

Institute of Energy and Climate Research (IEK)  
Safety Research and Reactor Technology (IEK-6)

# **Computer Code System V. S. O. P. (99/11) Update 2011 of V.S.O.P(99)-Version 2009 CODE MANUAL**

*H.J. Rütten, K.A. Haas, C. Pohl*





**Computer Code System V. S. O. P. (99/11)  
Update 2011 of V.S.O.P(99)-Version 2009  
CODE MANUAL**

*H.J. Rütten, K.A. Haas, C. Pohl*

Berichte des Forschungszentrums Jülich; 4348  
ISSN 0944-2952  
Institute of Energy and Climate Research (IEK)  
Safety Research and Reactor Technology (IEK-6)  
Jül-4348

Vollständig frei verfügbar im Internet auf dem Jülicher Open Access Server (JUWEL)  
unter <http://www.fz-juelich.de/zb/juwel>

Zu beziehen durch: Forschungszentrum Jülich GmbH · Zentralbibliothek, Verlag  
D-52425 Jülich · Bundesrepublik Deutschland  
☎ 02461 61-5220 · Telefax: 02461 61-6103 · e-mail: [zb-publikation@fz-juelich.de](mailto:zb-publikation@fz-juelich.de)





## CONTENTS

	Page
<b>1. Introduction, Matter of Code Update</b>	<b>1</b>
<b>2. Basic Data Libraries</b>	<b>2</b>
2.1    GAM-Library	2
2.2    THERMOS-Library	3
<b>3. Installation of the Code System</b>	<b>5</b>
<b>4. Input Manual V.S.O.P.-MS</b>	<b>9</b>
<b>4.1    Steering the execution mode.</b>	<b>S1 – S3      9</b>
<b>4.2    Geometric reactor design</b>	<b>11</b>
4.2.1    2-dimensional (r-z – geometry)	BI1 – BI9      11
4.2.2    3-dimensional	TR1 – TR5      15
<b>4.3    Fuel element design</b>	<b>D1 – D17      18</b>
4.3.1    Specifications	D1 – D4      18
4.3.2    Design of fuel element-types and -variants	D5 – D17      23
4.3.2.1    Coated particles	D7 – D11      24
4.3.2.2    Spherical fuel elements	D12, D13      26
4.3.2.3    Prismatic fuel elements	D14 – D16      28
4.3.2.4    Additional nuclides	D17      29
<b>4.4    Reactor and fuel cycle</b>	<b>V1 – TX26      30</b>
4.4.1    Set up dimensions	V1      30
4.4.2    Definition of materials	V2 – V5      31
4.4.3    Design and operations	V6 – V17      33
4.4.3.1    Case identification	V6      33
4.4.3.2    Definition of reactor batches	V7 – V9      34
4.4.3.3    Data for the burnup calculation	V10, V11      36
4.4.3.4    Control poison search	V12 – V14      37
4.4.3.5    Print-out options and steering	V15      38
4.4.3.6    Steering the performance for spectrum and diffusion calculation	V16, V17      38
4.4.4    Fast and epithermal neutron spectrum	G1 – G12      39
4.4.5    Thermal cell spectrum	T1 – T13      44
4.4.6    Diffusion calculation	C1 – C21      50
4.4.6.1    Title card	C1      50
4.4.6.2    General control	C2 – C6      50
4.4.6.3    Description of neutron flux problem	C7 – C10      52
4.4.6.4    Simulation of void areas	C11 – C17      55
4.4.6.5    Fixed source, specified by zones	C18 – C21      57
4.4.7    Fuel cycle costs calculation	K1 – K12      59
4.4.8    Fuel management	R1 – R34      66
4.4.8.1    General definitions	R1 – R2      66
4.4.8.2    Data for individual fuel types	R3 – R4      67
4.4.8.3    Aging boxes for discharged fuel	R5      69



4.4.8.4	Instructions for the burnup cycles	R6 – R27	69
4.4.8.5	Criticality search for the reloads	R28 – R31	85
4.4.8.6	Redefinition of CITATION edit options	R32	87
4.4.8.7	Extracted nuclides for printout	R33	87
4.4.8.8	‘Status of core’ – data set for TINTE	R 34	87
4.4.9	Fuel power histogram for decay power evaluation	LF1 – LF3	88
4.4.10	Fuel irradiation histogram for entire isotope generation	P	89
4.4.11	Preparing THERMOS-library	TTTT1 – TTTT5	90
4.4.12	2d-Thermal hydraulics	TX1 – TX26	92
<b>5.</b>	<b>Input Manual V.S.O.P. - ZUT</b>		<b>108</b>
5.1	Steering the execution mode	<b>ZS</b>	<b>108</b>
5.2	Fuel element design	<b>DZ1 – DZ9</b>	<b>108</b>
5.3	Resonance integral calculation	<b>Z1 – Z17</b>	<b>113</b>
5.3.1	Short input	Z1 – Z6	113
5.3.2	Resonance parameters	Z7 – Z9	117
5.3.3	Explicit fuel element design	Z10 – Z16	119
5.3.4	Opening of a new resonance integral data set (‘resint’)	Z17	122
<b>Appendix:</b>	<b>Structure of the code and program tasks</b>		<b>123</b>
<b>References</b>			<b>126</b>

## **List of Figures**

	<b>Page</b>
Fig. 1: Installation scheme of code executables and libraries	5
Fig. 2: Built-in fission product chain	20
Fig. 3: Calculation tasks V.S.O.P. (99/11)	124
Fig. 4: The basic programs of the two code sections	125

## **List of Tables**

Table I: GAM-I-library	2
Table II: Available THERMOS libraries	3
Table III: THERMOS-library	4
Table IV: List of Data Sets	6
Table V: Sequence of nuclides	19
Table VI: Fission product yields	21
Table VII: Alternative specifications of fuel rods	29
Table VIII: Available formulas of heat capacity	98
Table IX: Available formulas of thermal conductivity	99
Table X: Alternative specifications of spherical fuel elements	111



## **1. Introduction, Matter of Code Update**

V.S.O.P. is a computer code system for the comprehensive numerical simulation of the physics of thermal reactors. The application of the code implies processing of cross sections, the set-up of the reactor and of the fuel element, neutron spectrum evaluation, neutron diffusion calculation, fuel burnup, fuel shuffling, reactor control, and thermal hydraulics of steady states and transients. The neutronics calculations can be performed in up to three dimensions. Thermal hydraulics is restricted to gas-cooled reactors in two spatial dimensions. Evaluation of fuel cycle costs over the reactor life time is made using the present worth method. A broad description of the features of the code has been published in Ref. /1/.

Presently there is a lot of national and international research being performed on strategies to transmute long-lived radioactive nuclides –produced during reactor operation- into short-lived ones by separation of these isotopes from the nuclear waste and subsequent recycling in thermal reactors, thus achieving a reduction of the time period required for the safe enclosure of the nuclear waste in the long-term repositories. Recycling these elements leads to much higher concentrations in the applied fuel elements than in case of conventional fuel like low-enriched Uranium or highly-enriched Uranium with Thorium as fertile material, exclusively. This involves the necessity for a more detailed numerical treatment of these isotopes, in particular of an explicit treatment of the Doppler-broadening and the spatial and energetic shielding in the resonance range of their neutron cross-sections.

While in the last published version of the code-system, V.S.O.P. 99/09 /1/ such an explicit treatment of the resonance properties was performed only for Th-232, U-238, Pu-240 and Pu-242, this procedure has now been extended involving also the Minor Actinides Np-237, Am-241, Am-243, Cm-242 and Cm-244 (see Fig. 1 and Tab. IV).

A broad description of the extension of the resonance data basis of the code is given in /2/.

This manual describes the updated libraries and input data of the new code version 99/11. Users not familiar with earlier versions of the code system also need Ref. /1/ for basic information.

## 2. Basic Data Libraries

### 2.1 GAM-Library

**Table I: GAM-I-library**

Id.-no.	Id.-no.	Id.-no.
1 H-1 Mat 125 ENDFB-VII	64 Pd-105 Mat 4634 ENDFB-VII	123 Gd-158 Mat 6443 ENDFB-VII
2 H-2 Mat 128 ENDFB-VII	65 Pd-106 Mat 4637 ENDFB-VII	124 Tb-159 Mat 6525 ENDFB-VII
3 Be-9 Mat 425 ENDFB-VII	66 Pd-107 Mat 4640 ENDFB-VII	125 Au-197 Mat 7925 ENDFB-VII
4 B(nat) Mat 5 ENDFB-VII	67 Pd-108 Mat 4643 ENDFB-VII	126 Pb Mat 82 ENDFB-VII
5 C Mat 600 ENDFB-VII	68 Pd-110 Mat 4649 ENDFB-VII	127 Bi-209 Mat 8325 ENDFB-VII
6 Th-232 Mat 9040 ENDFB-VII	69 Ag-109 Mat 4731 ENDFB-VII	128 Li-6 Mat 325 ENDFB-VII
7 Pa-233 Mat 9137 ENDFB-VII	70 In-115 Mat 4931 ENDFB-VII	129 Li-7 Mat 328 ENDFB-VII
8 U-233 Mat 9222 ENDFB-VII	71 Cd Mat 48 ENDFB-VII	130 B-10 Mat 525 ENDFB-VII
9 U-234 Mat 9225 ENDFB-VII	72 Cd-110 Mat 4837 ENDFB-VII	132 U-237 Mat 9234 ENDFB-VII
10 U-235 Mat 9228 ENDFB-VII	73 Cd-111 Mat 4840 ENDFB-VII	133 Np-237 Mat 9346 ENDFB-VII
11 U-236 Mat 9231 ENDFB-VII	74 Cd-112 Mat 4843 ENDFB-VII	135 V Mat 2300 ENDFB-VII
12 U-238 Mat 9237 ENDFB-VII	75 Cd-113 Mat 4846 ENDFB-VII	137 Ti Mat 22 ENDFB-VII
13 Np-239 Mat 9352 ENDFB-VII	76 Cd-114 Mat 4849 ENDFB-VII	139 Ag-107 Mat 4725 ENDFB-VII
14 Pu-239 Mat 9437 ENDFB-VII	77 Te-126 Mat 5243 ENDFB-VII	140 Nb-93 Mat 4125 ENDFB-VII
15 Pu-240 Mat 9440 ENDFB-VII	78 Te-128 Mat 5249 ENDFB-VII	141 W(nat) Mat 74 ENDFB-VII
16 Pu-241 Mat 9443 ENDFB-VII	79 Te-130 Mat 5255 ENDFB-VII	142 Ru-105 Mat 4452 ENDFB-VII
17 Pu-242 Mat 9446 ENDFB-VII	80 I-127 Mat 5325 ENDFB-VII	143 Rh-105 Mat 4531 ENDFB-VII
22 N-14 Mat 725 ENDFB-VII	81 I-129 Mat 5331 ENDFB-VII	144 Cs-134 Mat 5528 ENDFB-VII
23 O-16 Mat 825 ENDFB-VII	82 Xe-128 Mat 5437 ENDFB-VII	145 Ce-144 Mat 5849 ENDFB-VII
24 Mg Mat 12 ENDFB-VII	83 Xe-130 Mat 5443 ENDFB-VII	146 Pr-142 Mat 5928 ENDFB-VII
25 Al-27 Mat 1325 ENDFB-VII	84 Xe-131 Mat 5446 ENDFB-VII	147 Pm-148 Mat 6152 ENDFB-VII
26 Si Mat 14 ENDFB-VII	85 Xe-132 Mat 5449 ENDFB-VII	148 Pm-148m Mat 6153 ENDFB-VII
27 Cr Mat 24 ENDFB-VII	86 Xe-134 Mat 5455 ENDFB-VII	149 Zr-95 Mat 4040 ENDFB-VII
28 Mn-55 Mat 2525 ENDFB-VII	87 Xe-135 Mat 5458 ENDFB-VII	151 Ru-103 Mat 4446 ENDFB-VII
29 Fe(nat) Mat 26 ENDFB-VII	88 Xe-136 Mat 4551 ENDFB-VII	152 Xe-133 Mat 5452 ENDFB-VII
30 Co-59 Mat 4279 JEF-1	89 Cs-133 Mat 5525 ENDFB-VII	153 Ce-141 Mat 5840 ENDFB-VII
31 Ni Mat 28 ENDFB-VII	90 Cs-135 Mat 5531 ENDFB-VII	154 Pr-143 Mat 5931 ENDFB-VII
32 Cu Mat 29 ENDFB-VII	91 Cs-137 Mat 5537 ENDFB-VII	155 Pm-149 Mat 6155 ENDFB-VII
33 Se-82 Mat 3449 ENDFB-VII	92 Ba-134 Mat 5637 ENDFB-VII	156 I-131 Mat 5337 ENDFB-VII
34 Br-81 Mat 3531 ENDFB-VII	93 Ba-136 Mat 5643 ENDFB-VII	160 Accumulative fission prod.
35 Kr-83 Mat 3640 ENDFB-VII	94 Ba-137 Mat 5646 ENDFB-VII	164 B-11 Mat 528 ENDFB-VII
36 Kr-84 Mat 3643 ENDFB-VII	95 Ba-138 Mat 5649 ENDFB-VII	165 Hf-174 Mat 7225 ENDFB-VII
37 Kr-85 Mat 3646 ENDFB-VII	96 La-139 Mat 5728 ENDFB-VII	166 Hf-176 Mat 7231 ENDFB-VII
38 Kr-86 Mat 3649 ENDFB-VII	97 Ce-140 Mat 5837 ENDFB-VII	167 Hf-177 Mat 7234 ENDFB-VII
39 Rb-85 Mat 3725 ENDFB-VII	98 Ce-142 Mat 5843 ENDFB-VII	168 Hf-178 Mat 7237 ENDFB-VII
40 Rb-87 Mat 3731 ENDFB-VII	99 Pr-141 Mat 5925 ENDFB-VII	169 Hf-179 Mat 7240 ENDFB-VII
41 Sr-88 Mat 3837 ENDFB-VII	100 Nd-142 Mat 6025 ENDFB-VII	170 Hf-180 Mat 7243 ENDFB-VII
42 Sr-90 Mat 3843 ENDFB-VII	101 Nd-143 Mat 6028 ENDFB-VII	171 W-182 Mat 7431 ENDFB-VII
43 Y-89 Mat 3925 ENDFB-VII	102 Nd-144 Mat 6031 ENDFB-VII	172 W-183 Mat 7434 ENDFB-VII
44 Zr Mat 40 ENDFB-VII	103 Nd-145 Mat 6034 ENDFB-VII	173 W-184 Mat 7437 ENDFB-VII
45 Zr-90 Mat 4025 ENDFB-VII	104 Nd-146 Mat 6037 ENDFB-VII	174 W-186 Mat 7443 ENDFB-VII
46 Zr-91 Mat 4028 ENDFB-VII	105 Nd-148 Mat 6043 ENDFB-VII	175 Pm-151 Mat 6161 ENDFB-VII
47 Zr-92 Mat 4031 ENDFB-VII	106 Nd-150 Mat 6049 ENDFB-VII	176 U-232 Mat 9219 ENDFB-VII
48 Zr-93 Mat 4034 ENDFB-VII	107 Pm-147 Mat 6149 ENDFB-VII	177 Pu-238 Mat 9434 ENDFB-VII
49 Zr-94 Mat 4037 ENDFB-VII	108 Sm-147 Mat 6234 ENDFB-VII	178 Am-241 Mat 9543 ENDFB-VII
50 Zr-96 Mat 4043 ENDFB-VII	109 Sm-148 Mat 6237 ENDFB-VII	179 Am-242 Mat 9546 ENDFB-VII
51 Mo Mat 42 ENDFB-VII	110 Sm-149 Mat 6240 ENDFB-VII	180 Am-242m Mat 9547 ENDFB-VII
52 Mo-95 Mat 4234 ENDFB-VII	111 Sm-150 Mat 6243 ENDFB-VII	181 Am-243 Mat 9549 ENDFB-VII
53 Mo-96 Mat 4237 ENDFB-VII	112 Sm-151 Mat 6246 ENDFB-VII	182 Cm-242 Mat 9631 ENDFB-VII
54 Mo-97 Mat 4240 ENDFB-VII	113 Sm-152 Mat 6249 ENDFB-VII	183 Cm-243 Mat 9634 ENDFB-VII
55 Mo-98 Mat 4243 ENDFB-VII	114 Sm-154 Mat 6255 ENDFB-VII	184 Cm-244 Mat 9637 ENDFB-VII
56 Mo-100 Mat 4249 ENDFB-VII	115 Eu-151 Mat 6325 ENDFB-VII	185 Th-233 Mat 9043 ENDFB-VII
57 Tc-99 Mat 4325 ENDFB-VII	116 Eu-153 Mat 6331 ENDFB-VII	186 U -239 Mat 9240 ENDFB-VII
58 Ru-100 Mat 4437 ENDFB-VII	117 Eu-154 Mat 6334 ENDFB-VII	187 Np-238 Mat 9349 ENDFB-VII
59 Ru-101 Mat 4440 ENDFB-VII	118 Eu-155 Mat 6337 ENDFB-VII	188 Np-240 0-SIGMA
60 Ru-102 Mat 4443 ENDFB-VII	119 Gd-154 Mat 6431 ENDFB-VII	189 Pu-243 Mat 9449 ENDFB-VII
61 Ru-104 Mat 4449 ENDFB-VII	120 Gd-155 Mat 6434 ENDFB-VII	190 Am-244 Mat 9552 ENDFB-VII
62 Rh-103 Mat 4525 ENDFB-VII	121 Gd-156 Mat 6437 ENDFB-VII	
63 Pd-104 Mat 4631 ENDFB-VII	122 Gd-157 Mat 6440 ENDFB-VII	

## 2.2 THERMOS-Library

The THERMOS-library data are given in 30 energy groups ranging from  $10^{-5}$  through 2.05 eV. The library (Tab. III) is subdivided into 2 parts:

- 1) The absorbers with identification numbers identical to those in the GAM-I-library.
- 2) The scatterers with identification numbers made of 4 digits.

For the scattering nuclides scattering kernels have formerly been constructed applying different scattering laws and different temperatures. Tab. III gives the respective information. The basic thermal library provides data in the form of the 96-energy group structure of the THERMALIZATION spectrum code on the basis of ENDF/B-VII. It has been condensed to THERMOS libraries using a neutron spectrum which is representative for the considered reactor (see Table II).

For this purpose the VSOP input must be prepared for the respective reactor design case with one representative spectrum calculation. On input card T1 a blank space for variable CIDTHER tells the code to run THERMALIZATION instead of THERMOS, and the thermal neutron spectrum is preserved for the condensation of the cross sections (see input description of sections 4.4.5 and 4.4.11).

**Table II: Available THERMOS libraries**

Data set name	Neutron spectrum typical for:
therm1515	HTR
therm1516	LWR
therm1517	HWR
therm1518	*
therm1519	*

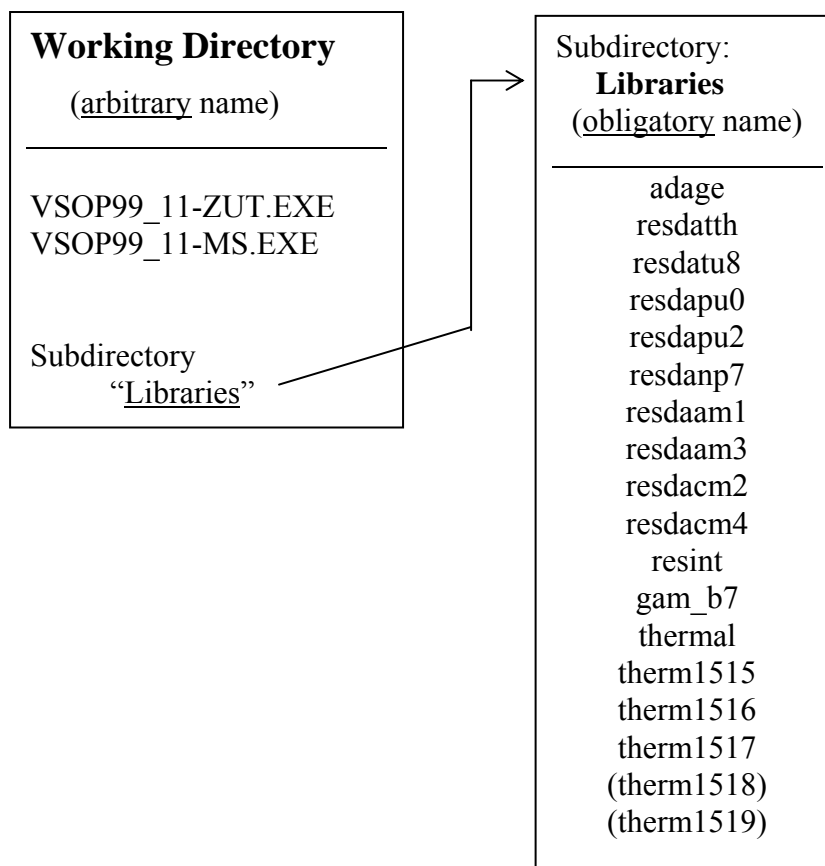
\* reserved for additional libraries to be generated by the user, if desired

**Table III: THERMOS-library**

Id.-no.		Absorber									
		H-1	]	see Scatterer							
		H-2									
		Be-9									
4		B(nat)	see GAM-library								
		C	see Scatterer								
6		]	see GAM-Library								
:											
22											
		O-16	see Scatterer								
24		]	see GAM-library								
:											
190											
Id.-no.		Scatterer									
1012	Beryllium	980 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1013	Beryllium	1366 K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1014	Beryllium	1422 K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1022	Be in BeO	900 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1023	BeO	900 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1101	Hydrogen	293 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1102	Hydrogen	323 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1103	Hydrogen	373 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1104	Hydrogen	473 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1105	Hydrogen	573 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1111	Deuterium	293 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1112	Deuterium	323 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1113	Deuterium	373 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1114	Deuterium	473 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1115	Deuterium	573 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1121	Oxygen	293.6K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1122	Oxygen	323.6K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1123	Oxygen	373.6K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1124	Oxygen	473.6K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1125	Oxygen	573.6K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1126	Oxygen	900 K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1127	Oxygen	1200 K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1128	Oxygen	1350 K	ENDFB-VII	Free gas kernel	Haas/Brockmann/Ohlig	3.2009					
1600	Carbon	300 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1601	Carbon	400 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1602	Carbon	500 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1603	Carbon	600 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1604	Carbon	700 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1605	Carbon	800 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1606	Carbon	900 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1607	Carbon	1000 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1608	Carbon	1100 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1609	Carbon	1200 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1610	Carbon	1300 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1611	Carbon	1350 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1612	Carbon	1500 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1613	Carbon	1650 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1614	Carbon	1800 K	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					
1615	Carbon	2000 k	ENDFB-VII	Scatt. law data	Haas/Brockmann/Ohlig	3.2009					

### 3. Installation of the code system

The FORTRAN source of the code system is structured in two parts to be used for the construction of two executable codes by the compilation and linking procedure. The first executable is named VSOP-ZUT. This code section is used to set up a matrix of resonance cross sections to be used in following applications of the MAIN-section of V.S.O.P. The latter code section is available as the executable code VSOP-MS. The two executables should be positioned within the same directory of the permanent memory device. We name this directory the “Working Directory” (see Fig. 1). The working directory must have a subdirectory, which must be named “Libraries”, containing the various library data files. Necessary read- and write- data transfer from and to these data sets – illustrated in Fig.1- is done automatically during the execution of the code via this path. The name (and possibly the path) of the card image input and of the printout data sets (this sequence) have to be given as arguments when starting the program. All other data sets –unless they are automatically scratched after the end of code execution- are written onto the working directory and they are available for further use ( e.g. Restart-libraries, data to be graphically displayed etc.). A list of the data sets possibly produced or used is given in Table IV. Storage requirement for the executables and the basic libraries associated with the code amounts to about 15 MB. The source codes consist of about 65000 Fortran statements. They have been compiled, linked and used under the WINDOWS-XP operating system.



**Fig. 1: Installation scheme of code executables and libraries**



**Table IV: List of Data Sets**

Units for intermediate or long-term storage of data not automatically scrapped at the end of a calculation:

**a) VSOP-MS**

<b>Log. Unit No.</b>	<b>Data set name</b>	<b>ASCII (A)/ Binary (B)</b>	<b>Description</b>
5	not fixed	(A)	Card image data input. DS-name to be defined by the user at the start of program execution.
6	not fixed	(A)	Print output. DS-name to be defined by the user at the start of program execution.
14	'rstold'	(B)	Read restart data (status of reactor operation), which were produced by a previous VSOP-calculation as data set 'rstnew' (see unit 15).
15	'rstnew'	(B)	Restart data written at the end of the last calculated burnup cycle, to be read from unit 14 as data set 'rstold' in a following restart.
16	'gam_b7'	(A)	GAM-library data.
17	'thermal'	(A)	THERMALIZATION-library data.
18	'thermxxxx'	(A)	THERMOS-library data. with 'xxxx' according to table II:
19	'thermix'	(B)	Results of THERMIX are stored onto this data set in a steady-state calculation. They are retrieved from this data set in a subsequent time-dependent calculation.
28	'nucdens'	(B)	<u>Optional</u> storage of atom densities of each batch.
30	'resint'	(B)	Effective resonance integrals (GAM-group structure) produced and stored in case of a VSOP-ZUT-calculation. To be read and used in a VSOP-MS-calculation.
35	'rstcit'	(B)	Restart data for neutron diffusion section.
37	'geom'	(A)	Geometry data for neutron diffusion and thermodynamics section.
42	'macsig'	(A)	Macroscopic cross sections are stored on this DS.
58	'therlist'	(A)	Some results of the transient THERMIX calculation are stored for further use e.g. in external plot routines.
59	'tempstat'	(A)	Point temperatures (solid material) of <u>steady-state</u> THERMIX-calculation.
61	'nakure'	(B)	Power histogram of the fuel batches for decay power evaluation in subroutine NACHW and in external codes NAKURE and TINTE/MGT /29,30/.
63	'adage'	(A)	Contains the ADAGE-library.
64	'tinte'	(B)	Preserves data for external use (TINTE/MGT code).
67	'origen'	(A)	Preserves data for external use (ORIGEN-JUEL-II).
68	'phiform'	(A)	Point neutron fluxes.
69	'origmod'	(A)	ORIGEN-JÜL-II library (MEDUL-reactors).

76	'birgexcl'	(A)	Core geometry, <u>2</u> -d.
77	'trigplot'	(A)	Core geometry, <u>3</u> -d.
80	'powform'	(A)	Point power densities.
98	'tempinst'	(A)	Point temperatures (solid material) during <u>transient</u> THERMIX calculation.
99	'keff'	(A)	Important data of operation-history.

#### **b) VSOP-ZUT**

24	'resdapu0'	(A)	Resonance parameters of $^{240}\text{Pu}$
25	'resdapu2'	(A)	Resonance parameters of $^{242}\text{Pu}$
26	'resdatu5'	(A)	Resonance parameters of $^{235}\text{U}$ (not part of the present code package)
27	'resdatth'	(A)	Resonance parameters of $^{232}\text{Th}$
28	'resdatu8'	(A)	Resonance parameters of $^{238}\text{U}$
31	'resdanp7'	(A)	Resonance parameters of $^{237}\text{Np}$
32	'resdaam1'	(A)	Resonance parameters of $^{241}\text{Am}$
33	'resdaam3'	(A)	Resonance parameters of $^{243}\text{Am}$
34	'resdacm2'	(A)	Resonance parameters of $^{242}\text{Cm}$
35	'resdacm4'	(A)	Resonance parameters of $^{244}\text{Cm}$

5, 6, 30:      see a) VSOP-MS



## 4. Input Manual V.S.O.P.-MS *(log. unit 5)*

### 4.1 Steering the execution mode. S1 – S3

Card S1		Format (A4,3I4)
1	MODE	<p>= vsop: Complete V.S.O.P.-calculation. Data input may consist of the following parts: card types S, BI <u>or</u> TR (see variable I3D), D, V, G, T, C, K, R, LF, P, TTTT and TX.</p> <p>= geom: Provide geometric reactor design only. Data input consists of cards S, BI (2-d -) <u>or</u> TR (3-d - calculation), exclusively.</p> <p>= fuel: Provide fuel elements design only. Data input consists of cards S and D, exclusively.</p> <p><u>The values of the following 3 items have no meaning in case of a code restart, i.e. if JTPE7 &gt; 0 on card S3!</u></p>
2	JSER	<p>= 0: Diffusion calculation, control poison adjustment, burnup.</p> <p>= 1: Diffusion calculation, burnup.</p> <p>= 2: Diffusion calculation.</p> <p>= 3: Same as 0, but control poison adjustment also in the reflector.</p> <p>= 4: Cell burnup calculation (no diffusion calculation, <math>K_{inf}</math> and group fluxes by means of subroutine KINF).</p> <p>= 5: Same as 4, with control poison adjustment.</p>
3	I3D	<p>= 0: 2-dimensional (r - z) - geometry.      Cards BI required.</p> <p>= 1: 3-dimensional (x - y- z) - geometry.      Cards TR required.</p> <p>= 2: 3-dimensional (<math>\Phi</math> - r - z) - geometry.      Cards TR required.</p>
4	ITTT	<p>= 0: No effect.</p> <p>&gt; 0: Calculate TTTT (section 4.4.11) in order to prepare a new 30-groups THERMOS-library out of the 96-groups THERMALIZATION-library.</p>

Card S2		Format (A72)
		Literal description of case.

Card S3 only if MODE = 'vsop' on card S1.

Card S3		Format (4I4)
1	JTPE7	= 0: Normal start. > 0: Restart. JTPE7 is the identification number of restart data to be retrieved from data set 'rstold'. Data input continues with cards R6 (optionally, see IRR9 below) or R7.
2	JTPE9	= 0: No effect. > 0: Prepare restart data with id. no. JTPE9 from this calculation, write them onto data set 'rstnew' to be used for a following restart.
3	IRR9	= 0: No effect. > 0: For restart only: Card R6 will be given to re-define the options for the first cycle of the restart.
4	IPKEFF	= 0: No effect. > 0: List of operation-history is displayed at the end of a calculation and written onto formatted data set 'keff'.

## 4.2 Geometric reactor design

(only if MODE = 'vsop' or 'geom' on card S1)

### 4.2.1 2-dimensional (r-z – geometry). BI1 – BI9

Cards BI only if I3D = 0 on card S1.

Card BI1		Format (4I6)
1	NCASE	<p>= 0: <u>Parallel</u> flow of spherical fuel elements in vertical flow channels, or no movement of the fuel during reactor operation. Read cards BI1 - BI5.</p> <p>= 1: Flow of fuel pebbles <u>with different speed</u> in various radial channels and/or along non-vertical trajectories. Read cards BI1 - BI9.</p>
2	IPUT	<p>= 0: Normal output.</p> <p>= 1: Test output in addition.</p>
3	IPLOT	<p>= 0: No effect.</p> <p>&gt; 0: Store data for plots on formatted data set 'birgexcl'.</p>
4	KANAL	<p>Pebble bed: Number of flow channels inside the core. (<math>\leq 13</math>) (see NCASE)</p> <p>Non-moving fuel: Number of radial coarse meshes (equal IMAX resulting from card BI3).</p>

For each of the KANAL channels one card BI2.

Card BI2		Format (3I6)
1	KANTYP	<p>= 1: For the <u>outermost</u> core channel.</p> <p>= 0: For all other core channels.</p>
2	KAN	<p>&gt; 0: Number of axial regions in this channel (<math>\leq 100</math>). For each region a set of macroscopic cross sections will be generated. For use in the diffusion calculation, these data are transferred to the grid which is defined on cards BI4. The total number of regions (core + reflector area) is restricted to 1500.</p> <p>= 0: One region only.</p>
3	IBATCH	<p>&gt; 0: Number of batches per region (<math>\leq 15</math>!).</p> <p>The total number of batches in the core is restricted to 2000.</p> <p>= 0: One batch only.</p>

Coarse meshes define the CITATION- and THERMIX- material compositions, the fine meshes define the grid for the neutron flux- and temperature calculation.

One card BI3 for each radial coarse mesh I.

Card BI3		Format (I6,E12.5,I6)
1	IOP(I),	<p>= 0: Coarse mesh is situated <u>within</u> the core area.</p> <p>= 1: Coarse mesh is situated <u>outside</u> the core, still covered by the neutron diffusion section.</p> <p>= 2: Outside the neutron diffusion area, used for THERMIX only.</p> <p>= -1: End of input for radial coarse meshes.</p>
2	DR(I),	Thickness of the I-th radial coarse mesh (cm). In case of NCASE=0 it also defines the width of the flow channel. For NCASE=1 the maximum width of the respective channel defined on card B9 is a good choice within the core area in most cases.
3	MR(I), I=1, ...	<p>Number of fine radial meshes in this coarse mesh. <u>Must be =1, if the coarse mesh represents a void area in any axial position.</u></p> <p>The total number of fine meshes must be <math>\leq 100</math>. Number of meshes within the core area must be <math>\leq 50</math></p> <p>The number of given radial coarse meshes <u>inside the diffusion area</u> defines IMAX (see card BI5).</p>

One card BI4 for each axial coarse mesh N.

Card BI4		Format (I6,E12.5,I6)
1	NOP(N),	<p>= 0: Coarse mesh is situated <u>within</u> the core area.</p> <p>= 1: Coarse mesh is situated <u>outside</u> the core, still covered by the neutron diffusion section.</p> <p>= 2: Outside the neutron diffusion area, used for THERMIX only.</p> <p>= -1: End of input for axial coarse meshes.</p>
2	DZ(N),	Thickness of the N-th axial coarse mesh. (cm)
3	MZ(N), N=1, ...	<p>&gt; 0: Number of fine axial meshes in this coarse mesh. <u>Must be =1, if the coarse mesh represents a void area in any radial position.</u></p> <p>= -1: This coarse mesh represents the void above a pebble-bed core.</p> <p>Total number of fine meshes must be <math>\leq 200</math> (<math>\leq 100</math> inside the core).</p> <p>The number of given axial coarse meshes <u>inside the diffusion area</u> defines NMAX (see card BI5).</p>

Each of the NMAX axial coarse meshes N requires one card BI5.

Card BI5		Format (24I3)
1 . IMAX	LAYVC (I,N), I=1,IMAX	<p>&gt; 0: Id.no. of CITATION material composition, which coarse mesh I is to be assigned to, starting with no. "1" for the first composition <u>outside</u> the core. (The numbers are preliminary and will be renumbered successively after the id. numbers of the core area have been internally defined).</p> <p>= 0: <u>Core area</u>. Id. numbers are defined by the code.</p>

Cards BI6 - BI9 only if NCASE =1 on card BI1.

Card BI6		Format (3I6,3E12.5)
1	KONUS	<p>= 0: No effect.</p> <p>= 1: An outer cone at the bottom of the core structural material is present.</p> <p>= 2: A central reflector column with <u>another</u> cone towards the core bottom is present.</p>
2	IZFEIN	Number of axial meshes of a superposed fine grid for cross section and flux transfer matrix ( $\leq 25000$ ).
3	JRFEIN	Number of radial meshes of the superposed fine grid ( $\leq 10000$ ).
4	EPSY	<p>Convergence criterion for the iteration on the radial position of the mesh points defining the flow channel curves (about 1.E-5).</p> <p>Only if KONUS &gt; 0:</p>
5	RKONUS	Radial thickness of the cone(s). (cm)
6	ZKONUS	Height of the cone(s). (cm)



For each of the KANAL channels one set of cards BI7 - BI9.

Card BI7		Format (I12,E12.5)
1	IJR	<p>&gt; 0: Number of axial mesh points for the definition of the outer limiting curve of this channel (<math>\leq 15</math>). Only for the inner core channels (KANTYP = 0). IJR = 1 defines a straight vertical line.</p> <p>= -1: The value of IJR is taken from the preceding channel. Drop card BI8.</p> <p>= 0: Last core channel. Drop cards BI8, BI9. Limiting curve is internally defined by the information of card BI3.</p>
2	VEKA	<p>&gt; 0.: Only when KANTYP = 0. Ratio of the volume of this channel per volume of the core. Radial mesh points of the limiting curve will be adapted to meet this volume of the channel.</p> <p>= 0.: No adaptation of the limiting curve.</p>
<p>Card BI8 only if IJR &gt; 0 on card BI7.</p> <p>Card BI8                      Format (6E12.5)</p>		
1 . IJR	XWE(J), J=1,IJR	Axial position of the coarse mesh points for the outer limiting curve of this channel (cm), starting from the top of the core (XWE = 0.) down to the bottom (positive values).
<p>Card BI9 only if IJR <math>\neq</math> 0 on card BI7.</p> <p>Card BI9                      Format (6E12.5)</p>		
1 . IJR	YWE(J), J=1,IJR	Radial position of the coarse mesh points for the outer limiting curve of this channel (cm). In case of an annular core, YWE(J) must be given as the distance from the inner limiting curve of the first core channel.

**4.2.2      3-dimensional . TR1 - TR5**  
**(only if MODE = 'vsop' or 'geom' on card S1)**

This part of code defines the 3-dim. pattern of regions in the reactor. VSOP-regions and CITATION-material compositions are identical. They are assigned with the same id. numbers.

Cards TR only if I3D > 0 on card S1.

Card TR1		Format (3I5)
1	MYX	= 0: 1 batch per region. > 0: Number of batches per region.  <u>Note:</u> The total number of regions as well as of batches is limited to 9999 !!
2	IPL	= 0: No effect. > 0: Plot data for plane no. IPL is written onto data set 'trigplot'. (For special purposes only).
3	ICORE	= 0: Normal. > 0: Just for plot data and only for x-y-z-geometry: = 2: Data of 1/2 core-plane are transmuted to 1/1 core-plane. = 4: Data of 1/4 core-plane are transmuted to 1/1 core-plane.

Meshes in X-direction (I3D = 1) or in  $\Phi$  - direction (I3D=2).

Card TR2		Format (6(I3,F9.3))
1	MX(I),	Number of fine meshes in the I-th coarse mesh in X- or in $\Phi$ -direction.
2	DX(I), I=1, ...	> 0.: Thickness of the I-th coarse X-mesh (cm) or $\Phi$ -mesh (degrees) = 0.: End of the input of coarse X- or $\Phi$ - meshes.  The number of given coarse X / $\Phi$ -meshes defines IMX.

Meshes in Y-direction (I3D = 1) or in R – direction (I3D = 2).

Card TR3		Format (6(I3,F9.3))
1	MY(J),	Number of fine meshes in the J-th coarse mesh in Y / R-direction.
2	DY(J), J=1, ...	<p>&gt; 0.: Thickness of the J-th coarse Y / R-mesh. (cm)</p> <p>= 0.: End of the input of coarse Y / R-meshes.</p> <p>The number of given coarse Y / R-meshes defines JMY.</p>

Meshes in Z-direction.

Card TR4		Format (6(I3,F9.3))
1	MZ(K),	Number of fine meshes in the K-th coarse mesh in Z-direction ( $\geq 2$ ).
2	DZ(K), K=1, ...	<p><math>\neq 0</math>.:  DZ(K)  gives the thickness of the K-th coarse Z-mesh. (cm)</p> <p>&lt; 0.: Core regions.</p> <p>&gt; 0.: Non-core regions (e.g. reflectors).</p> <p>= 0.: End of the input of coarse Z-meshes.</p> <p>The number of given coarse K-meshes defines KMZ.</p>

Definition of the pattern of regions:

For each of the planes (Z) K = 1,KMZ one set of cards TR5.

For each of the rows (R or Y) J = 1,JMY one card TR5.

Card TR5		Format (15I5)
1 . IMX	LAY3(I,J,K) I=1,IMX	<p><u>Only for the core:</u></p> <p>&gt; 0: Region id. number of the I-th coarse mesh (<math>\Phi</math> or X) in this row and plane. In the upper plane the code evaluates the maximum number NLP of core compositions.</p> <p>= 0: Id. no. of this region is internally defined by adding NLP to the LAY3(I,J,K-1) of the foregoing plane.</p> <p>.....</p>

Continuation of card TR5

		<p><u>Only for the non-core-compositions (reflectors etc.):</u> &lt; 0: Id. no. of this composition is internally defined by adding the maximum number of core compositions to the absolute of  LAY3(I,J,K) . Reflector id. numbers must be given in an unbroken sequence starting with “-1”.</p>
--	--	---

### 4.3 Fuel Element Design. D1 – D17

(only if MODE = 'vsop' or 'fuel' on card S1)

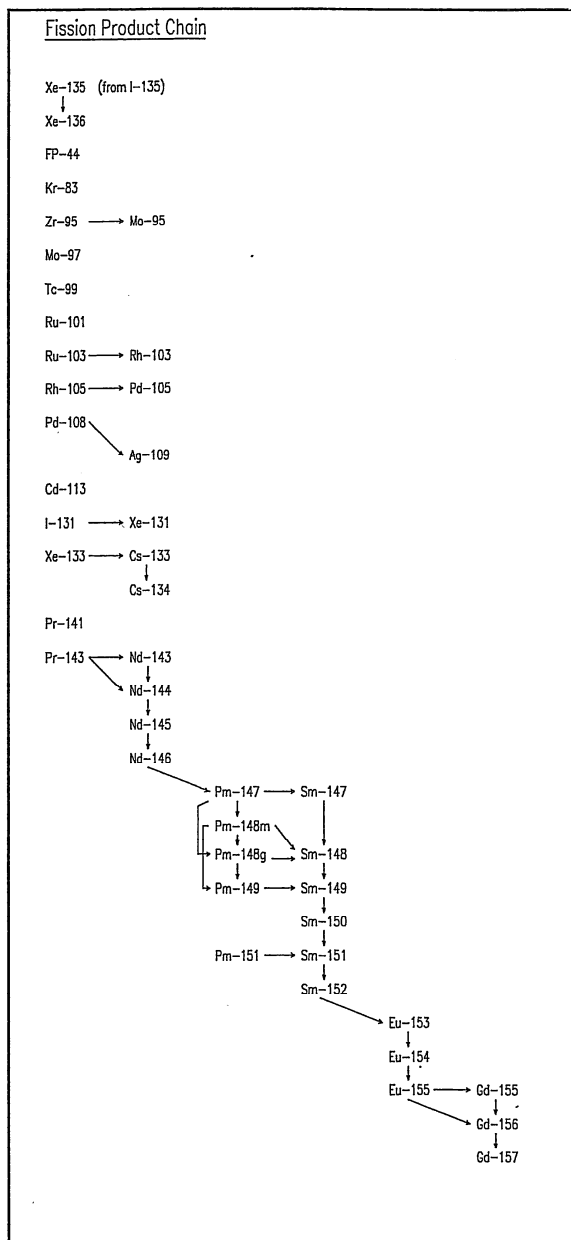
#### 4.3.1 Specifications. D1 – D4

Card D1		Format (3I4)
1	KMAT	Sum of nuclides - <u>except</u> the heavy metal isotopes to be included in the VSOP calculation (i.e. fission products, control poisons, non burning absorbers, scatterers). ( $\leq 172$ )
2	NHOM	= 0: Normal. = 1: Drop heterogeneous evaluation of fuel elements. Read homogenized atom densities on cards D17. The input sequence is : Cards D1, D2, D5, D6, D17, D5.
3	NDANC	Only when NHOM = 0: = 0: No effect. > 0: Definition of lattice type according to card Z10 (variable K) of VSOP-ZUT- input. Some values are calculated and printed, which should be used as input data for the Dancoff factor calculation in VSOP-ZUT.

Card D2		Format (18I4)
1 . KMAT	IMAT(I), I=1,KMAT	GAM-I-library identification numbers for the KMAT (card D1) nuclides in the sequence of <b>Table VI</b> , starting with the fission products (drop the heavy metal isotopes!).  <u>Note:</u> Nuclide id. numbers beyond the library can be used (i.e. IMAT(I) > 190). These nuclides must be identified on the cards V3.

**Table V: Sequence of nuclides**

	VSOP-Id.no.		GAM-I-Id.no.	
1.	Heavy metal isotopes are firmly assigned:			
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	Th-232 Th-233 Pa-233 U -233 U -234 U -235 U -236 U -237 U -238 U -239 Np-237 Np-238 Np-239 Np-240 Pu-238 Pu-239 Pu-240 Pu-241 Pu-242 Pu-243 Am-241 Am-242m Am-242 Am-243 Am-244 Cm-242 Cm-243 Cm-244	6 185 7 8 9 10 11 132 12 186 133 187 13 188 177 14 15 16 17 189 178 180 179 181 190 182 183 184	
2.	Fission products of chain definition:			
	29 30 31 ...	Xe-135 Accumulative fission product Further isotopes of the chain NO ≤ 49 fission products are allowed		
3.	Control poison:			
	subsequent	NC = 0-2 different nuclides are possible with concentrations adjustable to achieve given $K_{eff}$ .		
4.	Non burning absorbers:			
	subsequent	Absorbers for which concentrations remain unchanged during burnup, e.g. structural materials		
5.	Scatterers:			
	subsequent	NKER = 1-5 scatterers must be given at the end. 1. Scatterer must be C 2. Scatterer must be O		



	VSOP-No	GAM-No
<sup>135</sup> Xe	29	87
FP-44	30	160
<sup>136</sup> Xe	31	88
<sup>83</sup> Kr	32	35
<sup>95</sup> Zr	33	149
<sup>95</sup> Mo	34	52
<sup>97</sup> Mo	35	54
<sup>99</sup> Tc	36	57
<sup>101</sup> Ru	37	59
<sup>103</sup> Ru	38	151
<sup>103</sup> Rh	39	62
<sup>105</sup> Rh	40	143
<sup>105</sup> Pd	41	64
<sup>108</sup> Pd	42	67
<sup>109</sup> Ag	43	69
<sup>113</sup> Cd	44	75
<sup>131</sup> I	45	156
<sup>131</sup> Xe	46	84
<sup>133</sup> Xe	47	152
<sup>133</sup> Cs	48	89
<sup>134</sup> Cs	49	144
<sup>141</sup> Pr	50	99
<sup>143</sup> Pr	51	154
<sup>143</sup> Nd	52	101
<sup>144</sup> Nd	53	102
<sup>145</sup> Nd	54	103
<sup>146</sup> Nd	55	104
<sup>147</sup> Pm	56	107
<sup>148</sup> Pm-m	57	148
<sup>148</sup> Pm-g	58	147
<sup>147</sup> Sm	59	108
<sup>148</sup> Sm	60	109
<sup>149</sup> Pm	61	155
<sup>149</sup> Sm	62	110
<sup>150</sup> Sm	63	111
<sup>151</sup> Pm	64	175
<sup>151</sup> Sm	65	112
<sup>152</sup> Sm	66	113
<sup>153</sup> Eu	67	116
<sup>154</sup> Eu	68	117
<sup>155</sup> Eu	69	118
<sup>155</sup> Gd	70	120
<sup>156</sup> Gd	71	121
<sup>157</sup> Gd	72	122

**Fig. 2: Built-in fission product chain**

**Table VI: Fission product yields (values given in percentages)**

Isotope	Type	U -233	U -235	Pu-239	Pu-241
Se- 82	t	0.56262	0.33405	0.21092	0.11602
Br- 81	t	0.31171	0.21005	0.1768	0.06469
Kr- 83	t	1.0178	0.53076	0.29608	0.20498
Kr- 84	t	1.7034	0.98786	0.48029	0.35393
Kr- 85	c	2.1946	1.314	0.56834	0.39618
Kr- 86	c	2.8581	1.9528	0.75863	0.61392
Rb- 85	i	6.5296-5	8.23-5	5.85-5	5.3024-7
Rb- 87	t	4.0088	2.551	0.94936	0.75709
Sr- 88	t	5.4953	3.6228	1.3703	0.97473
Sr- 90	c	6.7952	5.9137	2.1134	1.5363
Y - 89	t	6.2568	4.8469	1.7075	1.2146
Zr (nat)		6.4467	5.803	2.6405	2.645
Zr- 90	i	0.05	0.047	0.0164	0.0164
Zr- 91	t	6.5194	5.926	2.4941	1.8315
Zr- 92	t	6.5949	5.966	3.018	2.2781
Zr- 93	c	7.011	6.3703	3.9031	2.9643
Zr- 94	c	6.8076	6.4228	4.4431	3.4018
Zr- 95	c	6.2478	6.4678	4.9212	4.0456
Zr- 96	t	5.6694	6.2506	5.0958	4.4232
Mo- 95	c	9.5909-4	1.641-4	1.492-3	1.2927-5
Mo- 96	i	6.5-3	5.85-4	7.7-4	7.7-4
Mo- 97	t	5.4533	5.96	5.608	4.8208
Mo- 98	t	5.1587	5.7787	5.8542	5.2217
Mo-100	t	4.4094	6.3096	6.977	6.2311
Tc- 99	c	4.9573	6.1284	6.1405	6.2085
Ru-101	t	3.2258	5.0501	5.9135	6.0948
Ru-102	t	2.4492	4.2032	6.0201	6.4843
Ru-103	c	1.7066	3.1411	6.9845	6.2611
Ru-104	t	1.0276	1.8239	5.9539	6.9764
Ru-105		0.48	0.9	5.47	5.47
Rh-103	i	1.4219-9	1.858-9	1.358-7	5.6028-5
Rh-105	c	0.47126	1.0199	5.4261	6.2183
Pd-105	i	3.4998-11	9.83-11	2.03-8	1.6908-6
Pd-106		0.24063	0.37759	4.6234	4.6314
Pd-107	c	0.11417	0.16317	3.2361	5.3339
Pd-108	t	0.061481	0.071032	2.2319	4.0191
Pd-110	t	0.025376	0.022338	0.62204	1.2091
Ag-109	t	0.043363	0.029903	1.4115	2.2836
Cd-111	t	0.020268	0.019714	0.27428	0.57261
Cd-112	t	0.014602	0.012802	0.10707	0.23001
Cd-113	c	0.013152	0.012425	0.078216	0.15494
Cd-114	t	0.012268	0.011256	0.046789	0.075514
In-115		0.020052	9.9367-3	0.040467	0.040537
Te-126	t	0.24081	0.057818	0.19996	0.077127
Te-128	c	0.94592	0.35046	0.85079	0.35555
Te-130	c	2.3671	1.4466	2.4971	1.6617
I -127	t	0.67853	0.13037	0.49173	0.23046
I -129	c	1.616	0.65911	1.5039	0.77864
I -131	c	3.7089	2.8325	3.738	3.1411
I -135	c	4.8597	6.3482	6.3007	6.95
Xe-131	i	8.4795-5	1.54-6	1.652-5	1.3066-6
Xe-132	t	4.8038	4.2498	5.2688	4.6411
Xe-133	c	6.0307	6.7859	6.9758	6.741
Xe-134	c	5.7588	7.6825	7.389	8.1081
Xe-135	i	1.3374	0.2541	1.1517	0.22923
Xe-135	c	6.1971	6.6023	7.4524	7.1792
Xe-136	c	6.7934	6.2701	6.6153	7.2871
Cs-133	i	3.6998-5	5.08-5	1.61-5	4.302-7
Cs-134	i	1.1969-3	3.57-5	4.61-4	3.5416-5
Cs-135	c	6.1	6.45	7.22	7.8
Cs-137	c	6.7889	6.269	6.6834	6.698
Ba-138	t	5.8863	6.8272	5.7173	6.4446

continued.....



	Continuation of Fission Product Yields				
La-139	t	5.885	6.4933	5.6456	6.2283
Ce-140	t	6.4334	6.3229	5.5751	5.894
Ce-141		6.24	5.73	6.11	6.11
Ce-142	t	6.6304	5.9247	5.0173	4.815
Ce-144		4.5117	5.962	4.4514	4.8644
Pr-141	t	6.6224	5.8929	5.3634	4.8534
Pr-143	c	5.8513	5.971	4.5613	4.5017
Nd-142		0.	0.009	0.0009	0.0009
Nd-143	i	2.4799-8	9.5-11	4.9-10	1.2106-10
Nd-144	t	4.6495	5.4523	3.834	4.1564
Nd-145	t	3.4248	3.9339	3.0833	3.2046
Nd-146	t	2.5973	2.9912	2.5333	2.7401
Nd-148	t	1.2867	1.69	1.6982	1.9257
Nd-150	c	0.49846	0.64593	0.99451	1.196
Pm-147	c	1.7753	2.2701	2.0769	2.2601
Pm-148m	i	2.7899-5	7.49-7	2.09-6	5.4125-7
Pm-148g	i	9.4395-7	5.73-6	2.09-6	5.4125-7
Pm-149		0.76953	1.0888	1.2617	1.4635
Pm-151		0.32293	0.42044	0.7772	0.90238
Sm-147	i	2.0099-10	0.	2.43-12	0.
Sm-148	i	1.7999-8	6.95-11	2.8-10	4.272-11
Sm-149		0.	0.	0.	0.
Sm-150	c	2.5782-3	5.413-4	1.7009-3	3.9438-4
Sm-151		0.	0.	0.	0.
Sm-152	t	0.20784	0.27057	0.59618	0.71704
Sm-154	t	0.04558	0.074689	0.27682	0.37979
Eu-153	t	0.10686	0.16264	0.37224	0.52815
Eu-154	i	3.7198-5	1.63-6	3.54-5	5.5626-6
Eu-155	c	0.021252	0.033025	0.17082	0.23181
Gd-154		0.	0.	0.	0.
Gd-155	i	3.6198-7	4.41-9	2.83-7	1.9109-8
Gd-156	t	0.011737	0.013517	0.11989	0.16955
Gd-157	t	6.7747-3	6.4651-3	0.076297	0.13153
Gd-158	t	2.2298-3	3.2163-3	0.040955	0.086707
Tb-159	t	9.2311-4	1.0394-3	0.021205	0.046741
	i = Independent fission yield c = Cumulative fission yield t = Total chain yield				
	<u>Accumulative Fission Product:</u>				
		<u>U-233</u>	<u>U-235</u>	<u>Pu-239</u>	<u>Pu-241</u>
		112.3	94.76	115.6	110.4

Cards D3, D4 only if NHOM = 0 on card D1.

Card D3		Format (A4,2I4,10F6.0)
1	CURCY	Literal abbreviation for the monetary unit MU.
2	NC	Number of different coated particle fabrication cost data. ( $\leq 6$ )
3	NF	Number of different fuel element fabrication cost data. ( $\leq 3$ )
4 . 9	FC(I), I=1,6	Fabrication costs of the I-th coated particle variant. (MU/ <b>kg</b> Heavy Metal)
10 . 12	FF(I), I=1,3	Fabrication costs of the I-th fuel element variant. (MU/ fuel element)
13	DK	Fabrication costs of “dummy” elements. (MU/ element)

Card D4		Format (3E12.5)
1	HK	Costs of head end and transportation. (MU/kg <sub>C</sub> )
2	AK	Costs of reprocessing. (MU/kg <sub>HM</sub> )
3	EK	Costs of waste treatment and disposal per 10% Fima. (MU/kg <sub>HM</sub> )

#### 4.3.2 Design of fuel element-types and -variants. D5 - D17

One set for each variant of each desired fuel type (limited to 27 different sets).

Calculation is terminated by one last card D5.

Card D5		Format (18A4)
1 . 18	TITLE(I), I=1,18	Literal description of fuel element-types and –variants.  TITLE(1) = ‘stop’: This terminates the sequence of cards D5 – D17.

Card D6		Format (5I4,E12.5)
1	NTYP	= 0: Spherical fuel elements. = 1: Prismatic block fuel element.
2	NFUTP	<u>Fuel</u> elements: NFUTP is given as a <u>positive</u> number, <u>Fuel-free</u> ("dummy") elements: NFUTP is given as a <u>negative</u> number: Identification of the elements in 4 digits IJKL: IJ: Type (of design and cost data), increasing numbers, ( $\leq 10$ ) KL: Variant ( e.g. for different enrichments), increasing numbers, starting from 01 for each type IJ.
3	NFCP	Input option for coated particle definition: = 0: Data from preceding design, or if NFUTP < 0 (dummy elements), or if NHOM = 1 (card D1). = 1: Read card D7 only. = 2: Read cards D7 - D11.
4	NFBZ	Option for pebble and block type element specific data: = 1: Read cards D12 - D13 or D14 - D16, respectively. = 0: Respective data like preceding design, or if NHOM = 1 .
5	NZUS	= 0: No effect. > 0: Number of nuclides for which atom densities will be specified on cards D17. ( $\leq 30$ ) Previously calculated values <u>are replaced</u> .
6	FF3	Variable is used for spherical elements only (NTYP=0). > 0: Volumetric filling fraction of spherical elements in the core. = 0: Default value (0.61) is used.

#### 4.3.2.1 Coated particles. D7 - D11

Card D7 only if NFCP > 0 on card D6.

Card D7		Format (6E12.5)
1	ANR	Fissile enrichment of the fuel (fissile/heavy metal). > 0.: Atom fraction. = 0.: If INDBS (card D8) = 7 .  Only in case of <u>pure uranium fuel</u> (INDBS=1-3) and U53 = 0.: < 0.: Weight fraction =  ANR .
2	U53	= 0.: Fissile uranium is $^{235}\text{U}$ . = 1.: Fissile uranium is $^{233}\text{U}$ .....



Card D10 only if INDBS = 7, 8 or 9 on card D8.

Card D10		Format (4E12.5)
1 . 4	PU(I), I=1,4	Atom fractions of the isotopic composition in plutonium: $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{241}\text{Pu}$ , $^{242}\text{Pu}$ . If required, an additional $^{238}\text{Pu}$ concentration may be defined on card D17.

Card D11		Format (6E12.5)
1,3,5	DCT(I),	Thickness of the I-th coating layer. (cm)
2,4,6	ROCT(I), I=1,NCT	Density of the I-th coating layer. (g/cm <sup>3</sup> ) (Numbered with increasing radius, NCT on card D8).

#### 4.3.2.2 Spherical fuel elements. D12, D13

Cards D12 - D13 only if NTYP = 0 and NFBZ = 1 on card D6.

Card D12		Format (5E12.5)
1	R1	= 0: for “Dummy”-Elements > 0: Outer radius of fuel zone. (cm) (Fuel zone consists of coated particles and graphite matrix).
2	R2	Outer radius of the sphere. (cm)  Only <u>one</u> of the following three variables must be specified in case of <u>fuel</u> elements. In case of “dummy” elements, they all must have a zero value.
3	FF1	Volume fraction: coat.part. / (coat.part. + matrix).
4	VMOD	Moderation ratio $N_C / N_{HM}$ .
5	ROSM	Density of the heavy metal, homogenized in the fuel zone (g / cm <sup>3</sup> )

Card D13		Format (6E12.5)
1	ROMTX	Density of graphite in the matrix. (g/cm <sup>3</sup> ). (= 0 for “dummy” elements)
2	ROSCH	Density of graphite in the outer shell. (g/cm <sup>3</sup> )
3	SR0	Inner radius of the matrix. (cm) (normally = 0.) > 0 for ”shell ball” design.
4	FRF(I), I=1,NF	= 0.: Fabrication costs of the I-th fuel element variant (card D3) are dropped (always true for “dummy” elements). > 0.: Fabrication costs of the I-th fuel element variant are used and multiplied by FRF(I). (Usually = 1.)

### 4.3.2.3 Prismatic fuel elements. D14 – D16

Cards D14 - D16 only if NTYP = 1 and NFBZ = 1 on card D6.

Card D14		Format (6E12.5)
1	R(1)	Radius of central graphite zone. (cm)
2	R(2)	Outer radius of inner cooling channel. (cm)
3	R(3)	Outer radius of inner graphite tube. (cm)
4	R(4)	Outer radius of the fuel zone. (cm)
5	R(5)	Outer radius of the outer graphite tube. (cm)
6	R(6)	Outer radius of the outer cooling channel. (cm)
		If FFUEL > 0. (card D15) insert "thickness" instead of "radius".

Only a selected set of the following parameters of the cards D15 and D16 is required. Possible combinations are given in Table VIII.

Card D15		Format (6E12.5)
1	FF1	Volume fraction: coat.part. / (coat.part. + matrix).
2	VMOD	Moderation ratio $N_C / N_{HM}$ .
3	BETA	Volume fraction of gaps (other than cooling channels) in the core relative to the bulk graphite volume.
4	GKAN	Number of fuel elements per square meter. ( $1/m^2$ )
5	FFUEL	= 0.: No effect. > 0.: Cross section of the fuel zone ( $cm^2$ ). Use R(4) = 0. on card D14 and insert "thickness" instead of "radius".
6	ACTIV	Active length of the fuel rods in the core. (cm)

Card D16		Format (4E12.5)
1	ROSM	Density of heavy metal, homogenized in fuel zone. (g/cm <sup>3</sup> )
2	ROMTX	Density of graphite in the matrix. (g/cm <sup>3</sup> )
3	ROSTR	Density of graphite in the cooling channel. (g/cm <sup>3</sup> )
4	ROHR	Density of graphite in the tubes. (g/cm <sup>3</sup> )

**Table VII: Alternative specifications of fuel rods**

No.	1	2	3	4	5
FF1	x	x			negative guess
VMOD	x		x		x
GKAN		x		x	x
ROSM			x	x	

#### 4.3.2.4 Additional nuclides. D17

Card(s) D17 only if NZUS > 0 on card D6.

Card D17		Format (I4,4X,E12.5)
1	NRGAM	GAM-I-lib. identification no. of nuclide with additionally given atom density.
2	DENG	Atom density (atoms / (barn cm), homogenized).  <u>Note:</u> Use 1 card for each of the NZUS ( $\leq 30$ ) additional nuclides.



#### 4.4. Reactor and fuel cycle. V1 – TX26

(only if MODE = 'vsop' on card S1)

##### 4.4.1 Set up dimensions. V1

Card V1		Format (8I4)
1	N26	Number of energy groups in the diffusion calculation. ( $\leq 33$ )
2	MMAF	Maximum number of burnup cycles ( $\leq 5000$ )
3	MBATCH	Maximum number of batches to be filled into storage boxes. (See card R21).
4	MSTOB	Maximum number of storage boxes to be filled. (See card R21).
5	JTYP	Number of different fuel element types in the system. ( $\leq 10$ ) (See card R3).
6	MREP	Number of reprocessing mixtures, if present. ( $\leq 10$ ) (See card R3).
7	JABOX	Total number of aging boxes and jumble boxes as explicitly specified on card R5 (only if MREP > 0).
8	KMAZ	Only if "I3D = 0" on card S1: > 0: Maximum number of THERMIX- (= KONVEK-) compositions. = 0: Default value = 50 .

#### 4.4.2 Definition of materials. V2 – V5

Card V2		Format (4I4)
1	NO	Number of fission products ( $\leq 48$ ): = 0: Default value = 44, code uses the built-in fission product chain 0<NO<44: The code drops the last surplus ones of the built-in chain. > 44: See KETT and card V4. (See also cards D1 (KMAT) and D2).
2	KETT	= 0: No effect. > 0: Chain information of the last KETT fission products will be defined on cards V4. This option can be used to extend the chain structure or to define a new one.
3	NLT	= 0: No effect. > 0: Number of fission products, for which new yields and decay constants will be defined on card V5.
4	NC	Number of control poison nuclides. ( $\leq 2$ )

Card(s) V3 only if some nuclides of the library shall be duplicated and used with new id. numbers IMAT(I) > 190 for special purposes. One card V3 for every new id. number.

Card V3		Format (2I4)
1	JNEU	GAM-I-Id. number to be assigned to the new nuclide.
2	LMAT	GAM-I-Id. number of the original library nuclide of which the cross sections are to be duplicated.

Card(s) V4 only if KETT > 0 on card V2.

A total of KETT cards required, starting with the card for the fission product nuclide  
 $N = NO - KETT + 1$ .

Card V4		Format (4E12.5)
1	DIRAC(N,1)	Fractional production of nuclide N from N-1. > 0.: By capture. < 0.: By decay.
2	DIRAC(N,2)	Fractional production of nuclide N from N-2.
3	DIRAC(N,3)	Fractional production of nuclide N from N-3.
4	DIRAC(N,4)	Fractional production of nuclide N from N-4.

Card(s) V5 only if NLT > 0 on card V2.

A total of NLT cards is required, one for each fission product for which the yields are defined or altered.

Card V5		Format (I6,6X,5E12.5)
1	N	VSOP identification no. of a selected fission product nuclide.
2	YIELD1(N)	<sup>233</sup> U fission yield of nuclide N.
3	YIELD2(N)	<sup>235</sup> U fission yield of nuclide N.
4	YIELD3(N)	<sup>239</sup> Pu fission yield of nuclide N.
5	YIELD4(N)	<sup>241</sup> Pu fission yield of nuclide N.
6	XLAM(N)	Decay constant of nuclide N. (1/sec)

### 4.4.3 Design and operations. V6 – V17

#### 4.4.3.1 Case identification. V6

Card V6		Format (I8,6I4,2E12.5)
1	NRSTRT	= 0: No effect. = 1: Fuel shuffling. = 2: Fuel shuffling and iteration of the enrichment. * = 3: Fuel shuffling and reprocessing. = 4: Fuel shuffling, reprocessing and iteration. * * (Cards R28 - R31).
2	NKOST	= 0: No effect. > 0: Fuel cycle cost calculations (cards K1 - K12).
3	IBUCK	= 0: No feedback of leakage from diffusion to spectrum calculation. = 1: Feedback of the broad group leakage to GAM-I, and thermal leakage to THERMOS. = 2: Feedback of an average epithermal leakage to GAM-I, and thermal leakage to THERMOS.
4	MUHU(3)	= 0: Drop streaming correction in pebble bed. = 2: Streaming correction /28/ in power generating batches (only for pebble bed).
5	LOBNEW	= 0: Normal. = 2: Life history is preserved for ORIGEN-JÜL-II (all NON-MEDUL-reactors), starting from the first burnup cycle (data set 'origen').
6	IBASCH	= 0: No effect. > 0: For 3 - d - geometry: Number of batches in the upper plane of the core. Will be used only in connection with variable MULT on card V7.
7	IPRIN2	≥ 0: Print layout of batches at startup. = -1: No output.
8	SERCON	Convergence criterion for $K_{\text{eff}}$ when adjusting control poison or other atom concentrations. ( $\cong 0.0001$ )
9	ERR	> 0.: Truncation error limit to be used for the burnup and spectrum calculation. = 0.: Default value = 1.E-25 .

#### 4.4.3.2 Definition of reactor batches. V7 – V9

Each batch (see output of “Geometric reactor design” - section) requires one set of cards V7-V9. The sequence has to be as follows:

- 1) In-core batches, numbered from 1 through ....
- 2) Cone regions (= batches), numbered from (in-core batches + 1) through ....
- 3) Other non-power generating regions, numbered from 1 through ....  
(The number of in-core + cone batches is automatically added up).

Card V7		Format (4I6,6X,E12.5,18X,2I6)
1	NREAD	$\leq 100$ : Number of atom densities to be specified on subsequent cards V8. $> 100$ : Atom densities of fuel type IJ, variant KL are used. (NFUTP on card D6).
2	NCH1	NCH1 = 0, if NREAD $\neq 0$ . NCH1 $\neq 0$ , if NREAD = 0: $> 0$ : Number of a previously specified batch with the same atom densities. $< 0$ : Read new atom densities for this batch from data set ‘nucdens’, which have been stored in an earlier VSOP calculation (compare variable LIB $< 0$ on card R7).  NCH1  is the batch no. of data set ‘nucdens’ to be applied.
3	NCH5	$> 0$ : Number of a previously specified batch with the same control poison data. = 0: Use data of batch no. 1. $< 0$ : Read card V9.
4	NFTST	Only if NREAD $\leq 100$ : Definition of fuel type id. no. of this batch. Only if fuel is defined by cards V8, otherwise the id. no. is taken from batch no. NCH1. In reflector regions the id. no. is 0 .
5	WPART	Fraction of the volume of this batch per region: = 0.: In the batches of the <u>first region</u> the code makes WPART = 1. / (number of batches per region). In the other batches of the core the code copies WPART of the corresponding batch of the preceding region. In the regions of the reflectors the code makes WPART = 1. $> 0$ .: Redefinition of the volume fraction of this batch. If redefinition is specified, it must be given for all batches of this region, and it holds for all subsequent regions until redefined.

Continuation of card V7		
6	MULT	= 0: No effect. > 0: The id. no. of this batch is defined by $KD18 = KD18 + MULT * IBASCH$ (Card V6). (Useful in 3-d- geometry for the batches in the lower planes).
7	KD18	> 0: Id. no. of the batch for which the information of this card is to be applied. It will also be applied for all subsequent batches until redefined. <u>Note:</u> The sequence of the reflector batches (= regions) must correspond to the numbering defined on input cards BI5 or TR5, respectively. < 0: Last card V7, holding for the batch  KD18 .
<p>Atom densities: Card V8 only if <math>0 &lt; NREAD \leq 100</math>. A total of NREAD cards is required.</p> <p>Card V8                      Format (I4,4X,E12.5)</p>		
1	L	VSOP-identification number of the nuclide with atom density > 0.
2	DEN	Atom density (atoms per barn cm). All densities must be given homogenized.
<p>Control poison: Card V9 only if <math>NC &gt; 0</math> on card V2, and if <math>NCH5 &lt; 0</math> on card V7. One card V9 for each control poison nuclide.</p> <p>Card V9                      Format (2E12.5)</p>		
1	POISM	The control poison nuclide(s) in all batches of one region have the same limitations. Minimum atom density of control poison in this region. (e.g. = 0.)
2	POISL	Maximum atom density of control poison in this region.

#### 4.4.3.3 Data for the burnup calculation. V10, V11

Cards V10-V11 only if JSER  $\neq$  2 on card S1.

Card V10		Format (4E12.5)
1	DELDAY	Length of large burnup time steps (time between possible diffusion calculations). (days)
2	POWER	Thermal core power. (watts)
3	FIWATT	Initial value of Fissions/Ws: = 0.: Starting value = $3.087\text{E}+10$ ( $^{235}\text{U}$ ) > 0.: Optional starting value. <u>Note:</u> In the course of the proceeding burnup, an actual value of FIWATT is calculated by the code according to DIN 25485. This value then depends on the fraction of the fission rates of the different fissile isotopes.
4	ZKFIND	Minimum allowed value of $K_{\text{eff}}$ . The present burnup cycle is terminated, when $K_{\text{eff}}$ equals ZKFIND. Fuel shuffling is then performed, if specified. In case of control poison adjustment, ZKFIND is the target $K_{\text{eff}}$ .

Card V11		Format (2I4)
1	JNSTOP	Last large burnup time step in one burnup cycle. ( $\leq 95$ )
2	JNUM	Number of small time steps in one large step. Renormalization of the neutron flux to the specified reactor power is done for each small time step.

#### 4.4.3.4 Control poison search. V12 - V14

Cards V12-V14 only if JSER = 0, 3, 5 on card S1.

Card V12		Format (18I4)
1	JSMAX	Maximum number of control poison iterations for any region at one time step. All batches of the region are treated simultaneously. ( $\cong 50$ )
2	JSSMAX	Maximum number of control poison iterations for the total core at one time step. ( $\cong 200$ )
3	LSIM	Number of regions, for which the control poison is adjusted <u>simultaneously</u> . LSIM regions form a poison area for simultaneous poison adjustment.
4	KSS	Length of the list of regions for control poison adjustments. The ratio KSS / LSIM gives the number of poison adjustment areas.
5 .	NPOIS(I), I=1,KSS	This list gives the sequence of regions in which the adjustments are performed.

Card V13		Format (6E12.5)
1 . KSS	PINMIN(I), I=1,KSS	Minimum fraction of control poison insertion in the I-th region to be adjusted. (e.g. = 0.)

Card V14		Format (6E12.5)
1 . KSS	PINMAX(I), I=1,KSS	Maximum fraction of control poison insertion in the I-th region to be adjusted. (e.g. = 1.)



#### 4.4.3.5 Print-out options and steering. V15

Card V15		Format (5I4)
1	IPRIN(1)	<p>Spectrum calculation:</p> <p>= -1: Minimal output.</p> <p>= 0: Thermal selfshielding factors, only.</p> <p>= 1: Same as 0, plus averaged thermal cross sections.</p> <p>= 2: Same as 1, plus fine group neutron fluxes.</p> <p>= 3: Same as 2, plus broad groups averaged cross sections for materials with concentration &gt; 0.</p> <p>= 4: Same as 3, for all materials.</p> <p>= 5: Maximum output including details of neutron transport.</p>
2	IPRIN(2)	<p>= 0: No output.</p> <p>= 1: Print layout of batches before shuffling.</p> <p>= 2: Same as 1, plus atom densities (only in combination with IPRIN(3) ≥ 0).</p>
3	IPRIN(3)	<p>Burnup calculation:</p> <p>= -1: Global neutron balance.</p> <p>= 0: Detailed neutron balance.</p> <p>= 1: Same as 0, plus characteristic data for all fuel batches.</p>
4	IPRIN(4)	<p>= 0: Perform spectrum calculation only at start of first burnup time step.</p> <p>Instructions on card V16 are neglected.</p> <p>= 1: Repeat spectrum calculation as defined on card V16.</p>
5	IPRINO	<p>Burnup calculation (ADAGE):</p> <p>= 0: No output.</p> <p>= 1: Short output (cross sections + total flux).</p> <p>= 2: Detailed output.</p>

#### 4.4.3.6 Steering the performance for spectrum and diffusion calculation. V16, V17

Card V16		Format (18I4)
1	ISPEKT(1)	<p>≥ 0: No. of the first large burnup time step in which the spectrum calculation is to be repeated prior to the diffusion calculation.</p> <p>.....</p>
2 . 18	ISPEKT(I), I=2,18	<p>&gt; 0: No. of further time steps for spectrum calculation.</p> <p>= 0: If all ISPEKT = 0, spectrum calculation is performed in every time step.</p>

Card V17 only if JSER < 4 on card S1.

Card V17		Format (18I4)
1 . 18	IDIFF(I), I=1,18	<p>If all IDIFF(I) = 0: Diffusion calculation is performed at every time step.</p> <p>If at least one IDIFF(I) ≠ 0: The IDIFF(I) give the time steps at which diffusion calculation is to be performed.</p>

#### 4.4.4 Fast and epithermal neutron spectrum. G1 - G12

Card G1		Format (18X, 5I6)
1	<p>IDESIN</p> <p>MSTU</p> <p>MGHUS</p> <p>NSSS</p> <p>IPRSEL</p>	<p>Number of different fuel element designs (<math>\leq 10</math>). Only for different resonance integral data on cards G3-G5. The differentiation of fuel element designs for the resonance calculation is mostly the same as for the thermal cell calculation, i.e. IDESIN = NBER on card T6.</p> <p>Fission source spectrum :  = 1: <math>^{232}\text{Th}</math>, 2: <math>^{233}\text{Th}</math>, 3: <math>^{233}\text{Pa}</math>, 4: <math>^{232}\text{U}</math>, 5: <math>^{233}\text{U}</math>, 6: <math>^{234}\text{U}</math>, 7: <math>^{235}\text{U}</math>, 8: <math>^{236}\text{U}</math>,  9: <math>^{237}\text{U}</math>, 10: <math>^{238}\text{U}</math>, 11: <math>^{239}\text{U}</math>, 12: <math>^{237}\text{Np}</math>, 13: <math>^{238}\text{Np}</math>, 14: <math>^{239}\text{Np}</math>, 15: <math>^{238}\text{Pu}</math>,  16: <math>^{239}\text{Pu}</math>, 17: <math>^{240}\text{Pu}</math>, 18: <math>^{241}\text{Pu}</math>, 19: <math>^{242}\text{Pu}</math>, 20: <math>^{243}\text{Pu}</math>, 21: <math>^{241}\text{Am}</math>, 22:  <math>^{242}\text{Am}</math>, 23: <math>^{242\text{m}}\text{Am}</math>, 24: <math>^{243}\text{Am}</math>, 25: <math>^{244}\text{Am}</math>, 26: <math>^{242}\text{Cm}</math>, 27: <math>^{243}\text{Cm}</math>, 28:  <math>^{244}\text{Cm}</math></p> <p>= 0: Unit fission source.</p> <p>Only if MSTU = 0:  GAM-I group no. in which the unit fission source is located.</p> <p>= 0: No selfshielding factors applied.  &gt; 0: Number of sets of selfshielding factors (cards G7-G12).  = -1: One single set of selfshielding factors to be applied in all regions (cards G8-G12).</p> <p>Output option of the selfshielding factors:  = 0: Broad energy group definition.  = 1: Selfshielding factors for the different nuclides.</p>

Card G2		Format (6E12.5)
1 . NDR	TEMZUT(I), I=1,NDR	<p>Temperature of the resonance absorbers in “NDR” different spectrum calculations. (°C). = 0., if no fuel in the regarded region, e.g. for reflectors.</p> <p>NDR is the total number of “regions”, which is depicted in the output of code section “Geometric reactor design”. (Table: “Region - batches in the region”).</p>

Card(s) G3 only if IDESIN > 1 on card G1.

Card G3		Format (12I6)
1 . NDR	NDES(I), I=1,NDR	Fuel element design number used for the spectrum calculation in region I.

For each design (IDESIN on card G1) 9 sets of cards G4-G5:

- 1) for  $^{232}\text{Th}$ ,
- 2) for  $^{238}\text{U}$ ,
- 3) for  $^{240}\text{Pu}$ ,
- 4) for  $^{242}\text{Pu}$ ,
- 5) for  $^{237}\text{Np}$ ,
- 6) for  $^{241}\text{Am}$ ,
- 7) for  $^{243}\text{Am}$ ,
- 8) for  $^{242}\text{Cm}$ ,
- 9) for  $^{244}\text{Cm}$

Card G4		Format (2E12.5,I6)
1	SM1	Two values of <u>homogenized</u> atom densities of the resonance absorber nuclide, for which sets of resonance integrals are available on data set 'resint'. These values should represent the highest and the lowest densities, occurring within the reactor, respectively.  $\geq 0$ .: Highest density of the absorber nuclide. [barn <sup>-1</sup> cm <sup>-1</sup> ] $= -1$ .: Density is taken from data set 'resint'.
2	SM2	$\geq 0$ .: Lowest density of the absorber nuclide. [barn <sup>-1</sup> cm <sup>-1</sup> ] $= -1$ .: Density is taken from data set 'resint'.
3	NZ	Number of sets of resonance integrals for each SM1 and SM2 densities ( $\leq 10$ !). These sets represent different temperatures of this absorber nuclide.
2 cards G5, the first one for SM1, the second one for SM2.		
Card G5		Format (12I6)
1 . NZ	IZUT(K), K=1,NZ	Id. numbers of the resonance integral sets to be read from data set 'resint'.

Definition of broad energy groups.

Card G6		Format (6E12.5)
1 .	CEG(I), I=1,N26-1	Desired lower energy limit of the fast energy group(s). (eV) (lowest value should be equal 1.86)

## Individual epithermal selfshielding factors. G7 - G12

Card G7 only if NSSS > 0 on card G1

Card G7		Format (12I6)
1 . NDR	NSET(I), I=1,NDR	Id. no. of the set of selfshielding factors to be applied in the spectrum calculation for region I.

Cards G8 - G12 only when NSSS ≠ 0 on card G1:

For each of the |NSSS| sets of selfshielding factors one set of cards G8-G12.

Card G8		Format (3I6)
1	MOBG	> 0: Number of broad epithermal energy groups for input of self-shielding factors (card G9). (Up to 67 groups can be defined). = 0: Broad energy groups same as defined on card G6 (the code sets MOBG = N26 - 1). < 0: Same broad energy groups as defined before.
2	LSUB	> 0: Number of sets of cross section-selfshielding factors SC (cards G10). (≤ 9) = 0: No input of SC.
3	NK	> 0: Number of sets of neutron flux-selfshielding factors SF (cards G11). (≤ 6) = 0: No input of SF.
<p>Card(s) G9 only if MOBG &gt; 0 <u>and</u> MOBG ≤ 67.</p> <p>Card G9</p> <p>Format (12I6)</p>		
1 . MOBG	MGBN(J), J=1,MOBG	Id. number of the GAM-I group with the highest energy in the broader energy group J.

<p>Card(s) G10 only if LSUB &gt; 0 on card G8. A set of (J=1,MOBG) cards G10 must be given for the MOBG broad energy groups.</p> <p>Card G10                      Format (6E12.5)</p>		
1 . LSUB	SC(L,J), L=1,LSUB	Broad energy group J: Cross section-selfshielding factor of set L.
<p>Card(s) G11 only if NK &gt; 0 on card G8. A set of (J=1,MOBG) cards G11 must be given for the MOBG broad energy groups.</p> <p>Card G11                      Format (6E12.5)</p>		
1 . NK	SF(K,J), K=1,NK	Broad energy group J: Neutron flux-selfshielding factor of set K.
<p>A card G12 is required for each nuclide (simplification of input can be defined by variable JT).</p> <p>Card G12                      Format (I6,2I2,6E10.4)</p>		
1	IDG	> 0: Id. no. of nuclide in the GAM-I library in rising sequence. Nuclides standing before the first given id. no. are assigned with selfshielding factors equal 1.0 . < 0: This is the last card G12.
2	JT	= 0: Information of this card applies also for all following nuclides, unless revised. = 1: Information of this card applies only for this nuclide.
3	LSC	= 0: No cross section-selfshielding factors applied. > 0: Id. no. of cross section-selfshielding factors (SC(LSC,J), J = 1, MOBG) to be applied for this nuclide.
4 .	ANT(K), K=1,NK	Fraction of the homogenized atom density to be assigned to neutron flux-selfshielding factor set K (only if NK > 0).

#### 4.4.5 Thermal cell spectrum - T1 - T13

Card T1		Format (A9,3X,6I6)
1	CIDTHER	<p><u>Data set name</u> of THERMOS-library to be used (one of the existing according to Table II, or a new one, which must have been generated before by means of THERMALIZATION).</p> <p><u>Blank value</u>: In case of a THERMALIZATION calculation (ITTT &gt; 0 on card S1). It shall be made for one spectrum zone, i.e. for one region, only. (See section 4.4.11 )</p> <p><u>The following variables must have a zero value, if no data set name is assigned to variable CIDTHER, i.e. in case of THERMALIZATION.</u></p>
2	NKER	<p>Number of scattering nuclides (<math>\leq 5</math>). (See also Table III)</p>
3	NKERAB	
4	NUTTE	
5	NUCT	<p>Number of <u>absorber</u> materials for which a scattering matrix is calculated internally (Brown St. Johnes). (<math>\leq 10</math>)</p> <p>= 1</p>
6	ITY	<p>Maximum number of scattering matrices - according to different temperatures - per one scattering nuclide to be used for interpolation (cards T3). (<math>\leq 20</math>)</p> <p>Identification of cell definition of which the geometry data are used for <u>streaming correction</u>.</p> <p>= 0: Use the first cell definition (for which the first set of cards T7-T12 is given).</p> <p>&gt; 0: Use the ITY-th cell definition.</p> <p>= -1: Define the geometry data to be used for the streaming correction on card T13. This is necessary if THERMOS cell definition is different from the real fuel element size (e.g. in case of “dummy” elements admixed to the fuel elements).</p>
7	MUP	<p>= 0: Normal.</p> <p>&gt; 0: Number of broader thermal groups (to be read on card(s) T2) for given individual selfshielding. (<math>\leq 30</math>). (See also cards T10 and T11)</p>

Card(s) T2 only if MUP > 0 on card T1.

Card T2			Format (6E12.5)
1 . MUP	EMU(I), I=1,MUP	Upper limit (eV) of the I-th thermal broader group for the given individual selfshielding, starting with the lowest thermal group.	

For each of the NKER scattering nuclides one set of cards T3-T4, in sequence of VSOP nuclides on card D2.

Card T3			Format (12I6)
1 . NUCT	IKER(J), J=1,NUCT	Id. no. of the J-th scattering matrix to be used for interpolation according to the actual temperature of this scattering nuclide.	
Card T4			Format (6E12.5)
1 . NDR	TCELS(J), J=1,NDR	Temperature of this scattering nuclide for spectrum calculation of region J. (°C)	

Card T5 only if NKERAB > 0 on card T1.

Card T5			Format (E12.5,10I6)
1	TKG	Relative temperature in the calculation of scattering matrices for absorber nuclides. (°K/293.6)	
2 .	IDTA(I), I=1,NKERAB	<u>GAM-I</u> -identification no. of nuclide I for which a scattering matrix is calculated internally.	



Card T6		Format (12I6)
1	NBER	Number of different cell definitions for the thermal spectrum calculation. Mostly same as IDESIN on card G1.
2 .	NTYSP(I), I=1,NDR	Identification no. of the cell definition used for spectrum calculation of region I.

For each of the NBER cell definitions one set of cards T7 - T12 required.

Card T7		Format (I6,6F6.0)
1	NGEOM	= 0: Cylindrical fuel element. = 1: Spherical fuel element.
2	TKG	Temperature for the initial guess of Maxwell neutron spectrum, relative to T0. (See STRT0 on this card). $\cong 1.5$
3	FUELL	Ratio: Volume of the cell / homogenized volume.
4	FUTYP	> 0.: Cell definition according to fuel element type identification IJ as specified by NFUTP on card D6. = 0.: All cell specifications must be given on cards T8-T9. Necessary in case of “dummy” elements admixed to the fuel elements.
5	STRT0	> 0.: Identification of the most important scattering nuclide. Its temperature will be used as base temperature T0, as required for TKG. STRT0 = 1., 2. .... identifies the first, second .... scatterer in sequence of VSOP nuclide list (cards D2, T3). = 0.: T0 = 293.6 °K.
6	PNORM	= 0.: Average cross sections are based on the average cell flux. > 0.: Average cross sections are based on the flux at the mesh point PNORM. < 0.: Average cross sections are based on the flux at the outer edge of the cell.
7	TLEAK	= -1.: Isotropic boundary condition. Read card T12. = 1.: White boundary condition.

Card T8		Format (20I1,2I2,4E12.5)
1 . 20	MTBL(J), J=1,20	Cell zone no. in which mesh point J is located. E.g. 11122223330000000000. The highest digit defines the number of cell zones <u>NCZ</u> ( $\leq 9$ ). Each cell zone <u>must</u> contain a scattering nuclide.
21	IBRENN	Skip if FUTYP > 0. Cell zone no. in which the fuel is located.
22	ICOAT	Skip if FUTYP > 0. > 0: Cell zone no. in which the coated particles are located. = 0: No calculation of coated particles heterogeneity.
23	COA(1)	Skip if FUTYP > 0. or ICOAT = 0 . Radius of the coated particle kernel. (cm)
24	COA(2)	Skip if FUTYP > 0. or ICOAT = 0 . Outer radius of the coating. (cm)
25	COA(3)	Skip if FUTYP > 0. or ICOAT = 0 . Volume fraction: coat. part. / (coat. part. + matrix).
26	COA(4)	Skip if FUTYP > 0. or ICOAT = 0 . Ratio: Nuclide density of matrix / <u>total</u> nuclide density of coating.
Card T9 only if FUTYP = 0. on card T7.		
Card T9		Format (6E12.5)
1 .	RED(I+1), I=1,NCZ	Outer radius of cell zone no. I. (cm) Inner radius of cell zone no. 1 is set to 0. (See variable MTBL on card T8 for NCZ).
A card T10 is required for each nuclide. For simplified input see variable JT.		
Card T10		Format (I5,I4,I1,10F6.3)
1	IDISO	> 0: Id. no. of nuclide in the THERMOS-library, starting with absorber nuclides in sequence of increasing THERMOS-library numbers. Followed by the scatterers with modified numbers 1000+J. Here, J = 1, 2 .... identifies the first, second .... scatterer in sequence of VSOP nuclide list, see cards D2 ,T3. < 0: -IDISO terminates the input of cards T10.

Continuation of card T10		
2	MUPN	= 0: Normal. > 0: Individual thermal selfshieldings of this isotope are given on cards T11.
3	JT	= 0: The fractional densities VB specified on this card are also valid for all subsequent nuclides, unless revised. This holds also for the selfshielding SFMU (card T11), if defined. = 1: The VB are valid only for this nuclide.
4	VB(1)	≥ 0.: Fraction of mass, based on the homogenized atom density and the respective volume, to be assigned to the 1. cell zone. (Always required in case of “dummy” elements admixed to the fuel elements!)
5	VB(L), L=2,NCZ	< 0.: Fractions are derived from data input of cards D (only if NHOM = 0 on card D1). = -1.: Nuclide distributed like fuel. = -2.: Nuclide distributed like moderator.
.	VB(NCZ+1)	Only if VB(1) ≥ 0.: Fraction to be assigned to the L-th cell zone.  The fraction of the nuclide assigned to the coated particle fuel zone ICOAT on card T8 must be further subdivided between kernel, coating and matrix. VB(NCZ+1) gives the fraction in the kernels.
Card(s) T11 only if MUPN > 0 on card T10.		
Card T11                      Format (6E12.5)		
1 . MUP	SFMU(K), K=1,MUP	Individual selfshielding of this isotope in the MUP broader thermal energy groups as defined on card(s) T2.
Card(s) T12 only if TLEAK = -1. on card T7.		
Card T12                      Format (6E12.5)		
1	ALBEDO(1)	Albedo at the outer edge of the cell for the lowest energy group no. 1.  .....

Continuation of card T12		
2	ALBEDO(2)	Albedo for the group no. 2 . = 0.: Use ALBEDO(1) for all energy groups. ≠ 0.: Read Albedos for all groups.
3 . 30	ALBEDO(J), J=3,30	Skipped if ALBEDO(2) = 0. Otherwise the group dependent Albedos must be given.

Card T13 only if ITY = -1 on card T1.

Card T13		Format (4E12.5)
1	FF(1)	Volumetric filling fraction of fuel elements in the core.
2	FF(2)	Inner radius of the fuel zone of the elements. (cm) (normal = 0.)
3	FF(3)	Outer radius of the fuel zone. (cm)
4	FF(4)	Outer radius of the element. (cm)

#### 4.4.6 Diffusion calculation. C1 - C21

Cards C1 – C21 only if item JSER  $\leq 3$  on input card S1 !

##### 4.4.6.1 Title card

Card C1			Format (18A4)
1 . 18	B(I), I=1,18	Literal description of case.	

##### 4.4.6.2 General control. C2 – C6

Card C2			Format (I3)
1	IOPT	001	

Control options.

Card C3			Format (3I3)
1	NGC10	Type of eigenvalue problem. = 0: Effective multiplication factor calculation. = -5: Fixed source (read cards C18 – C21).	
2	NGC15	Termination option (applied only to the flux iteration calculation). = 0: Terminate calculation and proceed as if converged if machine time or iteration count is exceeded (see also card C5). = 1: If limits are exceeded, terminate calculation and proceed as if converged only if the iterative process is converging. = 2: If limits are exceeded, terminate calculations.	
3	NGC24	= 0: No effect. = -1: Define - possibly unisotropic - diffusion constants on cards C11 – C17.	

Edit options.

Card C4		Format (7I3)
1	IEDG3	= 0: No effect. > 0: Print macroscopic group-to-group transfer cross sections.
2	IEDG4	= 0: No effect. > 0: Print macroscopic reaction rate cross sections.
3	IEDG5	= 0: No effect. > 0: Print gross neutron balance over system by group.
4	IEDG6	= 0: No effect. > 0: Print gross neutron balance by zone by group.
5	IEDG9	= 0: No effect. > 0: Print zone average flux values by group (IEDG6 = 0).
6	IEDG10	= 0: No effect. = 2: Only for 2-D-calculations: Print point flux- and point power density values, write them onto formatted data sets 'phi-form' and 'pow-form', respectively. IEDG10 is set equal zero for each temperature calculation and thus must be redefined for the next burnup cycle (IVSP(11) on card R7), if desired!
7	IEDG12	= 0: No effect. > 0: Print zone average power densities.

General iteration count and machine time limit.

Problems are terminated when the iteration count reaches the limit and the calculation proceeds as per NGC15 (see card C3).

Card C5		Format (3I3)
1	ITMX1	> 0: Maximum number of initial eigenvalue problem iterations. ( $\leq 999$ ) = 0: Default value = 200  The following items are machine time limits (min). Generally, calculations continue if time is exceeded as if convergence criteria had been satisfied.  .....

Continuation of card C5		
2	ITMX19	> 0: Limit for the initial eigenvalue problem. = 0: Default value = 60
3	ITMX20	> 0: Limit for all other eigenvalue problems. = 0: Default value = 30

General restraints.

Card C6		Format (2E12.5)
		Any calculation will be terminated if the following restraints are not met.
1	GLIM1	> 0.: Maximum multiplication factor. = 0.: Default value = 1.5
2	GLIM2	> 0.: Minimum multiplication factor. = 0.: Default value = 0.1

#### 4.4.6.3 Description of neutron flux problem. C7 – C10

Card C7		Format (I3)
1	IOPT	003

General description.

Card C8		Format (11I6)
		<p><u>Note:</u>  <u>2-dim.:</u> r = left → right  z = top → bottom</p> <p><u>3-dim.:</u> <u>Φ-r-z</u> or <u>x-y-z</u>  Φ or x = left → right  r or y = top → bottom  z = front → back</p>
1	NUAC11	<p>Left boundary condition (required for 2-d, 3-d).  = -1: Periodic.  = 0: Extrapolated (vacuum).  = 1: Reflected.</p>
2	NUAC12	<p>Top boundary condition (required for 2-d, 3-d).  = 0: Extrapolated.  = 1: Reflected.</p>
3	NUAC13	<p>Right boundary condition (required for 2-d, 3-d).  Set to -1 if NUAC11 = -1  = 0: Extrapolated.  = 1: Reflected.</p>
4	NUAC14	<p>Bottom boundary condition (required for 2-d, 3-d).  = 0: Extrapolated.  = 1: Reflected.</p>
5	NUAC15	<p>Front boundary condition (required for 3-d).  = 0: Extrapolated.  = 1: Reflected.</p>
6	NUAC16	<p>Back boundary condition (required for 3-d).  = 0: Extrapolated.  = 1: Reflected.</p>
7	NUAC17	<p>Number of zone to be an internal black absorber and to have the non-return boundary condition applied at its edges (see XMIS2 on card C10; this zone will be black to all groups unless additional data are supplied).</p>
8	NUAC18	<p>= 0: Only positive neutron flux allowed.  &gt; 0: Option to allow negative neutron flux.</p>
9	NUAC19	<p>= 0: No effect.  &gt; 0: Override use of Chebychev polynomials in adjusting the acceleration parameters.</p>



Continuation of card C8		
10	NUAC20	= -1: Force alternating direction line relaxation on rows and columns, and also fore and after for 3-d. = -2: Use only on rows and columns. > 0: Line relaxation only on rows. = 0: The code selects line relaxation on rows only with one inner iteration for all problems involving upscattering, otherwise three inner iterations for 3-d problems without I/O and five with data I/O during iteration, and alternating direction line relaxation for all 2-d problems.
11	NUAC23	Number of inner iterations. Normally not specified (see NUAC20 above).

#### Iteration convergence criteria

Card C9		Format (2E12.5)
1	EPI1	> 0.: Maximum relative flux change for the last iteration of each initialization eigenvalue problem. = 0.: Default value = 0.0001
2	EPI2	> 0.: Maximum relative change in the eigenvalue for the last iteration of eigenvalue problems. This applies to the multiplication factor calculation. = 0.: Default value = 0.00001

#### Miscellaneous data

Card C10		Format (3E12.5)
1	XMIS1	External extrapolated boundary constant. * = 0.: The code will use the built-in value for all extrapolated boundaries. (0.4692) > 0.: Specifies the constant for all extrapolated boundaries for all groups (see NUAC11 - 16 on card C8). <div style="text-align: right;">.....</div>

Continuation of card C10		
2	XMIS2	Internal black absorber boundary constant for the zone NUAC17. * = 0.: In connection with NUAC17 > 0 on card C8 the code will use the built-in value for all groups and the absorber will be black over all energy. (0.4692) > 0.: The constant for all groups applying to zone NUAC17.
3	XMIS6	Initial overrelaxation factor. Normally calculated by the code and not specified here.

$$* = -\frac{D}{\Phi} \cdot \frac{\partial \Phi}{\partial x}$$

#### 4.4.6.4 Simulation of void areas. C11 – C17

Cards C11 – C17 only if NGC24 = -1 on card C3

Card C11		Format (2I6)
1	JH	Number of regarded areas (card(s) C12). (≤ 200)
2	KH	Number of different cross section sets to be applied (cards C13 - C17). (≤ 20)

Card C12		Format (18I4)
1	IZONE(J),	Id. no. of cross section set to be applied to the J. area.
2	M1(J,1),	First CITATION zone located in the J. area.
3	M1(J,2), J=1,JH	Last CITATION zone located in the J. area.

One set of cards C13 – C17 for each of the  $K = 1, KH$  cross section sets.

Card C13		Format (6E12.5)
1 . N26	RDK(K,I), I=1,N26	Diffusion constants of the energy groups I. (Normally the radius of the cavity)
Card C14		
Format (6E12.5)		
1 . N26	SGA(K,I), I=1,N26	Macroscopic absorption cross sections of the energy groups I.
Card(s) C15 for each energy group I = 1,N26.		
Card C15		Format (6E12.5)
1 . N26	SGTR(K,I,J), J=1,N26	Macroscopic transfer cross sections from energy group I to energy groups J.
Card C16		
Format (3E12.5,I3)		
1	V2(K,1)	V2(K,L), L = 1, 3 : Factors to be multiplied to the diffusion constants  2-d (r - z) :        in r - direction. 3-d ( $\Phi$ - r - z) :   in $\Phi$ - direction 3-d (x - y - z) :   in x - direction
2	V2(K,2)	2-d (r - z) :        in z - direction 3-d ( $\Phi$ - r - z) :   in r - direction 3-d (x - y - z) :   in y - direction
3	V2(K,3)	2-d (r - z) :        = 0. 3-d ( $\Phi$ - r - z) :   in z - direction 3-d (x - y - z) :   in z - direction
4	IKEN	= 0: No effect. > 0: Group dependent factors will be defined on card C17.  .....

Card C17 only if IKEN > 0 on card C16.		
Card C17		Format (6E12.5)
1 . N26	FKEN(K,I), I=1,N26	Energy group dependent factors to be multiplied to the V2 of card C16.

#### 4.4.6.5 Fixed source, specified by zones. C18 – C21

Cards C18 – C21 only if NGC10 = -5 on card C3

Card C18		Format (I3)
1	IOPT	026

Card C19		Format (I3)
1	NFX2	= 0: Short output. > 0: Source (n/sec) will be edited by mesh points.

Card C20		Format (6E12.5)
1 . N26	V1F(I), I=1,N26	Fractions of the fixed neutron source distributed into each group starting with the highest energy group. These should sum to unity but are normalized to unity by the code.

One card C21 for each zone having a fixed neutron source ( $< 50$ ). Fixed source input is terminated by a 'blank' card C21.

Card C21		Format (6(I3,E9.3))
1	N2F(I),	$> 0$ : Zone number. $= 0$ : End of the 'fixed source' input
2 .	V2F(I), I=1, ....	Fixed source. (n/sec-cm <sup>3</sup> )

#### 4.4.7 Fuel cycle costs calculation. K1 - K12

Cards K1-K12 only if NKOST > 0 on card V6, or - in case of a Restart - if NEWCOST = 1 on card R6, then cards K1-K12 following card R6.

Card K1		Format (8X,7I4,A4,I4,A4)
1	NMAF	For the cost calculation the length of approach to equilibrium phase is assumed to be equal to NMAF burnup cycles. $NMAF \leq MMAF$ (card V1).
2	MXTYP	Number of different fuel types in the system ( $\leq 10$ ). For each type a set of cards K7-K10 is required.
3	ND2O	= 0: Normal. > 0: Heavy water moderated reactor. D <sub>2</sub> O expenditures included in cost calculation. Card K12 required. (This option may be used to simulate capital costs of power plant).
4	NPUFD	= 0: Normal. > 0: Pu feed cycle, for each period a Pu equivalence value is calculated according to specified FCC for uranium feed cycle on card K11.
5	IPRINT	= 0: Print-out without materials balance for each batch. = 1: Print-out includes materials balance.
6	IQ	= 0: Normal. > 0: Calculate average equilibrium FCC over the last IQ periods to obtain representative FCC for the equilibrium cycle in case it consists of more than 1 period
7	NEWCO	= 0: Neglect financing cost of fresh out-of-pile batches. (Normal when appropriate lead-times are used). = 1: Calculate financing cost of fresh out-of-pile batches for the time TOUT on card K4. This option only for cases with out-of-pile batches, i.e. KUGL > 0 on card R2.
8	\$	Monetary unit in which input is supplied. The user specifies the 4 character alphanumeric designation to be used in print-out, e.g. EUR or US\$.
9	\$X\$	The energy cost is calculated in units of \$\$ (see below) and \$X\$ is the conversion from \$ to \$\$\$. E.g. 100 means \$ = 100 \$\$.
10	\$\$	Monetary unit in which energy costs are calculated and printed in output, e.g. Cent.

Card K2		Format (4E12.5)
1	F	Annual load factor. Same as AAAA on card R2.
2	ETA	Net efficiency of power plant.
3	GLD	<p>&gt; 0.: Total lifetime of the power plant (a). Average FCC are calculated for GLD years assuming an approach to equilibrium phase of NMAF periods. For the rest of the lifetime the last (or the IQ last) calculated periods are defined to be the equilibrium period and repeated till the end of plant operation. For D<sub>2</sub>O cost calculation GLD is taken as amortization time for heavy water investments.</p> <p>&lt; 0.: Drop average FCC calculation.</p>
4	GMZ	Number of installments of electricity revenues within a period. Normally = 1., but for longer operation periods monthly or quarterly intervals of payment should be assumed.

Card K3		Format (6E12.5)
1	Z1	Pre-irradiation interest rate (1/a) on fuel expenditures.
2	Z2	Pre-irradiation interest rate (1/a) on fuel fabrication and D <sub>2</sub> O replacement costs.
3	Z4	Interest rate (1/a) on all capital, incl. electricity revenues during irradiation.
4	Z3	Post-irradiation interest rate (1/a) on capital to finance fuel credit (in effect discount rate).
5	Z5	Post-irradiation interest rate (1/a) on reprocessing and shipping costs.
6	ZL	Discount rate (1/a) for present worth leveling of all expenditures and revenues over reactor lifetime. In most cases all interest rates will be chosen the same with the possible exception of the present worth discount rate. The code offers the flexibility to model most of the economic situations arising for those special cases where this might be needed.

Card K4		Format (5E12.5)
1	SS	Tax rate (1/a) on fissile investments.
2	RES	Reserve factor ( $RES = 1. + \text{reserve}$ ) to account for additional fabrication costs for reserve elements in the initial core. In later cycles program sets $RES = 1$ . The capital charges arising from a reserve store are contained in the appropriate defined lead-times TIN and TFAB on card K9. Blank = 1.0 .
3	VERL	Recovery factor for reprocessing. (0.97 - 0.99)
4	YPA	Fraction of discharged $^{233}\text{Pa}$ decaying into $^{233}\text{U}$ during out-of-pile storage (normally = 1.0). If storage and reprocessing time are defined on card R2, the amount of $^{233}\text{U}$ reaching the reprocessing plant has already been explicitly accounted for, then $YPA = 0$ . ( $^{239}\text{Np}$ is assumed to decay completely into $^{239}\text{Pu}$ ).
5	TOUT	Storage time (days) before reuse of out-of-pile batches. Financing cost with interest rate Z4 is calculated during time TOUT. Also for fresh fuel if not NEWCO on card K1 is specified = 0. TOUT = -1. will cause the code to specify TOUT = cycle length for each cycle.



Card K5 is always required. The data for uranium ore and enrichment will be used to calculate the price of  $^{235}\text{U}$  for different fuel types and the changing value during depletion. If this option is to be by-passed, CU8(K) for all fuel types  $> 0$ . and CU5(K) specified accordingly, see cards K7.

Card K5		Format (6E12.5)
1	CU3O8	Cost of uranium ore as $\text{U}_3\text{O}_8$ (\$/lb $\text{U}_3\text{O}_8$ ). The price is given as per lb corresponding to common use in literature.
2	CO8F6	Cost of conversion of $\text{U}_3\text{O}_8$ to $\text{UF}_6$ (\$/kg U). The enriched end product is in the form $\text{UF}_6$ , the costs of converting the hexafluoride into $\text{UO}_2$ or any other compound, are included in the fabrication costs.
3	CTRENN	Separation cost. (\$/SWU)
4	TAIL	Tail enrichment, i.e., $^{235}\text{U}$ content in discarded uranium from enrichment plant.
5	XLOSS1	Fraction of losses in conversion of $\text{U}_3\text{O}_8$ to $\text{UF}_6$ (typically 0.005 - 0.01).
6	XLOSS2	Fraction of losses in conversion of enriched $\text{UF}_6$ to $\text{UO}_2$ or UC and in fabrication (typically 0.005 - 0.01).

Card K6 is always required. The costs of fresh  $^{232}\text{Th}$ ,  $^{233}\text{U}$  and fissile plutonium are assumed to be the same for all types of fuel. The discharge value may, however, vary according to composition and subsequent utilization and for each fuel type depreciation factors are specified on cards K8.

Card K6		Format (3E12.5)
1	CTH232	Cost of $^{232}\text{Th}$ . (\$/kg)
2	CU233	$\geq 0$ .: Cost of fissile $^{233}\text{U}$ . (\$/kg) $< 0$ .: Cost of $^{233}\text{U}$ is calculated relative to cost of 93% enriched $^{235}\text{U}$ with  CU233  as parity value. $\text{Cost}(^{233}\text{U}) =  \text{CU233}  * \text{Cost}(93\% ^{235}\text{U})$ .
3	CPUFIS	$\geq 0$ .: Cost of fissile $^{239}\text{Pu}$ and $^{241}\text{Pu}$ . (\$/kg) $< 0$ .: Cost of $\text{Pu}_{\text{fiss}}$ relative to cost of 93% $^{235}\text{U}$ with parity value  CPUFIS .

One set of cards K7 - K10 for each fuel type.

Card K7		Format (5E12.5)
1	ANSM	Type of heavy metal: 1.: Th(met.), 2.: ThO <sub>2</sub> , 3.: ThC, 4.: ThC <sub>2</sub> 5.: U(met.), 6.: UO <sub>2</sub> , 7.: UC, 8.: UC <sub>2</sub>
2	CU5	If CU8 (next variable) ≤ 0.: Initial reference enrichment of <sup>235</sup> U in uranium. All cost calculations are performed with the actual enrichment of a batch regardless of the reference enrichment for the type. Cost data on card K5 are used. If CU8 > 0.: Cost of <sup>235</sup> U (\$/kg). Price kept constant during calculation.
3	CU8	≤ 0.: Cost of <sup>238</sup> U = 0., and cost of <sup>235</sup> U calculated from batch enrichment and card K5. > 0.: Cost of <sup>238</sup> U (\$/kg). Supply <sup>235</sup> U cost as specified above. This option operates only if CU8 > 0. for <u>all</u> types!
4	CFAB	≥ 0.: Fuel fabrication cost (\$/kg HM) excluding cost of heavy metal. Monetary unit is variable \$ as specified on card K1 and given per kg initial HM in fuel element. < 0.: Data for this fuel element type is calculated by the code itself using basic cost data as specified on card D3.
5	CAUF	≥ 0.: Total costs of reprocessing, shipping and storage (\$/kg HM) payable at time TAUF (card K9) after discharge. Cost per kg discharged HM. < 0.: Data for this fuel element type is calculated by the code itself using basic cost data as specified on card D4.  Interests on HM during fabrication and reprocessing are calculated separately by the program for lead and lag times TIN and TEX on card K9.
Card K8		Format (4E12.5)
1	CHITH	= 0.: Irradiated and discharged fertile material (Th, U) has no value. > 0.: Cost of discharged fertile material depreciated by the factor CHITH.
2	CHIU3	= 0.: Discharged <sup>233</sup> U has no value. > 0.: Discharged <sup>233</sup> U cost depreciated by the factor CHIU3. .....

Continuation of card K8		
3	CHIU	= 0.: Discharged $^{235}\text{U}$ has no value. > 0.: Discharged $^{235}\text{U}$ cost - for actual enrichment in depleted fuel - depreciated by the factor CHIU.
4	CHIPU	= 0.: Discharged fissile $^{239}\text{Pu}$ and $^{241}\text{Pu}$ has no value. > 0.: Discharged $\text{Pu}_{\text{fiss}}$ cost depreciated by the factor CHIPU.
Card K9 Format (5E12.5)		
1	TORE	Lead-time (d) for payment of uranium ore for replacement fuel. Lead-time is counted prior to the time of loading the fuel into the reactor and start of irradiation.
2	TIN	Lead-time (d) for payment of enrichment service and conversion costs for fuel replacement relative to fuel loading. Also lead-time for purchase of $^{233}\text{U}$ and fissile plutonium.
3	TFAB	Lead-time (d) for payment of fabrication costs for replacement fuel relative to fuel loading. The lead-time for $\text{D}_2\text{O}$ replacement is taken the same as TFAB for fuel type 1.
4	TEX	Lag time (d) for credit for discharged fuel relative to time of discharge at end of irradiation. No difference between lag times for replacement and initial fuel.
5	TAUF	Lag time (d) for payment of reprocessing and shipping costs for discharged fuel relative to end of irradiation. Same for replacement and initial fuel.
Card K10 Format (3E12.5)		
1	TORE	Lead-time (d) for payment of uranium ore for initial core.
2	TIN	Lead-time (d) for payment of enrichment service and conversion costs for initial core.
3	TFAB	Lead-time (d) for payment of fabrication costs for initial core.  In general the lead-times for purchase of initial core will be longer than for replacement fuel as the amount of ore and the number of elements to be manufactured are larger.

Card K11 only if NPUFD > 0 on card K1.

Card K11		Format (6E12.5)
1	UUKOST(1)	Fuel cycle cost (\$\$/kW <sub>h</sub> ) for the first period for the corresponding uranium feed cycle. A Pu price is evaluated for this period to yield FCC equal to UUKOST(1).
NMAF	UUKOST (NMAF)	The FCC for the U-cycle must be specified for all periods NMAF. This calculation allows for NMAF < 30 only.

Card K12 only if ND2O > 0 on card K1.

Card K12		Format (6E12.5)
1	DOUTIN	Weight (kg) of total D <sub>2</sub> O in-pile and out-of-pile inventory. (D <sub>2</sub> O cost calculations may be used to simulate amortization of capital investment for the plant. The capital is then paid in installments at the beginning of each cycle or accounting period, in such a way that the installments leveled over the lifetime GLD give the total present worth value at the time of start-up. In this case DOUTIN could be interpreted as kW <sub>e</sub> of the power plant.)
2	CDNEU	Cost (\$/kg) of new D <sub>2</sub> O. (Capital cost including interest during construction at time of start-up in \$/kW <sub>e</sub> .)
3	CDALT	Cost (\$/kg) of old D <sub>2</sub> O (0., i.e. no value of station end-of-life).
4	ZD	Interest rate (1/a) on D <sub>2</sub> O investments (or capital costs).
5	SD	Tax rate (1/a) on D <sub>2</sub> O investments (or capital costs).
6	VD	D <sub>2</sub> O losses per year (normally 0.01). It is assumed that the D <sub>2</sub> O replacement expenditures have the same lead-time and interest rate as fabrication costs. (0.0 in case of plant cost).

#### 4.4.8 Fuel management. R1 - R34

Cards R1 - R34 only if NRSTRT > 0 on card V6.

##### 4.4.8.1 General definitions. R1 - R2

Card R1 only if NRSTRT = 3 or 4 on card V6, i.e. for fuel management with reprocessing.

Card R1		Format (6E12.5)
1 . KTOT	XREPRO(I), I=1,KTOT	<p>Reprocessing factor for material no. I. The reprocessing plant is simulated by reprocessing factors multiplied to the different nuclide quantities. The decay of the heavy metal isotopes is calculated for period TREPRO (card R2). The reprocessing factors are defined as:</p> <p>1.00 = No losses. 0.00 = Complete removal. 0.95 = 5% loss during reprocessing, etc.</p> <p>Data must be specified for all nuclides [KTOT = 28 (i.e. no. of heavy metal isotopes) + KMAT (card D1) non-heavy metal nuclides]. The same reprocessing factors are applied to all batches.</p>

Card R2		Format (7E10.3)
1	KUGL	<p>= 0.: Reactor without out-of-pile cycle. = 1.: Pebble bed reactor with out-of-pile fuel management: Fresh fuel stores for each type, reusable discharged fuel batches, and handling of discarded scrap fuel. = 2.: Reactor with out-of-pile cycle: As above, fuel may be replaced in any core position.</p>
2	TDOWN	Length of downtime during reload (days). The isotopic decay of the heavy metals is calculated for all in-core batches.
3	TSTORE	<p>Length of out-of-pile storage time (days) before reuse of the fuel. Decay is calculated for all out-of-pile batches, except for the fresh and for the scrap fuel. Financing costs are paid during time TSTORE.</p> <p>.....</p>

Continuation of card R2		
4	TREPRO	Length of cooling, shipping and reprocessing time (days) of discharged fuel. Decay is calculated during this period for scrap fuel batches and reprocessed fuel batches.
5	AAAA	Load factor of power plant. When fuel cycle costs are evaluated, same as F on card K2 in cost input.
6	BRUCH	Failure rate of discharged fuel (pebble bed reactor only). In each discharged batch a fraction BRUCH is assumed non-reusable and is added to the scrap batches.
7	AGEBOX	= 0.: No effect. = 1.: Aging boxes for reprocessing mixtures will be specified. Card R5 is required.

#### 4.4.8.2 Data for individual fuel types. R3 - R4

Cards R3-R4 only if KUGL > 0. on card R2. The cards are supplied as a set for each fuel type, i.e. JTYP (card V1) sets.

Definition of fresh fuel store.

Card R3		Format (2(I6,E12.5))
1	NTP1	Id. no. of the fuel type.
2	PARVL1	Volume (cm <sup>3</sup> ) of fuel store. The choice of fuel volume is arbitrary as long as no financing costs of fresh fuel store are calculated. In many cases it is advantageous to define the volume equal to the volume of one fuel element and when reloading specify the fraction of the store as no. of elements in the batch. If more fuel from the store than actually present is required, the store is regarded as unlimited. Fuel removed from the store does not change the remaining volume, neither does the isotopic composition change during the reactor life.
3	NISO	> 0: Number of isotopes on the following card(s) R4. The composition of fresh fuel is specified by the number NISO and by the card(s) R4. The rest of the isotope concentrations equals zero. .....

Continuation of card R3		
4	XMARX	<p>= 0: Card(s) R4 are skipped for this fuel type, and PARVL1 = 0.  &lt; -100: Isotope composition of the fresh fuel store has been defined by variable NFUTP on card D6.   NISO  = NFUTP.</p> <p>No. of the reprocessing mixture to which the scrapped fuel of this type is transmitted. Each mixture may consist of one or more fuel types. After each reload the discharged fuel is volume averaged to form a mixture, which at the next reload may be reprocessed and be used for refueling. <math>XMARX \leq 10</math>.</p> <p>If AGEBOX &gt; 0. (card R2) the fuel bound for a reprocessing mixture is first transferred to its corresponding aging box(es). If for all types <math>XMARX = 0</math>., no reprocessing mixtures are prepared.</p>
<p>Card(s) R4 only if NISO &gt; 0 on card R3.</p> <p>Card R4                      Format (4(I6,E12.5))</p>		
1	L	Id. no. according to VSOP list of first nuclide with atom density $\neq 0$ .
2	DAV(L)	Atom density of nuclide L in fresh fuel store for type NTP1.
3	L	Id. no. of second nuclide.
4	DAV(L)	Atom density of second nuclide.
.		Data for all NISO isotopes in fresh fuel store.
.		

#### 4.4.8.3 Aging boxes for discharged fuel. R5

Card R5 only if AGEBOX > 0. on card R2.

Card R5		Format (10I4)
1 . MREP	NAJB(J), J=1,MREP	<p>Number of aging boxes including one jumble box to be defined for the J-th reprocessing mixture. MREP is the total number of reprocessing mixtures defined by the XMARX sequence on card R3.  <math>NAJB \leq 10</math>.</p> <p><u>Note:</u></p> <ol style="list-style-type: none"> <li>1. Scrap fuel discarded from the reactor is loaded into the reprocessing mixture box J.</li> <li>2. It is transferred to the corresponding first aging box.</li> <li>3. Aging boxes are stepwise transferred to the next higher ones.</li> <li>4. Those with an age <math>\geq</math> TREPRO (card R2) are transferred to the corresponding jumble box J.</li> <li>5. If <math>NAJB(J) = 1</math>, the reprocessing mixture box J is immediately given to the jumble box.</li> <li>6. A fraction FOJB(J) (card R10) of the jumble box is loaded into the reprocessing mixture box J. It is ready for use after that reload, which will be performed after the following burnup cycle.</li> <li>7. That fraction which is not used, is returned to the jumble box J.</li> </ol>

#### 4.4.8.4 Instructions for the burnup cycles. R6 - R27

These cards will be read at the end of each burnup cycle. They define the fuel management prior to the subsequent cycle and give some new options for the next cycle.

Card R6 only if IRR9 > 0 on card S3, and only at the beginning of a restart. The preceding run ended after a fuel management performance. The restart starts at the beginning of the new burnup cycle. This card allows to change some options for this first cycle, which were given at the last card R7 of the preceding run.

Card R6		Format (6I3,I1,I2,5I3,3E12.5)
1	IPRIN(1)	Same as on card R7.
2	IPRIN(2)	Same as on card R7.
3	IPRIN(3)	Same as on card R7. (-2: Doesn't work).
4	IPRIN(4)	Same as on card R7.



Continuation of card R6		
5	NNSTOP	<p>= 0: No effect.</p> <p>&gt; 0: Number of large time steps per burnup cycle, i.e. redefinition of JNSTOP (cards V11 and R9).</p>
6	NNUM	<p>= 0: No effect.</p> <p>&gt; 0: Number of small time steps per large time step, i.e. redefinition of JNUM (cards V11 and R9).</p>
7	NEWCOST	<p>= 0: No effect</p> <p>= 1: Redefinition of cost data (only if NKOST &gt; 0 on card V6): Read cards K1 – K12, following card R6.</p>
8	NIAVC	<p>Has <u>no</u> meaning, if preceding item NEWCOST = 1 !</p> <p>= 0: No change of the option of average fuel cycle cost calculation.</p> <p>= 1: Drop average FCC calculation.</p> <p>= -1: Calculate average FCC.</p>
9	IBUC	<p>= 0: Leakage feed back option unchanged.</p> <p>= 1: Feedback of broad group bucklings to GAM-I and thermal leakage to THERMOS.</p> <p>= 2: Feedback of average epithermal buckling to GAM-I and thermal leakage to THERMOS.</p> <p>= 3: No feed back at all.</p>
10	MUHU3	<p>= 0: Streaming correction option unchanged.</p> <p>= 2: Streaming correction in power generating batches (only for pebble bed).</p> <p>= 3: No streaming correction at all.</p>
11	NOCPA	<p>= 0: Option of control poison adjustment unchanged.</p> <p>&lt; 0: If in the preceding run control poison adjustment was calculated, it can be stopped here.</p>
12	IVSP11	<p>= 0: No change of diffusion calculation option.</p> <p>&lt; 0: Drop diffusion calculation.</p> <p>&gt; 0: Repeat diffusion calculation as defined by the IDIFF on cards V17 / R12.</p>
13	INGC24	<p>= 0: No effect.</p> <p>&gt; 0: Value of option NGC24 (if previously defined equal -1 on card C3) is reset to zero value, starting with the next diffusion calculation.</p>
14	XDAY	Same as DELDAY on cards V10 and R9.
15	XPOW	Same as POWER on cards V10 and R9.
16	XKAY	Same as ZKFIND on cards V10 and R9.

Card R7		Format (6I3,3X,3I3,6I2,2X,9I2,I10)
1	IVSP(1)	<p><math>\leq 1</math>: The information of this card holds only for this shuffling and for the following burnup cycle.</p> <p><math>&gt; 1</math>: The information of this card holds for IVSP(1) shufflings and burnup cycles. The items 2 ... 10 are kept, <u>the others are set to 0.</u></p> <p><u>Output options:</u></p>
2	IPRIN(1)	<p>Spectrum calculation (same as on card V15):</p> <p>= -1: Minimal output.</p> <p>= 0: Thermal selfshielding factors, only.</p> <p>= 1: Same as 0, plus averaged thermal cross sections.</p> <p>= 2: Same as 1, plus fine group neutron fluxes.</p> <p>= 3: Same as 2, plus broad groups averaged cross sections for materials with concentration <math>&gt; 0</math>.</p> <p>= 4: Same as 3, for all materials.</p> <p>= 5: Maximum output including details of neutron transport.</p>
3	IPRIN(2)	<p>= 0: No output.</p> <p>= 1: Printout of the irradiation time of the batches.</p> <p>= 2: Same as 1, plus atom densities (only in combination with IPRIN(3) <math>\geq 0</math>).</p>
4	IPRIN(3)	<p>Burnup calculation (same as on card V15):</p> <p>= -2: All output dropped except <math>K_{eff}</math>.</p> <p>= -1: Global neutron balance.</p> <p>= 0: Detailed neutron balance.</p> <p>= 1: Same as 0, plus characteristics of <u>all</u> batches.</p>
5	NPRINT	<p>Fuel management operations at this reload:</p> <p>= -1: No fuel management output.</p> <p>= 0: Short summary.</p> <p>= 1: List of all operations.</p> <p>= 2: Detailed printout including atom densities in all batches before and after reload (very much!).</p>
6	IPRINT	<p>Fuel cycle costs calculation (same as on card K1):</p> <p>= 0: Printout without materials balance for each batch.</p> <p>= 1: Printout includes materials balance.</p>
7	IN2	<p>= 0: No effect.</p> <p><math>&gt; 0</math>: No. of the burnup time step for which a list of performance data will be printed.</p> <p><math>&lt; 0</math>: Print neutron balance averaged over the cycle.</p> <p style="text-align: right;">.....</p>

Continuation of card R7		
8	IPRIN(4)	<u>Steering the calculation performance:</u> = 0: Skip spectrum calculation. = 1: Repeat spectrum calculation as defined on cards V16 / R11.
9	IVSP(11)	= 0: Drop diffusion calculation. > 0: Repeat diffusion calculation as defined by the IDIFF on cards V17 / R12. = 2: Read card R32 for this fuel shuffling in order to redefine the CITATION edit options. (Does not work for the <u>first</u> diffusion calculation of a restart and for burnup cycles with THERMIX-calculation included).
10	NCYC	= 0: No effect. = 1: After this fuel management some fuel of the jumble boxes can be loaded into reprocessing mixtures. Here it is available for the fuel management after the next burnup cycle. Read card R10.
11	NKEEP	= 0: Use the previously defined fuel management scheme. = 1: Read a new fuel management scheme on the cards R21. = 2: Generate a new fuel management scheme with all batches staying in their position (no cards R21 are required). = 3: Generate a new fuel management scheme. Batches with individual fuel management instructions will be identified on cards R21. Non identified power generating batches will be shuffled to the next region. Non-power generating batches (e.g. reflectors) stay in their position. = 4: Same as 3. Also the non-identified power generating batches stay in their position. = 5: Generate a new fuel management scheme. For power generating batches: Fuel management instructions given for a batch on card R21 are also valid for all subsequent batches until redefined by a new card R21. Non-power generating batches (e.g. reflectors) stay in their position. = 6: Same as 3, but shuffling of each non identified power generating batch to the following batch within the same region.
12	IK	= 0: Normal. = 1: <u>Fuel management</u> is preserved for ORIGEN after <u>large time step 1</u> (equilibrium cycle treatment for MEDUL-reactors - see input description of ORIGEN-JUEL-II ) on data set 'origmod'. <u>Note:</u> The value of variable JNUM (see card R9) is changed to <u>1</u> . It must be redefined for the following burnup (shuffling-) cycles, if desired. JNSTOP on card R9 must be equal 2 .....

Continuation of card R7

13	LK	<p>= 2: Power histogram is preserved for decay heat calculation in thermal hydraulics part (THERMIX) or NAKURE-code starting from next cycle (data set 'nakure'). <u>IK must be defined on the very first card R7, if on card LF2 variable KT5 shall be '=0'!</u></p> <p>= 3: Stop the preservation of the data for decay heat calculation. Last preserved data are from preceding cycle. Read cards LF after the <u>very last</u> card R (last burnup cycle, IVSP(24) &gt; 0 on this card R7).</p> <p>= 0: Normal.</p> <p>= 2: Life history is preserved for ORIGEN-JUEL-II (all NON-MEDUL-reactors, see), starting from next cycle (data set 'origen').</p> <p>= 3: Stop the preservation of the data for ORIGEN-JUEL-II. Last preserved data are from preceding cycle. Read card P after the <u>very last</u> card R (last burnup cycle, IVSP(24) &gt; 0 on this card R7) and cards LF, if present.</p>
14	NTIK	<p>= 0: No effect.</p> <p>&gt; 0: Perform temperature calculation:</p> <p>= 1: Read new time steps ITEMP on card R13, and read new input for THERMIX on cards TX.</p> <p>= 2: Read new ITEMP on card R13, use previous THERMIX input.</p> <p>= 3: Use previous ITEMP, and give new THERMIX input.</p> <p>= 4: Use previous ITEMP, previous THERMIX input.</p>
15	NJ	<p>Only if NTIK &gt; 0:</p> <p>= 1: One single THERMIX calculation at each time step given by the ITEMP (steady state).</p> <p>&gt; 1: Time dependent THERMIX parallel to the VSOP (cards TX)</p> <p>= 2: Power for THERMIX is only the decay heat.</p> <p>= 3: Power for THERMIX is the decay heat plus the fission power of the individual time step.</p> <p><u>Redefinitions:</u></p>
16	IVOID	<p>= 0: No effect.</p> <p>= 1: Redefinition of void areas for CITATION on card R8.</p>
17	IREDE	<p>= 0: No effect.</p> <p>= 1: Redefinition of time steps, power, criticality constraints etc. on card R9.</p>
18	IVSP(16)	<p>= 0: No effect.</p> <p>= 1: Redefinition of time steps for spectrum calculation. Give ISPEKT on card R11 (same as card V16).</p> <p>.....</p>

Continuation of card R7

19	IVSP(17)	<p>= 0: No effect.</p> <p>= 1: Redefinition of time steps for diffusion calculation. Give IDIFF on card R12 (same as card V17).</p>
20	IRETEM	<p>= 0: No effect.</p> <p>= -1: Redefinition of the temperature of the resonance absorbers <u>or</u> of a scattering nuclide in one or more regions – changed by <u>the same value in each zone</u>. Read card R16, drop cards R14 + R15.</p> <p>= 1: Redefinition of the temperatures of all the regions. Read cards R14-R15 (same as card G2 and cards T4), drop card R16.</p> <p>= 2: Read new resonance integral definition on cards R17-R18 (same as cards G4-G5).</p> <p>= 3: Includes both options 1 and 2.</p>
21	LIB	<p>= 0: No effect.</p> <p>&gt; 0: Write data set 'tinte' ('status of core') for TINTE/MGT /29,30/ at time step LIB. Read card R34.</p> <p>&lt; 0: For each batch write atom densities on data set 'nucdens'.</p>
22	MUHU(1)	<p>= 0: No effect.</p> <p>&gt; 0: Extracted number of nuclides (<math>\leq 20</math>) for the output of atom densities at the end of the burnup cycle. Read id. numbers NUPRI(I) on card(s) R33.</p>
23	IWATER	<p>= 0: No effect</p> <p>&gt; 0: Calculation of water ingress to core and/or reflectors. Read cards R20A and R20B.</p>
24	IREDEF	<p>= 0: No effect.</p> <p>&gt; 0: Read new identification numbers of THERMOS-cell definitions for the regions on cards R7a (like card T6).</p>
25	IVSP(24)	<p>= 0: No effect.</p> <p>&gt; 0: Terminate the run after this fuel shuffling. The following burnup cycle will be the first cycle in a restart case.</p>

If IREDEF > 0 :

Read **Card(s) R7a (Variables and format like card T6)**

Card R8 only if IVOID = 1 on card R7 (only for the CITATION diffusion calculation).

Card R8		Format (18I4)
1	JH	Number of void areas. For each void area the following set of items:
2	IZONE(I),	Id. no. of a void cross section set to be inserted in the I-th void area (the cross section sets are defined on the cards C13 – C17 of CITATION. - see section 4.4.6.4).
.	M1(I,1),	First CITATION region located in the I-th void area.
.	M1(I,2), I=1,JH	Last CITATION region located in the I-th void area.

Card R9 only if IREDE = 1 on card R7.

Card R9		Format (3I4,3E12.5,4E6.0)
1	JNSTOP	= 0: No effect. > 0: Redefinition of the number of large burnup time steps per burnup cycle (see card V11). Must be =2, if IK=1 on card R7!
2	JNUM	= 0: No effect. > 0: Redefinition of small burnup time steps in one large step (see card V11).
3	IVSP(27)	= 0: Streaming correction as defined before. = 2: Streaming correction starting from now on.
4	DELDAY	= 0.: No effect. > 0.: Redefinition of the length of one large time step (days) (card V10).
5	POWER	= 0.: No effect. > 0.: Redefinition of thermal core power, Watts (card V10).
6	ZKFIND	= 0.: No effect. > 0.: Redefinition of end of cycle - $K_{eff}$ (card V10).
7	HNUC	= 0.: No effect. > 0.: Number of new atom densities to be read on card R19A. ( $\leq 12$ ) .....

Continuation of Card R9		
8	HPOS	Only if HNUC > 0.: > 0.: Number of batches to be loaded with the new atom densities (read card R19B). = 0.: Load additional materials into all power generating batches.
9	XTDOWN	= 0.: No effect. > 0.: Redefinition of length of down time during reload (TDOWN on card R2). < 0.: Set TDOWN = 0.
10	CONPOI	= 0.: No effect. > 0.: Read control poison adjustment data on cards R24 – R27. CONPOI gives the number of regions with control poison data. < 0.: Stop the control poison adjustments.

Card R10 only if NCYC = 1 on card R7.

Card R10		Format (6E12.5)
1 . MREP	FOJB(I), I=1,MREP	> 0.: Volumetric fraction of the I-th jumble box which shall be loaded into the reprocessing mixture I for the use at the reload after the following burnup cycle. < 0.: Volumetric fraction is calculated by the code.  FOJB(I)  gives the ratio: Volume to be loaded into the reprocessing mixture I / volume of the scrap fuel, which is discharged to the first aging box.

Card R11 only if IVSP(16) = 1 on card R7.

Card R11		Format (18I4)
1	ISPEKT(1)	≥ 0: No. of the first large burnup time step in which the spectrum calculation is to be repeated prior to the diffusion calculation.
2 . 18	ISPEKT(I), I=2,18	> 0: No. of further time steps for spectrum calculation. = 0: If all ISPEKT = 0, spectrum calculation is performed in every time step.

Card R12 only if IVSP(17) = 1 on card R7.

Card R12		Format (18I4)
1 . 18	IDIFF(I), I=1,18	<p>If all IDIFF(I) = 0: Diffusion calculation is performed at every time step.</p> <p>If at least one IDIFF(I) <math>\neq</math> 0: The IDIFF(I) give the time steps at which diffusion calculation is to be performed.</p>

Card R13 only if NTIK = 1 or 2 on card R7.

Card R13		Format (18I4)
1 . 18	ITEMP(I), I=1,18	<p>If all ITEMP(I) = 0: THERMIX temperature calculation at every time step.</p> <p>If at least one ITEMP(I) <math>\neq</math> 0: The ITEMP(I) give the time steps at which temperature calculation is to be performed.</p>

A set of cards R14 - R15 only if IRETEM = 1 or 3 on card R7.

Card R14		Format (6E12.5)
1 . NDR	SEMZUT(I), I=1,NDR	<p>&gt; 0.: Temperature of the resonance absorbers in the NDR different regions. (°C).</p> <p>= 0.: Temperature for region I stays unchanged.</p>
<p>For each of the NKER scattering nuclides (see card T1) one set of cards R15.</p>		
Card R15		Format (6E12.5)
1 . NDR	SCELS(I), I=1,NDR	<p>&gt; 0.: Temperature of this scattering nuclide for region I (°C).</p> <p>= 0.: Temperature stays unchanged.</p>



Card R16 only if IRETEM = -1 on card R7.

Card R16		Format (3I4,2E12.5)
1	NVAR	<p>= 1: Temperatures of the <u>resonance absorbers</u> are changed by <math>\Delta T = \text{TVAR}</math> (see 4<sup>th</sup> item on this card).</p> <p>= 2: Temperatures of <u>scattering nuclide</u> 1 are changed by <math>\Delta T = \text{TVAR}</math>.</p> <p>= 3: Like NVAR = 2, but for scattering nuclide 2</p> <p>= 4: Like NVAR = 2, but for scattering nuclide 3</p> <p>= 5: Like NVAR = 2, but for scattering nuclide 4</p> <p>= 6: Like NVAR = 2, but for scattering nuclide 5</p>
2	NXSA	ID-number of the first region to get a modified temperature.
3	NXSE	ID-number of the last region to get a modified temperature.
4	TVAR	Value of temperature change.
5	TMIN	Lowest occurring temperature is limited to TMIN.

Cards R17 - R18 only if IRETEM = 2 or 3 on card R7.

For each design (IDESIN on card G1) 4 sets of cards R17-R18, the first set for <sup>232</sup>Th, the second set for <sup>238</sup>U, the third set for <sup>240</sup>Pu, the fourth set for <sup>242</sup>Pu.

Card R17		Format (2E12.5,I6)
1	SM1	<p>Two values of <u>homogenized</u> atom densities of the resonance absorber nuclide, for which sets of resonance integrals are available on data set 'resint'. These values should represent the highest and the lowest densities, occurring within the reactor, respectively.</p> <p>≥ 0.: Highest density of the absorber nuclide. [barn<sup>-1</sup> cm<sup>-1</sup>]          = -1.: Density is taken from data set 'resint'.</p>
2	SM2	<p>≥ 0.: Lowest density of the absorber nuclide. [barn<sup>-1</sup> cm<sup>-1</sup>]          = -1.: Density is taken from data set 'resint'.</p>
3	NZ	Number of sets of resonance integrals for each SM1 and SM2 densities. These sets represent different temperatures of this absorber nuclide.

2 cards R18, the first one corresponds to SM1, the second one to SM2.

Card R18                      Format (12I6)

1 . NZ	IZUT(K), K=1,NZ	Id. numbers of the resonance integral sets to be read from data set 'resint'.
--------------	--------------------	---

Card R19A only if HNUC > 0. on card R9.

Card R19A                      Format (4(I6,E12.5))

1	INEW(I),	VSOP id. no. for the I-th new material.
2 .	DNEW(I), I=1,HNUC	Atom density for the I-th new material (1/(barn *cm)).

Card R19B only if HPOS > 0. on card R9.

Card R19B                      Format (12I6)

1 . HPOS	IBAE(I), I=1,HPOS	New materials only in the individual batches IBAE(I). ( $\leq 999$ )
----------------	----------------------	--

Cards R20A and R20B only if IWATER > 0 on card R7.

Card R20A		Format (2E12.5,3I6)
1	PPC	= 0.: No water ingress into reactor core (to reflectors only). > 0.: Water ingress into core; PPC = <u>Increase</u> of partial pressure of steam in the core (bars).
2	EPSI	Void fraction of the pebble bed.
3	NRVO	VSOP-material no. of oxygen.
4	NRVH	VSOP-material no. of hydrogen.
5	NZ	= 0: No water ingress into reflector batches. > 0: Number of reflector batches to undergo an ingress of water. Read card(s) R20B.

Card(s) R20B only if NZ > 0 on card R20A.  
1 card for each of the NZ reflector batches.

Card R20B		Format (I12,3E12.5)
1	NR	Id.-no. of the respective reflector batch.
2	PPR	<u>Increase</u> of partial pressure of steam in the respective batch (bars).
3	EPSI	Void fraction of the batch.
4	T	Steam temperature in this batch.

When NKEEP = 1 on card R7 one full set of cards R21 - R23 for each of the different reload batches is required. This defines the FM-scheme. When NKEEP = 3, 4, 5 or 6, these cards are only required for batches with important instructions. Batches which are only shuffled to the next region (NKEEP = 3) or to the next batch within the same region (NKEEP = 6) or stay in their position (NKEEP = 2 or 4) do not need the card R21.

FM means "Fuel Management".

TBP means "This Batch Position".

OPB means "Out of Pile Box".

RPM means "Reprocessing Mixture".

Card R21		Format (2I5,I2,6I4,3E12.5)
1	IX1	<p>= 0: If a card R21 is included for <u>each</u> batch.</p> <p>&gt; 0: When NKEEP = 3, 4, 5 or 6: No. of batch position to which this card R21 (and R22, R23) refers.</p> <p>&lt; 0: Last card R21 holding for the batch  IX1 .</p>
2	NRX	<p>= 0: Refueling of this batch position TBP with fresh fuel specified by I7.</p> <p>&gt; 0: Id. no. of a batch which is shuffled into TBP.</p> <p>&gt; 10000: Load storage box no. (NRX – 10000) into TBP. (This storage box must have been filled up at a previous reload!).</p> <p>&lt; 0: New atom densities are loaded into TBP. A set of  NRX  densities are defined on cards R22. The fuel type identification is unchanged (not a recommended option).</p>
3	NSB	<p>= 0: Normal.</p> <p>&gt; 0: No. of storage box into which this batch is to be filled. Data can be retrieved in the following reload.</p>
4	NREP	<p>= 0: No reprocessing.</p> <p>= 1: Reprocessing before loading into TBP. This option only when NRSTRT = 3 or 4 on card V6 and after having supplied cards R1.</p>
5	NSPALT	Number of materials for enrichment or re-enrichment. A card R23 must follow.
6	MAKEUP	<p>If NREP &gt; 0 and/or NSPALT &gt; 0:</p> <p>VSOP id. no. of the isotope used as make up material in reprocessed and/or re-enriched fuel. The heavy metal density of the new batch is adjusted to the initial value of the loaded fuel type.</p> <p>If MAKEUP = 0:</p> <p>No material is added. Thus a new heavy metal loading is defined.</p> <p style="text-align: right;">.....</p>

Continuation of card R21		
7	MANAGE	<p>= 0: Load fuel without any change into TBP.</p> <p>= 1: Treated is the content of a reprocessing mixture which is the considered OPB. It can optionally be loaded from a jumble box (comp. card R5 and NCYC on card R7). The content has been formed from the disloaded fuel of one or more fuel types (XMARX on card R3) and <u>has been summed up over previous cycles.</u></p>
The following part of card R21 depends on the option <u>MANAGE</u> .		
<b><u>MANAGE = 0:</u></b>		
8	I7	<p>= 0: Fuel type no. same as batch NRX.</p> <p>&gt; 0: Fuel type to be loaded into TBP (only with out of pile FM, KUGL &gt; 0 on card R2).</p>
9	I8	Dummy.
10	R1	<p>= 0.: Fissile enrichment stays unchanged.</p> <p>&gt; 0.: R1 defines a new enrichment for the loaded fuel. Only relevant if fresh fuel is used.</p>
11	R2	<p>When NRX &gt; 0 and use of <u>in-core-batches</u>:</p> <p>= 0.: New volume of TBP is defined by the batch NRX, which is loaded.</p> <p>&gt; 0.: R2 is the fraction of the in-core batch to be loaded into TBP.</p> <p>When NRX &gt; 0 and use of <u>storage boxes</u>:</p> <p>= 0.: The total storage box volume is used for loading into TBP. By this way a new volume is assigned to TBP. A maximum is given by filling up the region's volume.</p> <p>&gt; 0.: R2 is the fraction of the storage box to be loaded into TBP.</p> <p>When NRX = 0:</p> <p>&gt; 0.: Fraction of the total volume of the out of pile fuel of type I7 to be loaded into TBP. If KUGL = 1 (on card R2) the volume of all batch positions in the upper region is automatically limited to the region's volume. The fresh fuel store is unlimited.</p>
12	R3	<p>= 0.</p> <p>.....</p>

**MANAGE = 1:**

8	I7	New fuel elements are performed in the following way: The identification number and the total heavy metal content are taken from the fresh fuel type numbered by I7. The isotopic composition of the new fuel elements is taken over from the reprocessing mixture numbered by I8.
9	I8	Id. no. of the used reprocessing mixture.
10	R1	Enrichment $N_{\text{fiss}}/N_{\text{HM}}$ for the new formed elements.
11	R2	> 0.: Fraction of the total reprocessing mixture (RPM) volume to be treated and loaded into the volume of TBP. < 0.: The RPM volume fraction  R2  is related to that part of the total volume, which has been left over from preceding loading procedures during the present fuel management step. If depletion would be necessary, the program reduces the RPM volume fraction R2 instead.
12	R3	= 0.: New volume of TBP is that one which has been made available from the RPM. > 0.: New volume of TBP is R3 * volume of the upper region which the presently considered batch belongs to. = 1.: The upper region is filled up. The new definition of the TBP volume immediately causes a corresponding change in the used RPM volume fraction R2. < 0.: The specified fraction of the RPM volume is reprocessed. No fissile material is added or removed. Only make up material is added or removed in order to achieve the required enrichment R1 for the defined fuel type I7. The presently considered TBP volume is modified. For the presently considered TBP a volume WERA =  R3  * volume of the upper region is made available. If the prepared new volume of fuel elements is larger than WERA, the fraction R2 will be reduced. If it is smaller, the WERA will be reduced correspondingly.
Card(s) R22 only if NRX < 0 on card R21.		
Card R22                      Format (4(I6,E12.5))		
1,3,5 . 2,4,6 .	NPX(J),  CPX(J), J=1, NRX	VSOP id. no. of the J-th nuclide with the atom density $\neq 0$ .  Atom density of the J-th nuclide. If = 0., the nuclide needs not to be specified.

Card(s) R23 only if NSPALT > 0 on card R21.

Card R23

Format (4(I6,E12.5))

1,3,5 . 2,4,6 .	IDFISS(J),  FICOMP(J), J=1,NSPALT	VSOP id. no. of the J-th nuclide used for re-enrichment.  Relative fraction of the J-th nuclide in the enrichment composition. The sum of all FICOMP in the composition must be equal 1. Only the fissile isotopes in FICOMP are used to calculate enrichments, so the composition may also contain fertile materials, for instance 0.93 <sup>235</sup> U and 0.07 <sup>238</sup> U. The original fissile / HM ratio in the batch before re-enriching be YSPALT, the code distinguishes two different cases:  <u>Case 1:</u>  R1 > YSPALT, new material with the relative composition specified in FICOMP is added to make up the difference (R1 - YSPALT).  <u>Case 2:</u>  R1 < YSPALT, the original HM composition in the batch is unchanged, but the densities of all HM are reduced to obtain the fissile/HM ratio R1. The out of pile volume fraction R2 (card R21) is reduced correspondingly. To maintain the correct HM density the designated make up material (normally a fertile isotope) is added. Here, the FICOMP data are obsolete.
.	IXTYPE	= 0: Normal. > 0: The fuel in this batch position is given a new fuel type no. after reprocessing and/or re-enrichment. Redefinition of types may be necessary in order to use pertinent cost data for recycled fuel.
.	HMETAV	= 0.: Normal. > 0.: New heavy metal density for use in this batch position, only of significance in connection with the MAKEUP option (on card R21). For some types of reactors the heavy metal loading in a particular batch position may have to be varied during the life-time of the reactor, for instance during the running-in phase.

Cards R24 - R27 only if CONPOI > 0. on card R9.  
One card R24 for each of the CONPOI regions with control poison data.

Card R24		Format (I12,2E12.5)
1	KR	Id. number of the considered region.
2	POISL(1)	Maximum atom density of the first control poison nuclide.
3	POISL(2)	Maximum atom density of the second control poison nuclide (if defined).

**Cards R25 - R27 like cards V12 - V14 !**

#### 4.4.8.5 Criticality search for the reloads. R28 - R31

Cards R28 - R31 only if NRSTRT = 2 or 4 on card V6.

Card R28		Format (18I4)
1	JARIT	<p>= 0: No iteration for this reload, skip cards R29 - R31.  &gt; 0: Total number of batches to be iterated, length of following list of batch id. no's. The atom densities of the materials specified on card R30 are iterated to give reactivity K-search.</p>
2	NCOL(I), I=1,JARIT	Id. no. of the I. batch.
.	ITVAR	<p>= 0: No effect.  &gt; 0: Use different sets of materials to increase resp. decrease enrichment to obtain correct <math>K_{\text{eff}}</math>. Two sets of cards R29 - R30:  First set in case <math>K\text{-search} &gt; K_{\text{eff}}</math> core, second set in case <math>K\text{-search} &lt; K_{\text{eff}}</math> core. Code reads both sets of cards and selects the required one in each case.</p>
.	IR16	<p>= 0: Normal.  &gt; 0: Read card R31 with new heavy metal densities for iteration batches. IR16 is the number of batches in which the HM density is redefined and used to determine the amount of make up material to be added. The option may be necessary for reactors where the moderation ratio and HM loading in the fuel types vary during reactor life, for instance during the running-in phase.</p>



If JARIT > 0 on card R28: At least one set of cards R29 - R30.

If ITVAR > 0 on card R28: Two sets of cards R29 - R30.

Card R29		Format (2(I6,E12.5))
1	ITMAT	Total number of materials iterated, i.e. length of materials list on card R30. ( $\leq 28$ )
2	XKEFF	<p>&gt; 0.: <math>k(o)</math>, reactivity specification for iteration search in cycle i.</p> <p>= 0.: Use same <math>k(o)</math> as beginning of last cycle, <math>k^i(o) = k^{i-1}(o)</math>.</p> <p>&lt; 0.: Determine a <math>k(o)</math> value for beginning of next cycle so that the end of cycle reactivity <math>k(\min)</math> is reached after the specified number of time steps JNSTOP. The extrapolation is made from <math>k^i(o) = (k^{i-1}(o) - k^{i-1}(\text{JNSTOP})) + k(\min) *  XKEFF </math> and <math>k(\min) = \text{ZKFIND}</math> (card V10). The value of XKEFF may be used to adjust for uncertainties in <math>k(\min)</math>. <u>This is black magic.</u></p>
3	MAKEUP	VSOP id. no. of nuclide to adjust heavy metal density in batches to either initial value in batch or as specified on card R31.
4	XTYPE	<p>= 0.: Fuel type no. of batches is not altered.</p> <p>&gt; 0.: New fuel type no. for batches. Same no. is given to all batches for which iteration is performed.</p>
Card R30		Format (4(I6,E12.5))
1	IDIT(1)	VSOP id. no. of first nuclide used in iteration.
2	COMPIT(1)	Relative fraction of first nuclide.
3	IDIT(2)	VSOP id. no. of second nuclide.
4	COMPIT(2)	Relative fraction of second nuclide.
.	.	The relative fractions of all ITMAT (card R29) nuclides must be equal 1. If all COMPIT = 0., the existing relative fractions in the batches remain unaltered during iteration.
.	.	

Card R31 only if IR16 > 0 on card R28.

Card R31		Format (I6,E12.5)
1	IR	Batch no. for which the following HM density is specified. The specification on this card only for those batches for which the HM density differs from the initial one.

Continuation of card R31		
2	HMETAV (IR)	New heavy metal density in batch no. IR, to be used when adjusting the make up material.  One card for each specified batch: I=1,IR16.

#### 4.4.8.6 Redefinition of CITATION edit options. R32

Card R32 only if IVSP(11) = 2 on card R7.

Card R32		Format (7I3)
		Redefinition of edit options. Same as card C4 (see input section 4.4.6.2).

#### 4.4.8.7 Extracted nuclides for printout. R33

Card R33 only if MUHU(1) > 0 on card R7.

Card R33		Format (12I6)
1 .	NUPRI(I), I=1, MUHU(1)	VSOP id. no. of nuclide for which printout is desired. Up to 20 nuclides can be specified.

#### 4.4.8.8 "Status of core"- data set for TINTE/MGT. R34

Card R34 only if LIB > 0 on card R7.

Card R34		Format (18A4)
1 . 18	TITEL(I), I=1,18	Literal description of the case to be transferred to the TINTE/MGT code via data set 'tinte'.

#### 4.4.9 Fuel power histogram for decay power evaluation. - LF1 - LF3

Only if IK = 3 on any card R7.

Card LF1 sets up the dimensions.

Card LF1		Format (3I6)
1	KMAX	Number of VSOP <u>burnup cycles</u> required for the set-up of the full irradiation history of the individual batches (compare KT5 > 0 on card LF2).
2	LMAX	Number of all VSOP <u>time steps</u> of the KMAX burnup cycles.
3	MTMAX	Number of graded time steps to be generated ( $\leq 49$ ).

Card LF2		Format (5I6)
1	IOUT	Output option: = 0: Short output. = 1: Recommendable. = 2: Additional test output.
2	ICOMPA	= 0: The generated library of all batches in the graded time steps is printed out from batch no. 1. > 0: Print out starts from batch no. ICOMPA.
3	ICOMPE	= 0: Print out ends at the last batch. > 0: Print out ends at batch no. ICOMPE.
4	LT0	= 0: Default. Evaluation starts from the last time step of the given cycle. > 0: Time step of the given cycle, from which the precursory history evaluation begins.
5	KT5	= 0: No effect. = 1: Preserve only the last VSOP cycle and prepare KMAX identical cycles out of it. > 1: Preserve only VSOP cycle with id. no. KT5 and prepare KMAX identical cycles out of it.

Card LF3		Format (4E12.5)
1	TN	Time span (days) to be covered by the coarse new intervals ( $\geq$ maximum fuel element residence time + out of pile times).
2	DT	First coarse time interval (days). Normally the same as the last VSOP time step.
3	TOOP	<u>MEDUL-fueling only:</u> Time span (days) between fuel discharge from the core and its reload onto the core. Zero power is assumed during this shuffling procedure.
4	TEPS	> 0.: Convergence limit for iterative calculation of the incremental parameter of the coarse time steps. = 0.: Default value = 0.1 .

#### 4.4.10 Fuel irradiation histogram for entire isotope generation. - P

Only if LK = 3 on any card R7.

Card P		Format (3I6)
1	LXS	Number of time steps with spectrum calculation (for dimensioning only).
2	LT0	= 0: Normal. Evaluation starts from the last time step of the given cycle. > 0: Time step of the given cycle, from which the precursory history evaluation begins.
3	IOUT	Output option: = 0: Recommendable. = 1: Additional test output.

#### 4.4.11 Preparing THERMOS-library. TTTT1 - TTTT5

Only if ITTT > 0 on card S1.

Sequence of input cards:

- S1 - G6:** VSOP input of case identification.
- TTTT1, TTTT2:** THERMALIZATION input without selfshielding factors.
- T1:** Blank card.
- TTTT3 - TTTT5:** Preparing (condensing) new THERMOS library.

Card TTTT1		Format (12I6)
1	JNTAPE	Id. no. of the thermal 96 groups THERMALIZATION-library on data set 'thermal'. Only choice at present: JNTAPE = <u>115</u> .
2	NKER	Number of different scattering nuclides for the present spectrum run.
3	IDKER(1,I),	VSOP-id.no. of the first scatterer.
4	IDKER(2,I),	Thermal library-id.no. of scattering matrix to be applied.
.	I=1,NKER	
.		NKER different pairs of id. numbers and scattering matrices.

Card TTTT2		Format (3E12.5)
1	TOM	Temperature in calculation of Maxwellian neutron energy distribution for starting iterations of thermal spectrum. (°K)
2	EPSI	Criterion of convergence of flux iteration. ( $\cong 0.0001$ )
3	WAT	Acceleration of convergence: 0. = no, 1. = yes.

Card TTTT3		Format (A9,I3,4I6,E12.5)
1	DSIDTP	Data set name of the THERMOS library to be replaced or to be generated in addition to existing libraries. For possible choices see Table II.
2	ITTTT	> 0: Reduced output.
3	IEBE	Nuclide no. with full output.
4	ITUTEU	> 0: Print out of scattering matrices.
5	KERNE	Number of scattering matrices to be condensed for the THERMOS library. = 1000: Condensing of all scattering matrices.
6	ITOT	> 0: All absorbers.
7	T	Temperature (°K) for Maxwellian flux for eventually condensing absorbers.

Card TTTT4 only if KERNE  $\neq$  1000 on card TTTT3.

Card TTTT4		Format (12I6)
1	IDKER(1,J),	GAM-I-id.no. of the J-th scattering matrix.
2	IDKER(2,J), J=1,KERNE	VSOP-id.no. of the J-th scattering matrix.

Card TTTT5		Format (10I5)
1 . 30	NG(I), I=1,30	Number of the lowest THERMALIZATION group within the I-th THERMOS group to be formed.

#### 4.4.12 2d-Thermal hydraulics. TX1 – TX26

Only if NTIK = 1 or 3 on card R7.

Card TX1			Format (18A4)
1 . 18	TITLE(I), I=1,18	Literal description.	

Card TX2			Format (18I4)
1	IFKON	<u>Steering the calculation:</u> = 0: <u>No</u> calculation of gas temperature and gas streaming. = -1: Coupling between the temperatures of gas and solid material by heat transfer coefficient $\alpha$ . Recommended for steady state calculations, <u>not valid in transient runs</u> . = 1: Coupling via the source/sink distribution.	
2	IPRINT	= 0: Minimum output.(Recommended when temperature calculation is frequently repeated during the VSOP-run). = 1: Standard output. See also item "IPASS" (this input card). = 2: More detailed output. = 3: Maximum output (very much!).	
3	IPUN	= 0: No effect. Steady state calculation only: = 3: <u>Preserve</u> temperature fields on data set 'thermix' as start-up values for a transient calculation.	
4	IFRSTA	= 0: No effect. = 3: <u>Read</u> temperature fields from data set 'thermix' as start-up values for a transient calculation. .....	

Continuation of card TX2

5	INTVAL	<p>= 0: Steady state run.            = 1: Transient calculation: The time steps are given by the burnup scheme (JNSTOP, DELDAY on card R9).</p>
6	IFRED	<p>= 0: For steady state calculation.            &gt; 0: Calculation of the decay power according to DIN 25485, using the fuel life history (see cards LF).</p> <p><u>Iterations:</u></p>
7	MITMAX	<p>&gt; 0: Maximum number of iterations of temperature calculation.            = 0: Default value = 2000</p>
8	IKORM	<p>&gt; 0: Maximum number of changes of the relaxation factor.            = 0: Default value = 100</p>
9	IFREL	<p>= 0: Inner iteration in radial direction (I).            = 1: Inner iteration in axial direction (N).</p>
10	ITLAM	<p>&gt; 0: Repeat calculation of temperature dependent material data for every ITLAM-th time step (only for steady state THERMIX-KONVEK iteration).            = 0: Default value = 10</p>
11	NLOOP	<p>&gt; 0: Maximum number of THERMIX-KONVEK ("Loop") iterations ( steady state).            = 0: Default value = 100</p>
12	IEXPR	<p>= 0: No effect.            = 1: Write steady state temperature field onto data set 'tempstat'.            = 2: Write temperature fields during transient calculation onto data set 'tempinst'. Read card TX3.</p>
13 . 17	ICODEF(I), I=1,5	<p>= 0: <u>Must</u> be = 0 in steady state calculations.            &gt; 0: Id. numbers of one or more (<math>\leq 5</math>) THERMIX-compositions, whose properties shall be redefined for the <u>transient</u> calculation. Read a new set of cards TX8 and TX9 for each of these compositions, following card TX6. <u>(Not allowed for the compositions representing the gas source or gas sink!)</u>.</p>
18	IPASS	<p>Has effect only if item "IPRINT" (this input card) equals 1 and only for the steady-state calculation.            = 0: Printout of fuel element temperatures for each batch, i.e. for each fuel passage of a multi-pass fuelling strategy.            &gt; 0: Printout for batch (passage) no. "IPASS" only.</p>



Card TX3 only if IEXPR = 2 on card TX2.

Card TX3		Format (2E12.5)
1	PHIA	Start of temperature table at axial position PHIA (lower value according to THERMIX mesh point positions). (cm)
2	PHIE	End of temperature table at axial position PHIE. (cm)

Card TX4		Format (10F6.1,E12.5)
1	QNORM	> 0.: Total power (MW). Input power field is normalized to QNORM. In a transient run the QNORM must be the reactor power, for which the life histogram was calculated. = 0.: Drop normalization.
2	ETHA	> 0.: Convergence criterion for local THERMIX temperature field. (°C) = 0.: Default value = 0.01
3	OVREL	> 0.: Maximum relaxation factor. = 0.: Default value = 1.7
4	ORMIN	> 0.: Minimum relaxation factor. = 0.: Default value = 0.6
5	TDIFF	> 0.: Relative convergence criterion of the time independent THERMIX-KONVEK iteration. = 0.: Default value = 0.0005
6	EFAK	> 0.: Multiplication factor for maximum allowable error level, which stops the run. = 0.: Default value = 1.
7	DTVOR	> 0.: Maximum allowed relative temperature change $\Delta T / T$ in a time interval $\Delta t$ of a transient run. The time intervals $\Delta t$ are correspondingly adapted. = 0.: Default value = 0.05
8	ZEITMI	> 0.: Minimum length of the time intervals $\Delta t$ in a transient run. (sec) = 0.: Default value = 60.
9	EPSST	= 0.: Emission coefficient of graphite spheres from internal function GREPS(T). > 0.: New emission coefficient (e.g. for coated spheres). .....

Continuation of card TX4		
10	ZEITNW	= 0.: (Special option).
11	FDOSE	Only in case of steady-state calculation (INTVAL = 0 on card TX2): Factor to convert the dose of fast neutrons with an energy E > CEG(1) (see card G6) into EDN-values.

Card TX5		Format (7E8.0,4I4)
1	EPSI1	> 0.: Relative criterion of convergence for gas temperature. = 0.: Default value = 1.E-5
2	EPSI2	> 0.: Criterion of convergence for mass flow. = 0.: Default value = 0.01
3	OVM1	> 0.: Extrapolation factor for iterations on mass flow (every 10 iterations an extrapolation is provided with 1 + OVM1). = 0.: Default value = 0.5
4	EPSI4	> 0.: Relative criterion of convergence of the avg. gas temperature in the outer iterations between gas temperature and mass flow. = 0.: Default value = 0.02
5	CP	> 0.: Specific heat capacity of the gas. (J/kg/°K) = 0.: Default value = 5195. (He).
6	PRAN	> 0.: Prandtl-constant of the gas. = 0.: Default value = 0.66
7	DRUCK	Pressure of the gas. (bar)
8	IFZDR	= 0: Pressure of the system is constant. = 2: Pressure changes according to temperature. Gas inventory is constant.
9	ITM1	> 0: Maximum number of iterations for gas temperature. = 0: Default value = 100
10	ITM2	> 0: Maximum number of iterations for mass flow. = 0: Default value = 500
11	ITM3	> 0: Maximum number of outer iterations between gas temperature and mass flow. = 0: Default value = 5

Card TX6 only if INTVAL = 1 (transient calculation) on card TX2.

Card TX6		Format (F6.1,2I2,3E10.3))
1	DZEIT1	Length of the first <u>small</u> time interval. (sec)
2	NPRIN1	> 0: Print the fields of temperature and streaming for each NPRIN1-th <u>small</u> time steps. = 0: Default value = 50 .
3	NKONV1	> 0: Run the calculation of gas temperature and gas streaming every NKONV1 <u>small</u> time steps (only if IFKON $\neq$ 0 on card TX2). = 0: Default value = 1
4	ZEI1	End of the first <u>large</u> time interval. (hours)  The following <u>large</u> time intervals are defined by variable DELDAY (card R9). The <u>small</u> intervals are defined by DZEIT2.
5	DZEIT2	= 0.: Free choice of the <u>small</u> intervals. < 0.: Also free choice, but maximum =  DZEIT2 . (sec)
6	PSPALT	= 0.: No effect > 0.: Redefinition of the pressure in the gap compositions of THERMIX

Cards TX7 – TX17 only if INTVAL = 0 (steady state calculation) on card TX2.

For cards TX8 and TX9 see also variable ICODEF on card TX2!

Card TX7		Format (4I4)
1	IFRFI	= 0
2	IFRFA	= 0: Fixed temperature of the last radial composition defined by item TVOR on card TX8. = 1: Adiabatic boundary condition in the last radial mesh.
3	IFRFL	= 0: Fixed temperature of the first axial composition defined by item TVOR on card TX8. = 1: Adiabatic boundary condition in the first axial mesh.
4	IFRFR	= 0: Fixed temperature of the last axial composition defined by item TVOR on card TX8. = 1: Adiabatic boundary condition in the last axial mesh.

One card TX8 (optionally followed by TX9 - TX12) for each THERMIX composition numbered continuously increasing.

Card TX8		Format (A3,6I3,10E5.0,I1)
1	BEM	<p>Literal description of this composition, 3 digits. Free choice, except for:</p> <p>= HET: Temperatures are calculated in the inner of the fuel elements.  <u>Possible only for a pebble-bed core!</u>            Analysis of temperature/volume.</p> <p>= DBH: In a transient calculation the average and the maximum temperature of this composition is displayed as a function of time.</p> <p>= END: Termination of cards TX8, drop all other items of this card.            Code sets variable KMAX = number of THERMIX compositions equal to highest value, which was assigned to variable K1.            Each of HET, DBH, END must be declared <u>only one time</u></p>
2	K1	Id. no. of this composition.
3	IFTV	<p>= -1: "Solid material zone". Temperature calculation comprises the heat exchange with the coolant by source/sink heat transfer <u>within the meshes of this zone</u>.</p> <p>= 0: "Solid material zone". No heat exchange with the coolant is involved.</p> <p>= 1: "Fluid zone". No temperature calculation is performed for this zone (Temperature fixed to initial value TVOR). Coupled with the neighbors by the heat transfer coefficient ALP on this card.  <u>Note:</u> For instance these zones are used as a heat sink at the outer boundary of the system. <u>At least two meshes</u> are required.</p>
4	IFWKT	<p>= 0: Heat capacity given by C on this card.</p> <p>&gt; 0: Identification no. of the material function for temperature dependent heat capacity (see <b>Table VIII</b>).</p>
5	IFLT	<p>= 0: Thermal conductivity <math>\lambda</math> given by LAM on this card.</p> <p>&gt; 0: Identification no. of the material function for temperature and dose dependent <math>\lambda</math> (see <b>Table IX</b>).</p> <p>= 7: The temperature dependent function of id. no. = 7 uses LAM0 of this card as <math>\lambda(T = 0^\circ\text{C})</math>.</p> <p>= 4: In case of EPS1 and EPS2 &gt; 0. (see below) the function uses LAM0 of this card as pressure (bar) of the gas in the gap (convection). In case of EPS1 and EPS2 = 0. the function uses helium at the pressure 1 bar. No heat radiation.</p> <p style="text-align: right;">.....</p>

**Tab. VIII: Available formulas of heat capacity**

<i>Id.no.</i>	<i>Material function of temperature dependent heat capacity</i>	
1	Reactor graphite, SGL, Grade A, NBG10	density 1.75 gr / cm <sup>3</sup>
2	Reactor graphite, SGL, Grade A, NBG10	density 1.80 gr / cm <sup>3</sup>
3	Core barrel, SA-240 grade 316	
4	Pressure vessel, SA-508	
6	Steatite	
7	Reactor graphite (HRB)	density 1.75 gr. / cm <sup>3</sup>
8	Carbon bricks (like Reakt. graph.)	density 1.55 gr. / cm <sup>3</sup>
11	V2A - Steel (Hoesch)	DIN 4541
12	Thermal shield (HRB)	
13	Reactor graphite (HRB)	density 1.70 gr. / cm <sup>3</sup>
14	Reactor graphite (HRB)	density 1.60 gr. / cm <sup>3</sup>
15	Reactor graphite (HRB)	density 1.80 gr. / cm <sup>3</sup>
16	Al <sub>2</sub> O <sub>3</sub>	no f(T)

**Tab. IX: Available formulae of thermal conductivity**

<i>Id.no.</i>	<i>Material function</i>
1 Sodium (liquid)	
2 Graphite (Matrix)	T = irradiation temperature
3 Graphite (Reflector)	Interpolation from tables (see Subroutine GFIT)
4 EPS > 0.: Helium EPS = 0.: Static Helium	LAM0 = pressure (bar) 1 bar
6 Zehner- Schlünder for Steatite	Experiment (K. Verföndern)
7 Reactor graphite	LAMDA(0) = LAM (Comp.)
8 Carbon bricks	"Lukasiewicz"
9 Static air	1 bar
10 Thermal shield (HRB)	
11 V2A - Steel (Thyssen	DIN 4541
13 Steatite	for heterogeneous calculation
14 Graphite balls	Experiment (Robolt)
15 Armed concrete	
16 Prismatic core	axial
17 Carbon-felt	in vacuum
18 Carbon-felt	in Ar- or N <sub>2</sub> atmosphere
19 Anti-friction bearing steel	100CR6
20 Static Nitrogen	
21 Kaowool-mat	in air (Jül 992RB)
22 H A W-glass	
23 Pebble bed	Schürenkrämer (II.84), (Combination of No. 25 and No. 26 for $4 \times 10^{21}$ EDN)
24 Ball graphite, Binkele/A3 graphite	Function of temperature and neutron dose (explicit)
25 LAMDA-eff., pebble bed	Function of temperature and neutron dose (Robolt)
26 Lambda eff., pebble bed	Function of temperature and dose (Zehner- Schlünder)
27 Lambda eff., pebble bed	Function of temp. and dose (Robolt+Zehner-Schlünder)
28 Al <sub>2</sub> O <sub>3</sub>	linear (Salmang/Scholz "Keramik")
29 Gilsonit coke (AGL-IE 1-24)	Irradiated at 760 °C (Binkele)
30 Core barrel, SA-240, grade 316	
31 Pressure vessel, SA 508, grade 3	
32 Reactor graphite, SGL grade A	Function of temperature, dose and irradiation temperature

Continuation of card TX8

6	IDIR	Only if EPS1 (and EPS2) > 0.: = 0: Radiation in radial direction. = 1: Radiation in axial direction.
7	NTVAR	= 0: No effect. > 0: In case of fluid zone (IFTV = 1) provide NTVAR time dependent temperatures on card TX12 ( $\leq 10$ ).
8	RHO	Volumetric fraction of solid material in this composition. RHO is used for calculation of the heat capacity.
9	C	= 0.: When IFWKT > 0. > 0.: Heat capacity of the solid material. ( $\text{J}/\text{cm}^3/\text{°K}$ )
10	LAM	= 0.: When IFLT > 0. > 0.: Thermal conductivity in solid material zones (only if IFTV = 0 or -1). ( $\text{W}/\text{cm}/\text{°K}$ )
11	LAM0	= 0.: Default. > 0.: If IFLT = 7, LAM0 is $\lambda(T = 0^\circ\text{C})$ . If IFLT = 32, the conductivity according to function 32 is modified by the factor LAM0. If IFLT = 4 and EPS1 > 0. and EPS2 > 0., LAM0 is the pressure of the gas in this composition.
12	EPS1	= 0.: No heat radiation. > 0.: Coefficient of emission for heat radiation; <u>inner radial/ upper axial</u> wall of the gap. (Maximum number of compositions with heat radiation = 19).
13	EPS2	Like EPS1, for <u>outer / lower</u> wall.
14	R1R2	Horizontal gap: = 0. Radial gap: Ratio: inner radius / outer radius.
15	TVOR	= 0.: Start-up temperature field results from the input temperature field of the cards TX15 - TX17. > 0.: Fixed temperature of this composition ( $^\circ\text{C}$ ) superior to the start-up temperatures of the cards TX15 - TX17.
16	WPR	= -1.: Field of fission power density results from CITATION. It will be normalized to QNORM (card TX4). $\geq 0$ .: Power density of this composition. ( $\text{W}/\text{cm}^3$ )  .....

Continuation of card TX8		
17	ALP	<p>= 0.: No effect.</p> <p>&gt; 0.: Heat transfer coefficient in fluid zones (only if IFTV = 1). (W/cm<sup>2</sup>/°K)</p> <p><u>Note:</u> ALP <math>\cong</math> 0.5: Temperature at the boundary close to that of this fluid zone. ALP <math>\cong</math> 0.01: Temperature at the boundary close to that of the adjacent zone.</p>
18	ISTR	<p>= 0: No gas streaming through this composition.</p> <p>= 1: Gas streaming; read card TX9 following this card TX8.</p>
Card TX9 only if ISTR = 1 on card TX8.		
Card TX9                      Format (2I6,6E6.0,I6)		
1	IFBQ	<p>= 0: When IFTV = -1 on card TX8. Convective heat source is computed in the meshes of this composition.</p> <p>= -1: No convective heat source evaluation (e.g. in voids).</p>
2	IFBR	<p>Type of composition:</p> <p>= 1: Gas streaming in the pebble bed.</p> <p>= 2: Gas streaming in vertical pipes. (Total number of such compositions <math>\leq</math> 30)</p> <p>= 5: Gas streaming in a horizontal void (no more than one mesh over its thickness). (10 horizontal voids at maximum!)</p>
3	PVOR	<p>&gt; 0.: Pressure at beginning of iterations. (bar)</p> <p>= -1.: Pressure = pressure of the gas (see DRUCK on card TX5).</p>
4	XKON	Additional pressure drop relative to computed pressure drop over the length of the channel (only if IFBR = 2). (1/cm)
5	ALPHA	<p>= 0.: Internal calculation of the coefficient of heat transition. In voids (IFBR = 5) use ALPHA = 0.</p> <p>&gt; 0., <math>\neq</math> 1: No internal calculation of ALPHA. Use the given value. (W/cm<sup>2</sup> K)</p> <p>= 1.: For the pebble bed.</p>
6	DHYD	<p>Hydraulic diameter (cm). Only if IFBR <math>\geq</math> 2.</p> <p>.....</p> <p><u>The following 2 items</u> are relevant for a <u>steady-state calculation</u> only:</p>



Continuation of card TX9		
7	STZUK	> 0.: <u>Source</u> of mass flow. (kg/s) < 0.: <u>Sink</u> of heat (mass flow). Mass flow according to conservation law (Not in the <u>first</u> radial or axial mesh!)
8	TFLVOR	Temperature of inlet gas. (°C)  In case of <u>time dependent</u> calculation only:
9	IFZST1	= 0: <u>No</u> forced cooling = 1: Time dependent forced mass flow. <u>Read input cards TX25, TX26.</u>
Cards TX10, TX11 only if BEM = "HET" on card TX8.		
Card TX10                      Format (E10.3,I5)		
1	HKUG	Diameter of the spherical fuel element. (cm)
2	NHZON	Number of radial mesh intervals in the sphere. ( $\leq 5$ )
I = 1,NHZON cards TX11.		
Card TX11                      Format (E10.3,2I5,E10.3)		
1	DI(I)	Inner diameter of the I-th radial mesh interval. (cm) <u>Caution:</u> I = 1 ... counts from the outer shell towards the inner.
2	NHMAT1(I)	Id. no. of temperature dependent thermal conductivity (see IFLT on card TX8).
3	NHMAT2(I)	Id. no. of temperature dependent heat capacity (see IFWKT on card TX8).
4	XFWQZ(I)	Shielding factor of the power density in the I-th shell (normally = 1. in the fuel shells, = 0. in the outer graphite zone).
Card TX12 only if NTVAR > 0 on card TX8.		
Card TX12                      Format (14F5.2)		
1	TKV(I),	Temperature. (°C)
2	ZEIV(I),	Time. (h)
.	I=1,NTVAR	

One card TX13 is required for each axial coarse mesh “N” (described on cards BI4).

Card TX13		Format (24I3)
1	KOC(1,N)	Id. no. of THERMIX composition in the 1. radial coarse mesh.
.	.	
.	KOC(I,N)	Id. no. of THERMIX composition in the I-th radial coarse mesh.  (Radial coarse meshes are described on cards BI3)

Card TX14		Format (24I3)
1	IYEAR(I), I=1,KMAX	Operating time (years) assumed for the calculation of the fast neutron dose values of the materials in the KMAX different THERMIX-compositions. These are required and applied only, if material function no. 32 (see Table IX) is used for the calculation of the thermal conductivity of the respective material.

Card TX15		Format (2I5,6E10.3 / 7E10.3)
1	IPOLI	= 0: Linear interpolation of temperature input of cards TX17. = 1: Logarithmic interpolation (radial).
2	IE	= 0: Drop cards TX16, TX17. Start-up temperature field read from dataset ‘tempstat’. > 0: Number of radial mesh points for start-up temperature input.
3	RE(I), I=1,IE	Only if IE > 0: Radial mesh points for start-up temperature input on cards TX17. Continuation cards according to given FORMAT.

Cards TX16 - TX17 only if IE > 0 on card TX15.

Card TX16		Format (2I5,6E10.3 / 7E10.3)
1	IPOLN	= 0: Linear interpolation of temperature input of cards TX17. = 1: Logarithmic interpolation (axial).
2	NE	Number of axial mesh points for start-up temperature input.
3	PHE(I),	Axial mesh points for start-up temperature input on cards TX17.
.	I=1,NE	Continuation cards according to given FORMAT.

One card TX17 for each of the N = 1,NE axial mesh points.

Card TX17		Format (7E10.3)
1 . IE	T(I,N), I=1,IE	Start-up temperature at mesh point I, N.

Cards TX18 and TX19 only in case of a transient calculation (INTVAL = 1 on card TX2).

Card TX18		Format (I6,3E12.5)
1	MC2	= 0: No effect. > 0: Read card TX19 with definition of THERMIX compositions for <u>time dependent</u> output of the “heat storage”. (Also stored on data set ‘therlist’).
2	SIG	= 0.: Default value = 1. > 0.: Factor to be multiplied with the explicitly evaluated decay power function.
3	A0	Initial fissile enrichment of the fuel. (w%)
4	SM	Avg. heavy metal content per fuel element (incl. pure graphite spheres). (g/sphere)

Card TX19 only if MC2 > 0 on card TX18.

Card TX19		Format (72I1)
1 . KMAX	IKO(I), I=1,KMAX	"Heat storage" fraction id. no. to which the heat of THERMIX composition I shall be added up. Possible "heat storage" fraction numbers: 1 - 5 (core data is <u>always</u> stored). IKO(I) = 0 means <u>no</u> storage.

Card TX20		Format (5E12.5)
1	DELTAT	Desired temperature interval ( $\Delta T$ ) for the numerical integration inside the fuel elements ( $^{\circ}\text{K}$ ). Up to 200 intervals are possible between TU and TO.
2	TU	Lowest surface temperature of fuel elements.
3	TO	Highest temperature at center of the fuel elements.
4	WRIT	= 0.: Program uses standard data of the thermal conductivity as a function of fast neutron dose and temperature. > 0.: Like = 0, but various test output of temperature integration inside the fuel elements in addition. < 0.: Thermal conductivity as a function of fast neutron dose and temperature will be given on the cards TX21 - TX24.
5	R0	= 0.: No effect. > 0.: Inner radius of the fuel matrix (if shell ball is considered).

Cards TX21 - TX24 only if WRIT < 0. on card TX20.

Card TX21		Format (5I6)
1	NSCH	Number of different functions of the thermal conductivity. ( $\leq 2$ )
2	KTEM(N), N=1,NSCH	Number of temperature mesh points for which the thermal conductivity will be given. ( $\leq 10$ )
.	LFAD(N), N=1,NSCH	Number of fast neutron dose mesh points for which the thermal conductivity will be given. ( $\leq 10$ )

For each of the NSCH thermal conductivity functions one set of cards TX22 - TX24.

Card TX22                      Format (6E12.5)		
1 . KTEM	TSTUE(K), K=1,KTEM	Temperature mesh points.
Card TX23                      Format (6E12.5)		
1 . LFAD	DSTUE(L), L=1,LFAD	Mesh points of fast neutron dose.
For each of the LFAD mesh points of the fast neutron dose one card TX24.  Card TX24                      Format (6E12.5)		
1 . KTEM	WLSTUE(K), K=1,KTEM	Thermal conductivity at the temperature mesh points. (W/cm/°C)

Cards TX25, TX26 only if at least one of the IFZST1 = 1 on cards TX9. Up to 100 time steps can be defined by cards TX26. Linear interpolation is provided between the time steps.

Card TX25		Format (4I10)
1	IZK1	Number of compositions with time dependent source of mass flow and / or inlet temperature. ( $\leq 3$ )
2 .	IZKOM(I), I=1,IZK1	Id. no. of the I-th composition.
<u>1 card TX26 for each time step:</u>		
Card TX26		Format (8F9.3)
1	ZVOR	> 0.: Time. (min) = 0.: End of the input of cards TX26.
2	ZDR	Pressure. (bar)
3	ZST(I)	Source of mass flow of the composition no. IZKOM(I). (kg/s)
4	ZTF(I), I=1,IZK1	Temperature of inlet gas of the composition no. IZKOM(I). (°C)

## 5. Input Manual V.S.O.P.-ZUT (log. unit 5)

### 5.1 Steering the execution mode. ZS

Card ZS		Format (A8)
1	MODE	<p>= zutalone: General input procedure for various kinds of fuel element geometry. Drop cards DZ, read <u>complete set of cards Z</u>.</p> <p>= data2zut: More comfortable input procedure (making use of internal “auxiliary” subroutine ZDATA2): Read <u>cards DZ and Z1-Z6</u>. This procedure is possible only for assemblies consisting exclusively of <u>spherical</u> fuel elements having coated particle fuel, and graphite being the only moderator element outside the coated particles.</p>

### 5.2 Fuel element design. DZ1 – DZ9 (only if MODE = ‘data2zut’ on card ZS)

One set for each variant of each desired fuel type (limited to 27 different sets).  
Calculation is terminated by one last card DZ1.

Card DZ1		Format (18A4)
1 . 18	TITLE(I), I=1,18	<p>Literal description of fuel element-types and –variants.</p> <p>TITLE(1) = ‘stop’: This terminates the sequence of cards DZ1–DZ9.</p>

Card DZ2		Format (3I4,E12.5)
1	NFUTP	<p>Identification of the fuel elements in 4 digits IJKL: IJ : Type (characterizes design), increasing numbers. (<math>\leq 10</math>) KL: Variant ( e.g. for different enrichments), increasing numbers, starting from 01 for each type IJ.</p>
2	NFCP	<p>Input option for the coated particle: = 2: Read cards DZ3 - DZ7. = 1: Read card DZ3 only. = 0: Data from preceding design.</p>

Continuation of card DZ2		
3	NFBZ	Input option for the fuel element: = 1: Read cards DZ8 - DZ9. = 0: Data from preceding design.
4	FF3	> 0.: Volumetric filling fraction of spherical fuel elements in the core. = 0.: Default value = 0.61

Card DZ3 only if NFCP > 0 on card DZ2.

Card DZ3		Format (E12.5)
1	ANR	Fissile enrichment of the fuel (fissile/heavy metal), atom fraction. = 0.: If INDBS (card DZ4) = 7 .

Cards DZ4 - DZ7 only if NFCP = 2 on card DZ2.

Card DZ4		Format (5I4)
1	INDBS	Fuel identification: = 1: $\text{UO}_2$ = 3: $\text{UC}_2$ = 5: UC - ThC = 7: $\text{PuO}_2$ = 9: $\text{PuO}_2$ - $\text{UO}_2$ = 2: UC = 4: $\text{UO}_2$ - $\text{ThO}_2$ = 6: $\text{UC}_2$ - $\text{ThC}_2$ = 8: $\text{PuO}_2$ - $\text{ThO}_2$
2	NCT	Total number of coating layers ( $\leq 5$ ), to be numbered with increasing radius.
3	NSIC1	Number of the 1. SiC coating layer, if present.
4	NSIC2	Number of the 2. SiC coating layer, if present.
5	IU8TH	Preparation of ZUT-data for: = 1: $^{232}\text{Th}$ = 3: $^{242}\text{Pu}$ = 5: $^{240}\text{Pu}$ = 7: $^{241}\text{Am}$ = 9: $^{242}\text{Cm}$ = 2: $^{238}\text{U}$ = 4: $^{235}\text{U}$ = 6: $^{237}\text{Np}$ = 8: $^{243}\text{Am}$ = 10: $^{244}\text{Cm}$ (Note: The resonance integrals of the MA are calculated by assuming an existing fuel (see INDBS) combined with the considered additional fraction of MA (see card DZ6). A calculation for <u>pure</u> MA is not provided so far.



Card DZ5		Format (4E12.5)
1	RK	Radius of the coated particle kernels. (cm)
2	ROBR1	Density of the kernels. (g/cm <sup>3</sup> )
3	ROBR2	= 0.
4	BETA	Enrichment of uranium $N_{U5} / N_U$ if INDBS = 4, 5, 6, 9 on card DZ4.

Card DZ6		Format (6E12.5)
1	ROBR3	Density of the minor actinides (MA) in the coated particle (g/cm <sup>3</sup> ). Considered is the metallic fraction of the oxide (MA O <sub>2</sub> ), the oxygen fraction is calculated automatically and –if existing- is added to the oxygen of the fuel material.
2	MFNP37	Mass fraction <sup>237</sup> Np (= 0. or = 1.)
3	MFAM41	Mass fraction <sup>241</sup> Am (= 0. or = 1.)
4	MFAM43	Mass fraction <sup>243</sup> Am (= 0. or = 1.)
5	MFCM42	Mass fraction <sup>242</sup> Cm (= 0. or = 1.)
6	MFCM44	Mass fraction <sup>244</sup> Cm (= 0. or = 1.)
(Note: This option is intended to calculate the resonance integral of a single MA, resonance integral calculations for mixed MA are not considered)		

Card DZ7 only if INDBS = 7, 8 or 9 on card DZ4.

Card DZ7		Format (4E12.5)
1 . 4	PU(I), I=1,4	Atom fractions of the isotopic composition in plutonium: <sup>239</sup> Pu, <sup>240</sup> Pu, <sup>241</sup> Pu, <sup>242</sup> Pu.

Card DZ8		Format (6E12.5)
1,3,5	DCT(I),	Thickness of the I-th coating layer. (cm)
2,4,6	ROCT(I), I=1,NCT	Density of the I-th coating layer. (g/cm <sup>3</sup> ) (Numbered with increasing radius, NCT on card DZ4).

Cards DZ9 – DZ10 only if NFBZ = 1 on card DZ2.

Only a selected set of the following parameters of the cards DZ9 and DZ10 is required. Possible combinations are given in Table X.

Card DZ9		Format (6E12.5)
1	R1	Outer radius of fuel zone. (cm) (Fuel zone consists of coated particles and graphite matrix).
2	R2	Outer radius of the sphere. (cm)
3	FF1	Volume fraction: coat.part. / (coat.part. + matrix)
4	VMOD	Moderation ratio $N_C / N_{HM}$ .
5	INDBK	= 0: No “dummy” elements. = 1: “Dummy” elements existing.
6	BK	Volume fraction: “dummy” elements / (fuel + “dummy”) elements. .....

**Table X: Alternative specifications of spherical fuel elements**

No.	1	2	3	4	5	6	7	8	9	10	11
INDBK	0	0	0	0	0	0	0	1	1	1	1
R1	x	x	x	x	x			x	x	x	x
R2	x	x	x				x	x	x	x	
FF1		x			x		x		x		x
VMOD			x	x	x	x	x	x	x		
ROSM	x			x		x		x		x	
BK										x	x

Card DZ10		Format (5E12.5)
1	ROSM	Density of heavy metal, homogenized in the fuel zone. (g/cm <sup>3</sup> )
2	ROMTX	Density of graphite in the matrix. (g/cm <sup>3</sup> )
3	ROSCH	Density of graphite in the outer shell. (g/cm <sup>3</sup> )
4	ROBK	Only relevant for INDBK = 1: > 0.: Density of graphite in the “dummy” elements. (g/cm <sup>3</sup> ) = 0.: Density of graphite in the “dummy” elements equals ROSCH.
5	SR0	Inner radius of the matrix. (cm) (normally = 0.) > 0. for ”shell ball” design.

## 5.3 Resonance integral calculation. Z1 – Z17

### Note:

If MODE = 'data2zut' on card ZS and resonance parameters provided from a library, the input is reduced to the cards Z1 - Z6.

In order to open a new direct access data set 'resint' for storage of the resonance integral values read cards Z17, Z6.

### 5.3.1 Short input. Z1 - Z6

Cards Z1 - Z5 can be repeated for N different cases. The input stream is terminated by the card Z6.

Card Z1		Format (I1,I5,I1,E9.4)
1	IEND	9
2	JI	00000
3	KI	1 (Number of items on this card).
4	RNRESO	<p>= 1.: Read resonance parameters for <math>^{235}\text{U}</math> from data set 'resdatu5'.            = 2.: Read resonance parameters for <math>^{232}\text{Th}</math> from data set 'resdatth'.            = 3.: Read resonance parameters for <math>^{238}\text{U}</math> from data set 'resdatu8'.            = 4.: Read resonance parameters for <math>^{242}\text{Pu}</math> from data set 'resdapu2'.            = 5.: Read resonance parameters for <math>^{240}\text{Pu}</math> from data set 'resdapu0'.            = 6.: Read resonance parameters from input cards Z7 – Z9.            = 7.: Read resonance parameters for <math>^{237}\text{Np}</math> from data set 'resdanp7'.            = 8.: Read resonance parameters for <math>^{241}\text{Am}</math> from data set 'resdaam1'.            = 9.: Read resonance parameters for <math>^{243}\text{Am}</math> from data set 'resdaam3'.            = 10.: Read resonance parameters for <math>^{242}\text{Cm}</math> from data set 'resdacm2'.            = 11.: Read resonance parameters for <math>^{244}\text{Cm}</math> from data set 'resdacm4'.</p> <p><u>From the value of RNRESO result different sequences of the following input cards:</u></p> <p>For RNRESO = 1.-5. and =7.-11. the sequence is:            a) MODE = 'data2zut': Z1 - Z6            b) MODE = 'zutalone': Z1, Z2, Z4, Z5, Z10 - Z16</p> <p>For RNRESO = 6. the sequence is:            Z1, Z2, Z4, Z7-Z8, Z5, Z9-Z16  <u>MODE must have the value 'zutalone'.</u></p>

Card Z2		Format (7E10.4)
1	ETEMP	Temperature of the resonance absorber. (°K)
2	ENERGU	Lower energy boundary for the set of resonance data to be respected. (eV)
3	ENERGO	Upper energy boundary for the set of resonance data to be respected. (eV)
4	ESOLVE	<p>Five digits IJKLM.0 as specification of the calculation method:</p> <p>I : Specifies the geometry of the absorber regions:  = 0: Infinite size <u>or</u> numerical computation of the geometric escape probability P(E). (Coated particle grain structure, see section A.6.1)  = 1: Cylindrical geometry  = 2: Slab.  = 3: Spherical, analytic formula of P(E).</p> <p>J : Specifies the method for scattering by the absorber:  = 1: Down scattering based on the computed neutron flux.  = 2: NR-approximation.  = 3: IM-approximation.</p> <p>K : In case of "double heterogeneous calculation" plus calculation of unresolved resonances (IEND=6 on card Z8), the coating material of the particles must be specified as moderator 1.  = 0: Moderator no. 1 is not present.  = 1: Down scattering in moderator no. 1 uses the computed neutron flux.  = 2: Down scattering assumes 1/E flux.</p> <p>L = 0: Moderator no. 2 is not present (cp. item K).  = 1: Down scattering in moderator no. 2 uses the computed neutron flux.  = 2: Down scattering assumes 1/E flux.</p> <p>M = 0: Normal output option.  &gt; 0: More output.</p> <p>.....</p>

Continuation of card Z2		
5	TESTA	These three digits IJK.0 for output options. (Use 001.0) I ≥ 1: Control data of the energy fine structure for each resonance. J ≥ 1: Partial probabilities at the mesh points of the P(E) – calculation. K ≥ 1: Mesh points of P(E), Dancoff factors and data of homogenization of the matrix zone.
6	EW(13)	Number of mesh points for P(E)-calculation. ( $\cong 20$ )
7	VAZVG	Volume of absorber / total cell volume.

Card Z3 only if MODE = ‘data2zut’ on card ZS.

Card Z3	Format (6E12.5)	
1	FUTYP	Fuel type and -variant specification to be applied. See variable NFUTP on card DZ2).
2	EAMOD1	Atomic weight of moderator material 1, which is admixed with the absorber. (only if K > 0 in ESOLVE on card Z2).
3	ESIGM1	$\sigma_s$ of the moderator 1 (only if K > 0 in ESOLVE).
4	EAMOD2	Atomic weight of moderator material 2, which is admixed with the absorber (only if L > 0 in ESOLVE).
5	ESIGM2	$\sigma_s$ of the moderator 2 (only if L > 0 in ESOLVE).
6	ECDANC	Dancoff factor. = 0.: For infinite absorber size <u>or</u> numerical computation of P(E) for the <u>spherical</u> fuel elements. > 0.: Dancoff-Ginsburg factor. Required for the cylindrical fuel element. <u>This ECDANC has higher priority than the internally calculated one</u> , which can optionally be ordered by the card Z11.

Card Z4		Format (2I6,6X,8I6)
1	IDSATZ	Identification number of this set of resonance integrals to be stored on data set 'resint' for further use in GAM-I-calculations (VSOP-MS).
2	IDNUCL	GAM-I-library identification no. of the absorber nuclide.
3 - 10	LOESCH(J), J=2,9	Id.-numbers of existing resonance integrals on data set 'resint' to be deleted prior to the creation of the new set. (LOESCH(1) is automatically set equal IDSATZ)

Card Z5		Format (4A3,24X,12A3)
1 . 4	HEAD(J), J=1,4	Literal heading, e.g. date.
5 . 16	HEAD(J), J=5,16	Literal heading, e.g. case identification.

Termination of the input sequence by card Z6.

Card Z6		Format (I1,I7I)
1	IEND	9
2		Blank: Terminates the sequence of resonance integral calculations.

### 5.3.2 Resonance parameters. Z7 – Z9

Cards Z7 – Z9 only if RNRESO = 6. on card Z1.

Note:

The input of resonance parameters on cards Z7 – Z8 must be terminated by a blank-card.

One card Z7 for each resolved resonance. In rising sequence of the energy EZERO.

Card Z7			Format (I1,I5,I1,5E9.4)
1	IEND	2	
2	J1	00005	
3	K1	5	
4	EZERO		Energy at the center of the resonance. (eV)
5	GAMN	$\Gamma_n$ (eV)	
6	GAGM	$\Gamma_\gamma$ (eV)	
7	R		= 0.: Mesh spacing under the resonance decided by the code. > 0.: Mesh spacing under the resonance.
8	S		Ratio: Range of integration / effective width. Give S = 5.

Card Z8 for the unresolved resonances.

Card Z8			Format (I1,I5,I1,6E9.4)
1	IEND	6	
2	J1	00000	
3	K1	6	
4	EC		Lower energy of the range of unresolved resonance evaluation. (eV)
5	GAMNO	Avg. [ $\Gamma_n^\circ$ ] (eV)	.....



Continuation of card Z8		
6	GMGM	Avg. [ $\Gamma_\gamma$ ] (eV)
7	G	Statistical weight.
8	D	Avg. spacing between the resonances. (eV)
9	EO	Upper energy of the range of unresolved resonance evaluation. (eV)

Card Z9		Format (I1,I5,I1,3E9.4)
1	IEND	1
2	JI	00001
3	KI	3
4	AZERO	Atomic weight of the absorber.
5	G	Statistical weight factor.
6	SIGPZ	$\sigma_s$ . Potential scattering cross section of the absorber.

### 5.3.3 Explicit fuel element design. Z10 - Z16

Cards Z10 - Z16 only if MODE = 'zualone' on card ZS.

Card Z10 only if Dancoff factor is to be calculated.

Card Z10		Format (I1,I5,I1,7E9.4)
1	IEND	7
2	K	Type of lattice: 00010: Square lattice up to the 4. neighbor. 00014: 4 x 4 bundle. } 00015: 5 x 5 bundle. } Finite lattice 00016: 6 x 6 bundle. } 00020: Triangular lattice up to the 4. neighbor. 00022: 2 - rods bundle. 00023: 3 - rods bundle. 00027: 7 - rods bundle. 00029: 19 - rods bundle.
3	KI	7
4	A	Radius of the rod. (cm)
5	B	Pitch. (Distance between the center lines of the rods). (cm)
6	DHUE	Cladding thickness. (cm)
7	DSP	Thickness of the gaps between the bundles (for K = 14, 15, 16) (cm)
8	SMOD	$\Sigma_{\text{tot}}$ of the moderator. (cm <sup>-1</sup> )
9	SHUE	$\Sigma_{\text{tot}}$ of the cladding. (cm <sup>-1</sup> )
10	SSP	$\Sigma_{\text{tot}}$ in the gaps. (cm <sup>-1</sup> )

Card Z11		Format (I1,I5,I1,3E9.4)
1	IEND	1
2	JI	00010
3	KI	3
4	SOLVE	Same value as ESOLVE on card Z2 must be given here.
5	ABAR	Radius (cm), for cylindrical or spherical fuel. Half thickness (cm), for slab. = 0.: Infinite absorber size, <u>or</u> explicit calculation of $P(\sigma_a)$ .
6	C	Dancoff factor. = 0.: For infinite absorber size <u>or</u> numerical computation of $P(E)$ for the spherical fuel elements. > 0.: Dancoff-Ginsburg factor. Required for the cylindrical fuel elements. <u>This C has higher priority than the internally calculated one</u> , which can optionally be ordered by the card Z10.

Card Z12		Format (I1,I5,I1,7E9.4)
1	IEND	1
2	JI	00013
3	KI	7
4	EDZERO	$N_{abs}$ atom density of absorber (atoms / (barn*cm)).
5	EAMOD1	Atomic weight of moderator no. 1.
6	ESIGM1	$\sigma_s$ of moderator 1. (barn)
7	EDIQU1	$N_{mod\ 1} / N_{abs}$ ratio.
8	EAMOD2	Atomic weight of moderator no. 2.
9	ESIGM2	$\sigma_s$ of moderator 2. (barn)
10	EDIQU2	$N_{mod\ 2} / N_{abs}$ ratio.

Cards Z13, Z14 only if numerical evaluation of P(E) is required (I = 0 in ESOLVE on card Z2).

Card Z13		Format (I1,I5,I1,6E9.4)
1	IEND	5
2	J1	00018
3	K1	6
4	R1	Radius of the kernel of a coated particle. (cm)
5	R2	> 0.: Outer radius of a coated particle. (cm) = 0.: Coated particles and matrix are treated homogenized.
6	R4	Outer radius of the matrix. (cm)
7	R5	> 0.: Outer radius of a spherical fuel element. (cm) = 0.: Cylindrical fuel element.
8	F	Volumetric filling fraction coat.part. / (coat.part. + matrix); (matrix including possible inner coolant / graphite zones)
9	H	= 0.: Default > 0.: Fraction of dummy graphite spheres in the pebble bed.

Card Z14		Format (I1,I5,I1,4E9.4)
1	IEND	5
2	J1	00025
3	K1	4
4	SI2	Avg. $\Sigma_{\text{tot}}$ of the coatings. (cm <sup>-1</sup> )
5	SI4	$\Sigma_{\text{tot}}$ in outer shell of a spherical element. (cm <sup>-1</sup> )
6	SI5	$\Sigma_{\text{tot}}$ in dummy graphite spheres. (cm <sup>-1</sup> )
7	ALPH	Ratio of: ( $\Sigma_{\text{tot}}$ of the matrix / average $\Sigma_{\text{tot}}$ of the coatings).

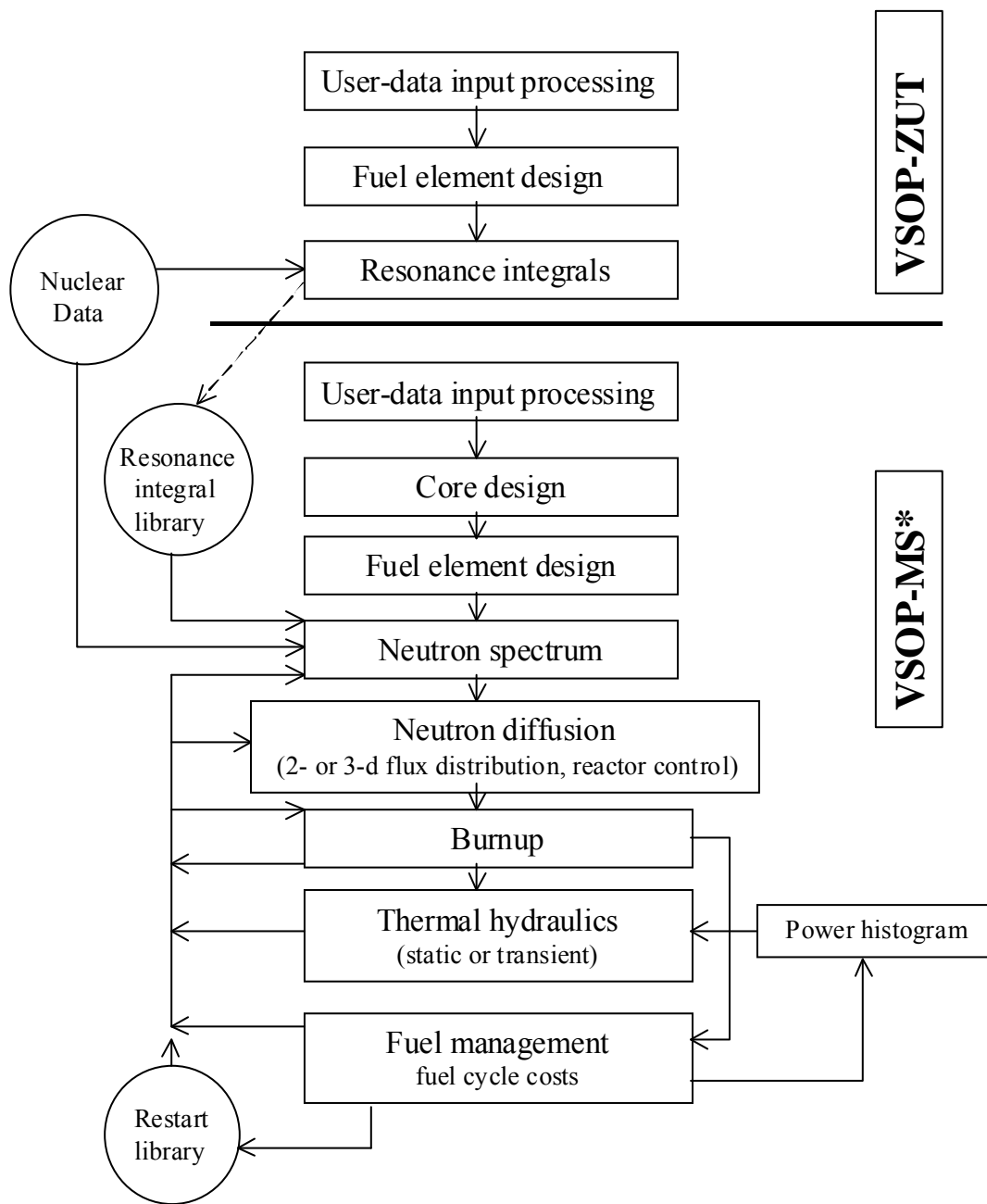
Card Z15		Format (I1)
1	IEND	8: Termination of input of <u>this</u> resonance integral calculation.

Card Z16		Format (A3)
1	HEAD(1)	REP: Another input case will follow (possible only for the same resonance absorber). END: Termination of the calculation.

#### 5.3.4 Opening of a new resonance integral data set ('resint'). Z17

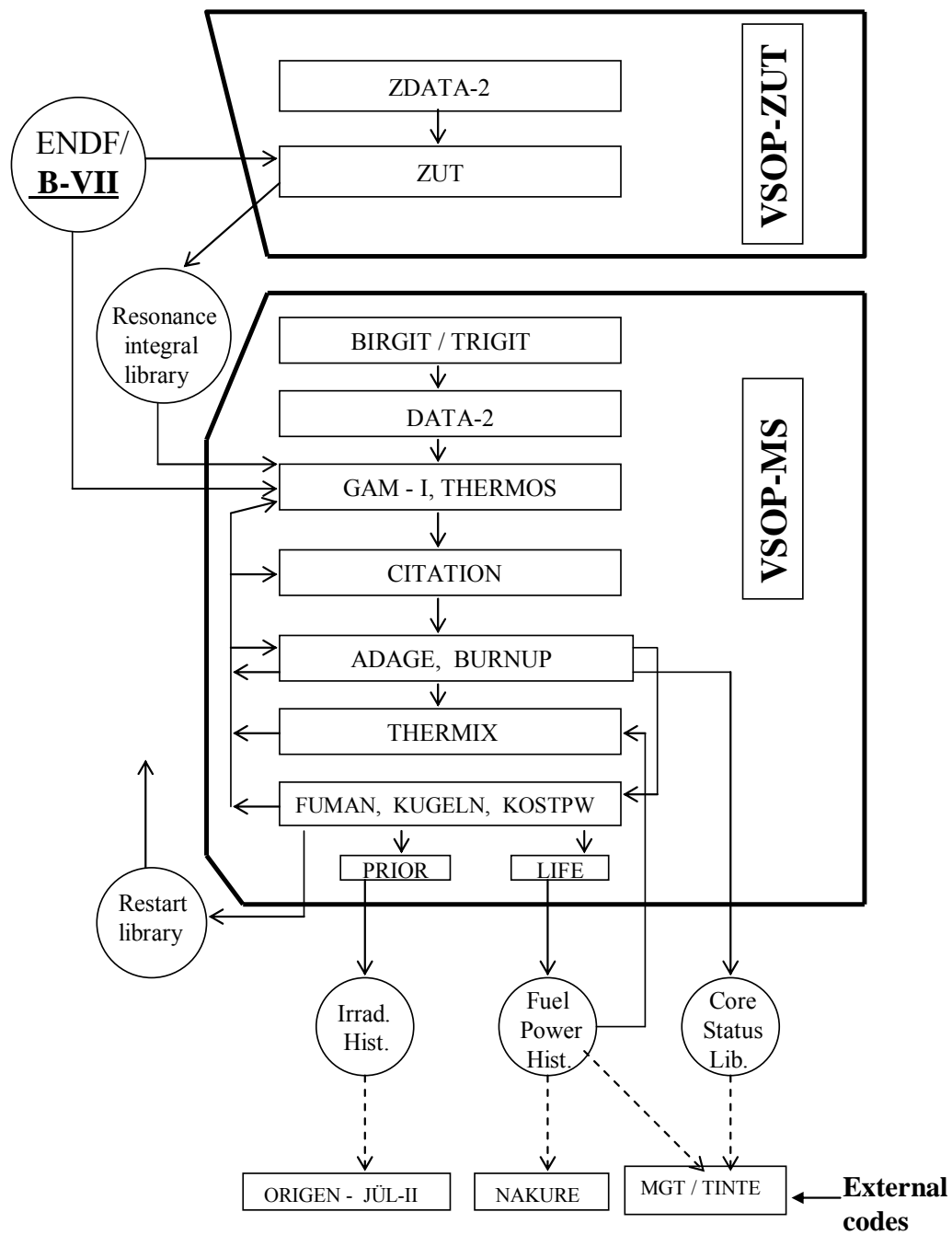
Card Z17		Format (1X,I5)
1	JI	= - 30: Opening of direct access data set 'resint' for the resonance integrals in GAM-I-group-structure.

**Appendix:    Structure of the code and program tasks**



\* MS = Main Section

**Fig. 3: Calculation tasks V.S.O.P. (99/11)**



**Fig. 4: The basic programs of the two code sections**



## References

- /1/ H. J. Rütten, K. A. Haas, H. Brockmann, U. Ohlig, C. Pohl, W. Scherer:  
„V.S.O.P. (99/09) *Computer Code System for Reactor Physics and Fuel Cycle Simulation; Version 2009*  
Jül-4326, June 2010
- /2/ S. Rezgui:  
“*Erweiterung der Resonanzdatenbasis für stationäre und transiente Neutronentransportprogramme*“  
Diplomarbeit Institut für Kernphysik, Universität Köln und Institut für Energie- und Klimaforschung (IEK-6), Forschungszentrum Jülich  
October 2011



Jül-4348  
Januar 2012  
ISSN 0944-2952