	2.98E-07	3.00E-07	3.01E-07	3.02E-07	3.03E-07	3.03E-07
ND-146	2.63E-07	2.67E-07	2.70E-07	2.72E-07	2.75E-07	2.76E-07	2.78E-07	2.79E-07	2.80E-07	2.81E-07	2.82E-07
PM-147	9.61E-08	9.70E-08	9.76E-08	9.81E-08	9.83E-08	9.85E-08	9.85E-08	9.84E-08	9.82E-08	9.80E-08	9.76E-08
PM-148M	3.44E-10	3.43E-10	3.40E-10	3.36E-10	3.31E-10	3.24E-10	3.16E-10	3.07E-10	2.97E-10	2.85E-10	2.69E-10
PM-148	4.03E-10	3.71E-10	3.37E-10	3.03E-10	2.69E-10	2.36E-10	2.05E-10	1.76E-10	1.48E-10	1.22E-10	9.64E-11
SM-147	2.65E-08	2.69E-08	2.74E-08	2.79E-08	2.84E-08	2.89E-08	2.94E-08	3.00E-08	3.05E-08	3.11E-08	3.16E-08
SM-148	2.78E-08	2.83E-08	2.88E-08	2.93E-08	2.97E-08	3.00E-08	3.04E-08	3.06E-08	3.09E-08	3.11E-08	3.13E-08
PM-149	8.39E-10	7.22E-10	6.13E-10	5.16E-10	4.30E-10	3.56E-10	2.92E-10	2.37E-10	1.89E-10	1.47E-10	1.11E-10
SM-149	8.73E-10	8.72E-10	8.67E-10	8.61E-10	8.53E-10	8.45E-10	8.37E-10	8.29E-10	8.23E-10	8.18E-10	8.14E-10
SM-150	1.07E-07	1.08E-07	1.10E-07	1.11E-07	1.12E-07	1.13E-07	1.13E-07	1.14E-07	1.14E-07	1.14E-07	1.15E-07
PM-151	1.42E-10	1.22E-10	1.04E-10	8.81E-11	7.41E-11	6.19E-11	5.13E-11	4.20E-11	3.38E-11	2.65E-11	2.02E-11
SM-151	4.48E-09	4.52E-09	4.55E-09	4.57E-09	4.59E-09	4.60E-09	4.62E-09	4.63E-09	4.63E-09	4.64E-09	4.65E-09

	(fuel5,12)	(fuel5,13)	(fuel5,14)	(fuel5,15)	(fuel5,16)	(fuel5,17)	(fuel5,18)	(fuel5,19)	(fuel5,20)	(fuel5,21)	(fuel5,22)
SM-152	5.11E-08	5.18E-08	5.24E-08	5.29E-08	5.34E-08	: 5.38E-08	5.41E-08	5.43E-08	5.45E-08	5.47E-08	5.48E-08
EU-153	3.75E-08	3.82E-08	3.87E-08	3.91E-08	3.95E-08	3.98E-08	4.01E-08	4.03E-08	4.05E-08	4.07E-08	4.08E-08
EU-154	7.00E-09	7.14E-09	7.26E-09	7.36E-09	7.45E-09	7.52E-09	7.58E-09	7.62E-09	7.66E-09	7.69E-09	7.71E-09
EU-155	2.11E-09	2.14E-09	2.16E-09	2.18E-09	2.19E-09	2.19E-09	2.19E-09	2.19E-09	2.19E-09	2.18E-09	2.17E-09
GD-155	2.04E-11	2.32E-11	2.66E-11	3.04E-11	3.48E-11	3.98E-11	4.55E-11	5.19E-11	5.91E-11	6.74E-11	7.68E-11
GD-156	1.38E-08	1.42E-08	1.45E-08	1.47E-08	1.49E-08	1.51E-08	1.53E-08	1.54E-08	1.55E-08	1.56E-08	1.57E-08
GD-157	1.59E-11	1.61E-11	1.62E-11	1.63E-11	1.63E-11	1.64E-11	1.64E-11	1.64E-11	1.65E-11	1.65E-11	1.64E-11
B-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SI	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04	2.75E-04
C	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02	5.23E-02
O-16	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04	2.46E-04

Cross-sections and depletion chains

The isotope chains to be treated and which were used in the VSOP99 equilibrium analyses are given below. Please note that although only Xe-135 of the Xe-135 chain is shown, the simplified iodine-xenon chain was treated. The lumped fission product was not included in the generated library, while the thorium chain is in VSOP99 by default although not applicable.

Table A.6: Isotopes included in the benchmark definition/burn-up chain

No.	Isotopes treated explicitly and identified for burn-up calculations	
1.	Heavy Metal Isotopes	
	1	TH-232
	2	TH-233
	3	PA-233
	4	U -233
	5	U -234
	6	U -235
	7	U -236
	8	U -237
	9	U -238
	10	U -239
	11	NP-237
	12	NP-238
	13	NP-239
	14	NP-240
	15	PU-238
	16	PU-239
	17	PU-240
	18	PU-241
	19	PU-242
	20	PU-243
	21	AM-241
	22	AM-242M
	23	AM-242
	24	AM-243
	25	AM-244
	26	CM-242
	27	CM-243
	28	CM-244
2.	Fission Products:	
	29	XE-135
	30	FP44
	31	XE-136

No.	Isotopes treated explicitly and identified for burn-up calculations	
	45	I -131
	46	XE-131
	47	XE-133
	48	CS-133
	49	CS-134
	50	PR-141
	51	PR-143
	52	ND-143
	53	ND-144
	54	ND-145
	55	ND-146
	56	PM-147
	57	PM-148M
	58	PM-148G
	59	SM-147
	60	SM-148
	61	PM-149
	62	SM-149
	63	SM-150
	64	PM-151
	65	SM-151
	66	SM-152
	67	EU-153
	68	EU-154
	69	EU-155
	70	GD-155
	71	GD-156
	72	GD-157
3.	Other Isotopes:	
	73	B - 10
	74	B - 11
	75	SI

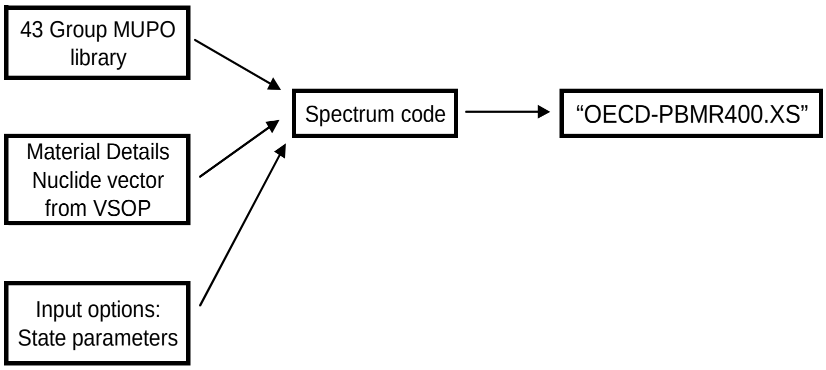
No.	Isotopes treated explicitly and identified for burn-up calculations	
	32	KR- 83
	33	ZR- 95
	34	MO- 95
	35	MO- 97
	36	TC- 99
	37	RU-101
	38	RU-103
	39	RH-103
	40	RH-105
	41	PD-105
	42	PD-108
	43	AG-109
	44	CD-113

No.	Isotopes treated explicitly and identified for burn-up calculations	
	76	CR
	77	MN- 55
	78	FE-(NAT)
	79	CO- 59
	80	NI
	81	CU
	82	MO
	83	B -(NAT)
	84	C
	85	O - 16
	86	H - 1

Appendix B: Cross-section generation process

A new standalone code called "SPECTRUM" was developed and used to generate the state-parameter-dependent transient benchmark cross-sections set called "OECD-PBMR400.XS", used in the coupled steady-state and transient cases. This section provides a short description of the code and basic library as well as some additional data used in the code. The code is based on the spectrum code called TISPEC, based on the MUPO programme ([8] and [9]).The calculational procedure has now been simplified significantly as shown in the following diagramme.

Figure B.1: Calculational procedure for generating "OECD-PBMR400.XS"



The procedure and input files to generate the cross-section library have borrowed extensively from the standard process to generate cross-sections as a function of polynomials for TINTE. The input file was kept similar to those used in the TISPEC code so that the same exported material isotopic data from VSOP99 could be used. For each material, a character title and material number is provided, followed by the isotopic composition defined by the nuclide ID and number density. The number and values of the five state parameters are also repeated for each material. The code then performs the spectrum calculation for all combinations of the state parameters and directly creates the multi-dimensional cross-section tables in the required format.

For completeness some of the additional data used in the code is also provided, which might be useful if participants later wish to create their own libraries and compare them with the benchmark. The kappa or energy release per fission is calculated for each material using the fission fractions of the different fissionable isotopes and the total energy released as given in Table B.1.

Table B.1: Fission energy release (MeV) for the fissionable isotopes [10]

Fissionable Isotope	^{235}U	^{232}Th	^{233}U	^{234}U	^{236}U	^{238}U	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Total utilisable energy per fission, $E_{f,eq}$	193.7*	185	191.1	189.6	191.9	194.8*	199.9*	197	202*	199.1

At the third meeting, the values were questioned since they seemed low. Comparisons with the WIMS9 library kappa information confirmed that they are ~4% lower. The values were, however, confirmed to correspond to the data used in TINTE and the DIN standard referenced in TINTE documentation (and also confirmed with JEFF 2.2 data where ^{235}U value is 193.73 MeV). Based on this, the data will thus not be updated in the OECD benchmark library.

The β's provided in the library were also calculated in the SPECTRUM code for each material in the same way (weighted average) by using the calculated fission fractions for ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{242}Pu (all the fissionable isotopes relative fissions). Therefore the β's are different for each material and case (state parameter set) but is not group-dependent. Also note that the β's used are physical values and not corrected by the appropriate importance functions to obtain the correct β_{eff}. Since the same cross-section library is used by all participants, it was decided to keep the β's unchanged, but when future comparisons are made with independent libraries, this should be taken into account.

* From supplement 1 of DIN 25 485 [6].

Appendix C: Cross-section table example

Two examples of the data given for a reflector and fuel material are given below.

Reflector material (MAT 1):

For the reflector material the data sets given are:

- number of state parameters (always 5);
- number of variations per state parameter (0 for fuel temperature, 7 for moderator temperature, 3 for fast buckling, 3 for thermal buckling, and 0 for xenon concentration).

For each of the 34 quantities (fast D radial, fast D axial, fast total cross-section, etc.) on the library, the following "Data set (0,7,3,3,0,63)" is given:

- seven moderator temperatures;
- three fast buckling data values;
- three thermal buckling data values;
- 7 x 3 x 3 = 63 total number of cross-sections/data values given for the combination of state parameters as described.

```
************************************************************
     1  "**** MODUL **REFL Graphite    0.                            "
*
   5
   0   7   3   3   0
*Fast D radial
  3.0000E+02  6.0000E+02  8.0000E+02  1.1000E+03  1.4000E+03  1.8000E+03  2.2000E+03
 -6.5000E-01 -1.0000E-04  1.0000E-02
 -1.1000E-03  5.0000E-05  1.0000E-02
  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01
  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01
  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01  9.5300E-01
  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01
  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01
  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01  9.5698E-01
  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01
  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01
  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01  9.9251E-01
*Fast D axial
                 Data set (0,7,3,3,0,63) ...
*Fast Total
                 Data set (0,7,3,3,0,63) ...
*Fast Abs
                 Data set (0,7,3,3,0,63) ...
*Fast Nu-Fiss
                 Data set (0,7,3,3,0,63) ...
*Fast Fission
                 Data set (0,7,3,3,0,63) ...
*Fast Down-scat
                 Data set (0,7,3,3,0,63) ...
```

```
*Fast 1/v
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 1
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 2
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 3
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 4
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 5
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 6
                 Data set (0,7,3,3,0,63) ...
*Fast Fiss engy
                 Data set (0,7,3,3,0,63) ...
*Fast Xe abs
                 Data set (0,7,3,3,0,63) ...
*Therm D radial
                 Data set (0,7,3,3,0,63) ...
*Therm D axial
                 Data set (0,7,3,3,0,63) ...
*Therm Total
                 Data set (0,7,3,3,0,63) ...
*Therm Abs
                 Data set (0,7,3,3,0,63) ...
*Therm Nu-Fiss
                 Data set (0,7,3,3,0,63) ...
*Therm Fission
                 Data set (0,7,3,3,0,63) ...
*Therm Up-scat
                 Data set (0,7,3,3,0,63) ...
*Therm 1/v
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 1
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 2
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 3
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 4
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 5
                 Data set (0,7,3,3,0,63) ...
*Delayed frac 6
                 Data set (0,7,3,3,0,63) ...
*Therm Fis engy
                 Data set (0,7,3,3,0,63) ...
*Therm Xe abs
                 Data set (0,7,3,3,0,63) ...
*Iodine yield
                 Data set (0,7,3,3,0,63) ...
*Xe yield
                 Data set (0,7,3,3,0,63) ...
```

Fuel material (MAT 101):

For the fuel material the data sets given are:

- number of state parameters (always 5);
- number of variations per state parameter (4 for fuel temperature, 7 for moderator temperature, 3 for fast buckling, 3 for thermal buckling and 3 for xenon concentration).

For each of the 34 quantities (fast D radial, fast D axial, fast total cross-section, etc.) the following "Data set (4,7,3,3,3,756)" is given:

- four fuel temperatures;
- seven moderator temperatures;
- three fast buckling data values;
- three thermal buckling data values;
- three xenon concentrations;
- 4 x 7 x 3 x 3 x 3 = 756 total number of cross-sections/data values given for the combination of state parameters as described.

```
************************************************************
   101  "**** MODUL **CORE  1***     221.                            "
*
   5
   4   7   3   3   3
*Fast D radial
  3.0000E+02  8.0000E+02  1.4000E+03  2.4000E+03
  3.0000E+02  6.0000E+02  8.0000E+02  1.1000E+03  1.4000E+03  1.8000E+03  2.2000E+03
 -1.0000E-04  1.0000E-04  4.0000E-03
 -2.5000E-03 -1.0000E-05  5.0000E-03
  1.0000E-15  2.0000E-11  8.0000E-10
  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00
  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00
  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00
  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00
  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00
  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00
  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00
  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00
  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00
  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00
  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00
  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00
  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00
  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00
  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00
  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00
  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00
  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00
  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00
  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00
  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00
  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00
  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00
  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00
  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00
  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00
  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00
  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00
  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00
  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00
  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00
  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00
  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00
  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00
  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00
  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00
  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00
  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00
  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00
  1.9665E+00  1.9674E+00  1.9684E+00  1.9652E+00  1.9665E+00  1.9674E+00  1.9684E+00
  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00
  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00
  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00
  1.9809E+00  1.9819E+00  1.9828E+00  1.9797E+00  1.9809E+00  1.9819E+00  1.9828E+00
  2.2514E+00  2.2524E+00  2.2530E+00  2.2537E+00  2.2514E+00  2.2524E+00  2.2530E+00
```

2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00
2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00
2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00
1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00
1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00
1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00
1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00
1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00
1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00
1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00
1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00
2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00
2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00
2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00
2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00
1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00
1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00
1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00
1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00
1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00
1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00
1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00
1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00
2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00
2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00
2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00
2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00
1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00
1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00
1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00
1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00
1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00
1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00
1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00
1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00
2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00
2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00
2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00
2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00
1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00
1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00
1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00
1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00
1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00
1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00
1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00
1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00
2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00
2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00
2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00
2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00
1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00
1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00
1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00
1.9665E+00	1.9674E+00	1.9684E+00	1.9652E+00	1.9665E+00	1.9674E+00	1.9684E+00
1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00
1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00
1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00
1.9809E+00	1.9819E+00	1.9828E+00	1.9797E+00	1.9809E+00	1.9819E+00	1.9828E+00
2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00
2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00
2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00
2.2524E+00	2.2530E+00	2.2537E+00	2.2514E+00	2.2524E+00	2.2530E+00	2.2537E+00

```
*Fast D axial
                 Data set (4,7,3,3,3,756) ...
*Fast Total
                 Data set (4,7,3,3,3,756) ...
*Fast Abs
                 Data set (4,7,3,3,3,756) ...
*Fast Nu-Fiss
                 Data set (4,7,3,3,3,756) ...
*Fast Fission
                 Data set (4,7,3,3,3,756) ...
*Fast Down-scat
                 Data set (4,7,3,3,3,756) ...
*Fast 1/v
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 1
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 2
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 3
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 4
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 5
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 6
                 Data set (4,7,3,3,3,756) ...
*Fast Fiss engy
                 Data set (4,7,3,3,3,756) ...
*Fast Xe abs
                 Data set (4,7,3,3,3,756) ...
*Therm D radial
                 Data set (4,7,3,3,3,756) ...
*Therm D axial
                 Data set (4,7,3,3,3,756) ...
*Therm Total
                 Data set (4,7,3,3,3,756) ...
*Therm Abs
                 Data set (4,7,3,3,3,756) ...
*Therm Nu-Fiss
                 Data set (4,7,3,3,3,756) ...
*Therm Fission
                 Data set (4,7,3,3,3,756) ...
*Therm Up-scat
                 Data set (4,7,3,3,3,756) ...
*Therm 1/v
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 1
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 2
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 3
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 4
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 5
                 Data set (4,7,3,3,3,756) ...
*Delayed frac 6
                 Data set (4,7,3,3,3,756) ...
*Therm Fis engy
                 Data set (4,7,3,3,3,756) ...
*Therm Xe abs
                 Data set (4,7,3,3,3,756) ...
*Iodine yield
                 Data set (4,7,3,3,3,756) ...
*Xe yield
                 Data set (4,7,3,3,3,756) ...
```

Appendix D: Applicable KTA-rules

Heat transfer and fluid property equations

Heat transfer between the spherical fuel elements and the coolant gas occurs in the thermal boundary layer surrounding the fuel element. In this thin layer it is considered that heat conduction is equal in importance to heat convection, whereas outside this layer the heat conduction is relatively small.

For a spherical fuel element in a gas stream, the heat transfer Q (in W) from the pebble to the surrounding gas is calculated by [4]:

$$Q = \alpha A_k (T_k - T_g) \quad (1)$$

Where:

A_k is the surface area of fuel element in m^2;

T_k, is the average fuel element surface temperature in K;

T_g is the gas temperature in K;

α is the mean heat transfer coefficient of the fuel element surface in Wm^{-2}K^{-1}.

$$Q = \alpha A_k (T_k - T_g)$$

The heat transfer coefficient α is calculated by [4]:

$$\alpha = \frac{\mathrm{Nu}\lambda}{d} \quad (2)$$

Where:

λ is the heat (thermal) conductivity of the gas in Wm^{-1}K^{-1};

Nu is the Nusselt number (dimensionless);

d is the outer diameter of the fuel element in m.

The heat conductivity of helium is well studied and is calculated from experimentally measured parameters [3]:

$$\lambda = 2.682\times10^{-3}\, T^{0.71(1.0-2.0\times10^{-6}P)}(1.0+1.123\times10^{-5}P) \quad (3)$$

Where:

P is the pressure in kPa;

T is the temperature in K.

The Nusselt number is a dimensionless coefficient of heat transfer and determines the size of the thermal boundary layer. The Nusselt number measures the enhancement of heat transfer from a surface which occurs in a "real" situation, compared to the heat transfer that would be measured if only conduction could occur. Typically, it is used to measure the enhancement of heat transfer when convection takes place. The Nusselt number for spherical fuel elements in a pebble bed core is given by [4]:

$$\mathrm{Nu} = 1.27\frac{\mathrm{Pr}^{1/3}}{\varepsilon^{1.18}} + 0.033\frac{\mathrm{Pr}^{1/2}}{\varepsilon^{1.07}}\mathrm{Re}^{0.86} \qquad 4$$

Where:

ε is the porosity of the bed, i.e. the relation between the volume filled by the gas and the total volume of the reactor packed with fuel elements. Thus $(1-\varepsilon)$ is the sphere packing factor;

Pr is the Prandtl number (dimensionless);

Re is the Reynolds number (dimensionless).

The Reynolds number is a non-dimensional parameter that compares the inertia to viscous forces. If the Reynolds number is low, then viscosity plays an important part in the flow phenomena. The Reynolds number determines whether the gas flow over the fuel spheres is laminar or turbulent. The two types of flow, laminar or turbulent, have different heat transfer mechanisms, and influence the formation and size of the thermal boundary layer. The Reynolds number is calculated by the following equation:

$$\mathrm{Re} = \frac{\left(\dot{m}/A\right)d}{\eta} \qquad 5$$

Where:

$\dot{m}$ is the helium mass flow through the core in kgs^{-1};

A is the core (sphere pile) cross-section in m^2;

η is the dynamic viscosity of the gas (helium) in $\mathrm{kgm}^{-1}\mathrm{s}^{-1}$, defined in Equation 7.

The Prandtl number is the non-dimensional ratio between the product of heat advection and viscous forces and the product of heat diffusion and inertial forces in a given fluid. Standard thermo-fluids textbooks define Pr as:

$$\mathrm{Pr} = \frac{\eta\, C_P}{\lambda} \qquad 6$$

Where:

λ is the heat (thermal) conductivity of the gas in $\mathrm{Wm}^{-1}\mathrm{K}^{-1}$, defined in Equation 3;

C_P is the specific heat of the gas at constant pressure;

([3] gives for helium $C_P = 5195\ \mathrm{Jkg}^{-1}\mathrm{K}^{-1}$);

η is the dynamic viscosity of the gas (helium) in $\mathrm{kgm}^{-1}\mathrm{s}^{-1}$.

The dynamic viscosity η of the coolant gas (helium) is a function of the temperature and is given as [3]:

$$\eta = 3.674\times10^{-7}\,T^{0.7} \qquad 7$$

Where:

T is the gas (helium) temperature in K.

The pressure drop through the core is defined by [5]:

$$\Delta P = H\,\Psi\left(\frac{1-\varepsilon}{\varepsilon^3}\right)\left(\frac{1}{2d\rho}\right)\left(\frac{\dot{m}}{A}\right)^2 \qquad 8$$

Where:

H is the height of the reactor core in m;

Ψ is the coefficient of pressure loss defined in Equation 10;

ρ is the density of the gas (helium) in kgm^{-3}.

The density of the helium is defined by [3]:

$$\rho = \frac{0.4814\left(\frac{P}{T}\right)}{\left(1+0.446\times 10^{-2}\frac{P}{T^{1.2}}\right)} \qquad 9$$

Where:

P is the pressure in kPa;

T is the temperature in K.

The coefficient of loss of pressure through friction shall be determined in accordance with the following empirical correlation [5]:

$$\Psi = \frac{320}{\left(\frac{\mathrm{Re}}{1-\varepsilon}\right)} + \frac{6}{\left(\frac{\mathrm{Re}}{1-\varepsilon}\right)^{0.1}} \qquad 10$$

Where:

Re is the Reynolds number defined in Equation 5.

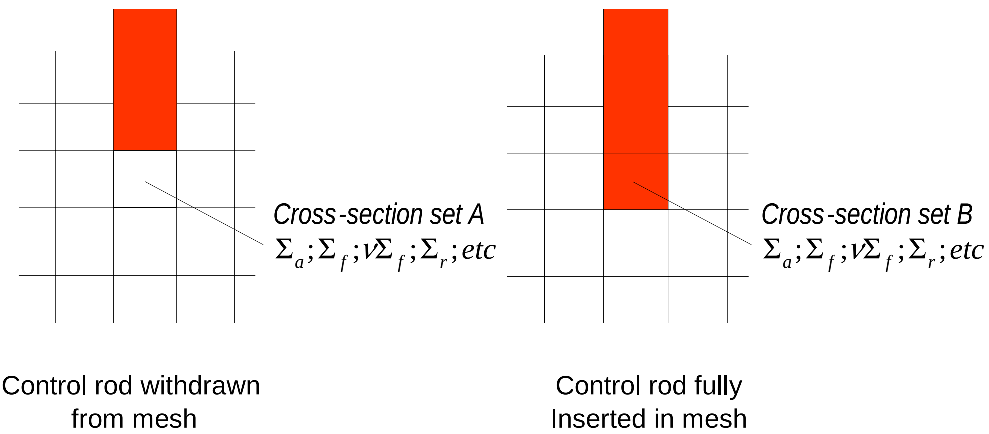
Appendix E: Additional notes needed for CASE 5

Modelling of control rods as grey curtain–Treatment of partially rodded meshes and prevention of the cusping effect

The control rods positioned in the side reflector cannot be represented explicitly in two-dimensional axisymmetric geometry. A number of models are commonly used to overcome this limitation. The "grey" curtain model is adopted in this benchmark. This models the 24 control rods as a ring or curtain of absorber material (for all azimuthal meshes – symmetry in 2D) by defining a material with an effective boron concentration that conserves the reactivity effect of the control rods. This method can be used with great success to conserve the reactivity effect of the control rods.

This model is easily implemented by means of overlaid cross-section sets. Typically, a cross-section set is defined for the control rod fully inserted and one for the control rod withdrawn from a given material mesh as shown in Figure E.1 below.

Figure E.1: Defining cross-section sets for the simulation of control rod movement



When continuous control rod movements need to be simulated, the same principle can be used by adjusting the neutron poison concentration in the given axial mesh where the control rods are partially inserted into.

A typical overlaid cross-section is calculated, in the case of Figure E.1, as $\Sigma = (1-\varsigma)\Sigma_A + \varsigma\,\Sigma_B$. The correct choice of the parameter ς $(0 \le \varsigma \le 1)$ is essential for modelling small control rod movements because the parameter is not linearly dependent on control rod position. If a simple linear relation or volume-weighting is used, the reactivity effect of the partial insertion will be overestimated since the self-shielding effect cannot be modelled correctly and the diluted boron has a relatively too large absorption effect. This leads to the so-called "cusping effect" where the rate of reactivity insertion as a function of rod movement is not smooth. This problem is solved if flux volume-weighting is used to obtain the effective boron concentration in the partially rodded mesh, but an axial flux shape is then needed to get the correct weighting. This axial flux shape within the mesh has to be calculated explicitly or estimated from the available flux information. Typically, this information is not available in many codes. If correct flux-volume-weighting can be performed, this is the preferred method to apply.

A simple approximate method to obtain a smooth reactivity insertion for the partially rodded meshes is given below and is based on the TINTE implementation developed at FZJ, the so-called "Linear Rod Motion Model" (ROMO) [11]. This model uses a special exponential interpolation algorithm for the poison concentration in the partially rodded mesh. The calculation of the variable absorber concentration c* as a function of the insertion length l of the rods in an annular region with partially inserted rods is given by:

$$c^*(l) \;=\; \frac{\ln\left(1 - \frac{l}{L} S\right)}{\ln\left(1 - S\right)} \;*\; c \;, \quad 0 \le l \le L$$

Where:

c absorber concentration in the rod region when rod bank is fully inserted in this region;

c*(l) absorber concentration in the rod region when rod bank is partially inserted in this region over the length l, according to the linear rod motion model;

l insertion length of the rod bank in the rod region;

L length (axial height) of the rod region;

S interpolation factor of the special exponential interpolation scheme of the linear rod motion model, also called "absorber blackness value" because it characterises the neutron absorber poison strength; it is always 0 < S < 1.

The cross-sections of the partially rodded meshes can thus be mixed in this way to reduce the cusping effects. The interpolation factor S is in general dependent on the mesh size and the blackness of the grey curtain and can be found by inspection by performing several K_{eff} calculations at various control rod positions and adjusting the value until a smooth curve, per mesh is obtained, resulting in potentially different S factors per mesh. This treatment is important for the Transient Case T-5. For the 50 cm meshes applicable in the benchmark a starting guess of 0.9 can be used.

A final note: If the mixing of the two sets of cross-sections by volume weighting is applied on a very fine sub-mesh (<5 cm) and not on the material mesh defined (50 cm), the cusping effect will still appear for each of these sub-meshes when they are partially rodded, but the overall effect is much reduced and should not introduce major variations in the overall results.

Calculation of the Kernel temperature (Required for Case T-5)

For steady-state calculations and for many slow transients, the approximation to model the fuel temperature to be the graphite temperature for the inner fuel containing shell (5 cm diameter) of the fuel-sphere is reasonable. This is due to the good thermal conductivity of the graphite, the relatively small differences in the coating properties compared to graphite and the small size of the UO_2 kernels. For fast reactivity insertion transients with steep power increases and it is well known that a heterogeneous kernel model is required to model the transient accurately [12]. In these cases the temperature differences between the kernel and surrounding graphite matrix are significant and the Doppler feedback effect is therefore quite different. The explicit model is therefore essential to model the heat-up of the UO_2 kernels.

An approximation to a complete explicit model is available in the TINTE code system [13] where the temperature in the UO_2 fuel kernel, used for cross-section reconstruction, is calculated for a steady-state case as:

$$T_f = \alpha'_f \, \dot{Q}'''_l + T_m$$

Where:

α'_f = user-supplied parameter;

$\dot{Q}'''_l$ = local heat production in the mesh (Watt/cc);

T_m = matrix (graphite) temperature.

It should be noted that the heat production is defined as being homogenised over a mesh (fuel sphere and helium) and include only the locally deposited heat component – in the benchmark definition this includes all fission heat. This will of course influence the definition of α'_f.

In the time-dependent case, the fuel temperature at the end of the time step is given in terms of the steady-state values as follows (subscripts 0 and 1 indicate the beginning and end of time step, respectively):

$$T_{f1} = A_1 + \left(T_{f0} - A_0\right)e^{-\lambda_f \Delta} + \left(A_0 - A_1\right)\frac{1 - e^{-\lambda_f \Delta}}{\lambda_f \Delta}$$

$$A_0 = \alpha'_f \, \dot{Q}'''_{l0} + T_{m0}$$

$$A_1 \equiv \alpha'_f \, \dot{Q}'''_{l1} + T_{m1}$$

$$\lambda_f = \frac{V_{be}}{SM\left(1 - \varepsilon_{be}\right)} \frac{M_U}{M_{UO_2}} \frac{1}{\alpha'_f \, c_{p,f}}$$

Δ = Time step length (s)

$$V_{be} = \frac{4}{3}\pi R_{be}{}^3$$

R_{be} = fuel sphere radius (3 cm);

SM = heavy metal loading per fuel sphere (9 g);

ε_{be} = pebble bed void fraction (0.39);

M_{UO_2} = molar mass of uranium dioxide fuel (270 g/mol);

M_U = molar mass of low enriched uranium metal (238 g/mol);

$c_{p,f}$ = specific heat capacity for UO_2 fuel (0.3 kJ/kg/K);

Implementation in TINTE:

Calculate λ_f once:

```
BEVOL=ZWPI*(2D0/3D0)*R**3 / TMEI

RHOF=SM*(270D0/238D0)/BEVOL

RHOCPF=RHOF*.3D0

WABL=1D0/PUEBH

ALAM=WABL/RHOCPF
```

Where:

zwpi: 2*π

tmei: Filling fraction

puebh: User supplied parameter α'_f

Calculate for each time step $e^{-\lambda_f \Delta}$ and $\dfrac{1-e^{-\lambda_f \Delta}}{\lambda_f \Delta}$

```
C*   EXPONENTIALFUNKTIONEN FUER PARTIKELBERHITZUNG

        EX=ALAM*DELTN

        IF (EX.GT.5D1) THEN

           EX0=0D0

           EX1=1D0/EX

        ELSEIF (EX.GT.1D-6) THEN

           EX0=DEXP(-EX)

           EX1=(1D0-EX0)/EX

        ELSE

           DD=(1D0+EX/2D0*(1D0+EX/3D0*(1D0+EX/4D0*(1D0+EX/5D0))))

           EX0=1D0/(1D0+DD*EX)

           EX1=DD/(1D0+DD*EX)

        ENDIF
```

Calculate T_{f1} for each mesh:

```
IF (INSTT) THEN
  A1=WQN1*PUEBH+TTPEL1
  A0=WQN0*PUEBH+TTPEL0
  TTFp= A1 + (TFUE0-A0)*EX0-(A1-A0)*EX1
ELSE
  TTFp=WQM*PUEBH+TTPEL1
ENDIF
```

Where:

WGN = power density at beginning and end of time step.

WGM = average power density over time step.

TTPEL = graphite temperature at beginning and end of time step.

INSTT = indicates time-dependent case.

A PUEBH factor of 2.6 should be used and was obtained by comparing TINTE calculations using the given approximated model to the detailed explicit kernel model (Beta version) in TINTE.

Appendix F: Simplified test cases

During the analysis of the PBMR 400 MW benchmark it seemed that participants could benefit from simplified test cases to make sure the models are spatially converged and correct. Such test cases with reference solutions were generously supplied by Dr Hyun Chul Lee from KAERI and could be used by participants to check their models. The results of this exercise will not be part of the final benchmark report.

The test cases are based on the same geometrical description as Steady-state Exercise 1. The problems are defined by replacing the materials with "50"(Fuel) and "153"(Reflector) in the Exercise 1 problem definitions. Appropriate boundary conditions are applied for each case.

- Calculational domain: 0 cm < r < 292.5, -200 cm < z < 1 250 cm (same as Exercise 1).
- Core: 100 cm < r < 185, 0 cm < z <1 100 cm (same as Exercise 1).

Table F.1: Cross-sections: fuel (Material 50 in Exercise 1)

g	D[g]	SigR[g]	NuSigF[g]	SigS[1->2]
1	2.015130E+00	2.610368E-03	2.035350E-04	
2	1.570900E+00	2.926290E-03	4.319000E-03	1.796640E-03

Table F.2: Cross-sections: reflector (material 153 in Exercise 1)

g	D[g]	SigR[g]	NuSigF[g]	SigS[1->2]
1	9.800900E-01	9.870875E-03	0	
2	7.996680E-01	1.866700E-04	0	9.862820E-03
SigR[1] = SigA[1] + SigS[1->2], SigR[2] = SigA[2]				

CASE 0-0:

Geometry → Homogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 50 (Fuel)

Boundary Conditions → Axial: Zero Net Current, Radial: Zero Net Current

Case	k_{eff}
Analytic Solution	1.09381
CAPP Code (310x290)	1.09381
CAPP Code (31x29)	1.09381

CASE 0-1:

Geometry → Homogeneous finite cylinder

Material → Core: 50(Fuel), Other: 50(Fuel)

Boundary Conditions -> Axial: Zero Flux, Radial: Zero Net Current

Case	k_{eff}
Analytic Solution	1.08732
CAPP Code (310x290)	1.08732
CAPP Code (155x145)	1.08732
CAPP Code (31x29)	1.08732

CASE 0-2:

Geometry → Homogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 50 (Fuel)

Boundary Conditions -> Axial: Zero In Current, Radial: Zero Net Current

Case	k_{eff}
CAPP Code (310x290)	1.08738
CAPP Code (155x145)	1.08738
CAPP Code (31x29)	1.08739

CASE 0-3:

Geometry → Homogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 50 (Fuel)

Boundary Conditions → Axial: Zero Net Current, Radial: Zero Flux

Case	k_{eff}
Analytic Solution	1.00576
CAPP Code (310x290)	1.00576
CAPP Code (155x145)	1.00576
CAPP Code (31x29)	1.00578

CASE 0-4:

Geometry → Homogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 50 (Fuel)

Boundary Conditions → Axial: Zero Net Current, Radial: Zero In Current

Case	k_{eff}
CAPP Code (310x290)	1.00781
CAPP Code (155x145)	1.00781
CAPP Code (31x29)	1.00783

CASE 0-5:

Geometry → Homogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 50 (Fuel)

Boundary Conditions → Radial: Zero Flux, Axial: Zero Flux

Case	k_{eff}
Analytic Solution	1.00005
CAPP Code (310x290)	1.00005
CAPP Code (155x145)	1.00006
CAPP Code (31x29)	1.00008

CASE 0-6:

Geometry → Homogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 50 (Fuel)

Boundary Conditions → Radial: Zero In Current, Axial: Zero In Current

Case	k_{eff}
CAPP Code (310x290)	1.00214
CAPP Code (155x145)	1.00214
CAPP Code (31x29)	1.00217

CASE 0-7:

Geometry: Heterogeneous finite cylinder

Material → Core: 50(Fuel), Other: 153(Reflector)

Boundary Conditions → Radial: Zero Flux, Axial: Zero Flux

Case	k_{eff}
CAPP Code (1240x1160)	1.03235
CAPP Code (930x870)	1.03234
CAPP Code (620x580)	1.03232
CAPP Code (310x290)	1.03224
CAPP Code (155x145)	1.03191
CAPP Code (31x29)	1.02412

CASE 0-8:

Geometry: Heterogeneous finite cylinder

Material → Core: 50 (Fuel), Other: 153 (Reflector)

Boundary Conditions → Radial: Zero In Current, Axial: Zero In Current

Case	k_{eff}
CAPP Code (1240x1160)	1.03271
CAPP Code (930x870)	1.03271
CAPP Code (620x580)	1.03269
CAPP Code (310x290)	1.03261
CAPP Code (155x145)	1.03228
CAPP Code (31x29)	1.02448

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List of abbreviations

Abbreviation or Acronym	Definition
2D	Two-dimensional
3D	Three-dimensional
AVR	Arbeitsgemeinschaft Versuchsreaktor (German for Jointly-operated Prototype Reactor)
BR	Bottom Reflector
CB	Core Barrel
CBCS	Core Barrel Conditioning System
CR	Control Rod
DIN	Deutsches Institut für Normung e. V. (German Institute of Standards)
DLOFC	Depressurized Loss of Forced Cooling
DPP	Demonstration Power Plant
Eskom	Eskom Limited - RSA
FZJ	Forschungszentrum Jülich GmbH (Jülich Research Centre)
GmbH	Gesellschaft mit beschraenkter Haftung (German for Proprietary Limited)
GT-MHR	Gas Turbine Modular High-temperature Reactor
HTGR	High Temperature Gas-cooled Reactor
HTR	High Temperature Reactor
IAEA	International Atomic Energy Agency
KTA	Kerntechnischer Ausschuss (German Nuclear Safety Standards Commission)
MEDUL	MeherfachDUrchLauf (German for recirculation)
MWd/tU	Megawatt days per tonne uranium
Necsa	South African Nuclear Energy Corporation
NPP	Nuclear Power Plant
OECD	Organization for Economic Co-operation and Development
PBMM	Pebble Bed Micro Model
PBMR	Pebble Bed Modular Reactor SOC Ltd.
PCU	Power Conversion Unit
PLOFC	Pressurized Loss of Forced Cooling
PyC	Pyrolytic Carbon
R&D	Research and Development
RCCS	Reactor Cavity Cooling System
RCS	Reactivity Control System
RPV	Reactor Pressure Vessel
RSS	Reserve Shutdown System
RU	Reactor Unit

SAS	Small Absorber Sphere
SCRAM	Safety Control Rod Axe Man (historic - as applied to reactor trip event)
SiC	Silicon Carbide
SR	Side Reflector
TBD	To be Determined
TINTE	Time Dependent Neutronics and Temperatures
TR	Top Reflector
TRISO	Triple Coated Isotropic Particle
USA	United States of America
VSOP	Very Superior Old Program
VSOP99	VSOP (Very Superior Old Program) version 99