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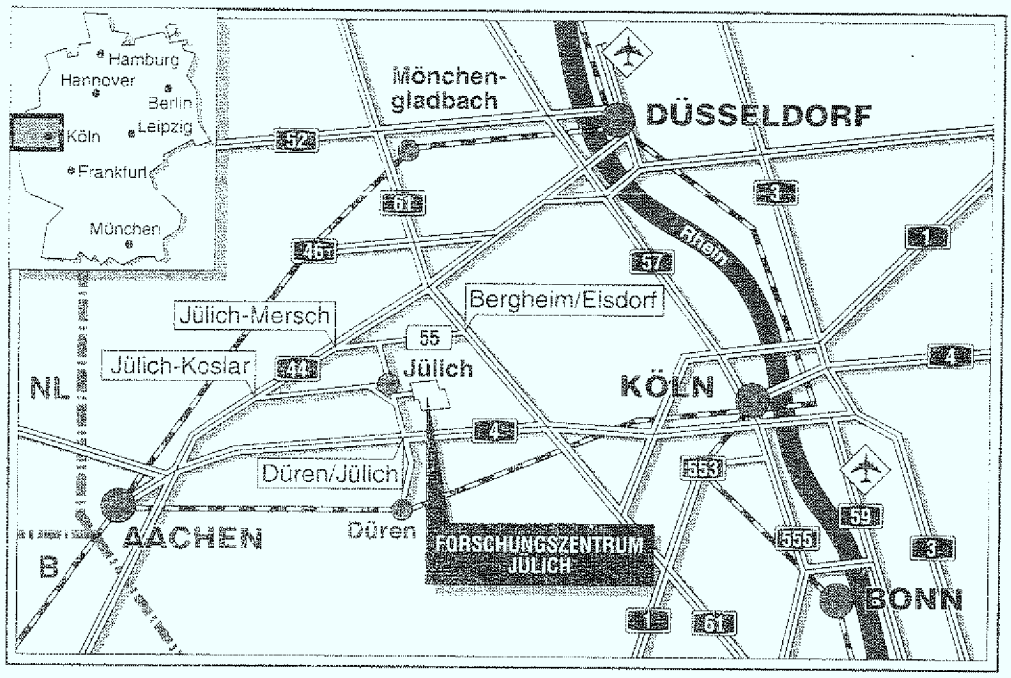
V.S.O.P. ('94)
Computer Code System for Reactor Physics and Fuel Cycle Simulation

Input Manual and Comments



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ABSTRACT

V.S.O.P. (Very Superior Old Programs) is a system of codes linked together for the simulation of reactor life histories and temporary in-depth research. In comprises neutron cross section libraries and processing routines, repeated neutron spectrum evaluation, 2-D diffusion calculation with depletion and shut-down features, in-core and out-of-pile fuel management, fuel cycle cost analysis, and thermal hydraulics (at present restricted to HTR's). Various techniques have been employed to accelerate the iterative processes and to optimize the internal data transfer. The storage requirement is confined to 17 M-Bytes.

The code system has extensively been used for comparison studies of reactors, their fuel cycles, simulation of safety features, developmental research, and reactor assessments. Beside its use in research and development work for the gas cooled High Temperature Reactor the code has successfully been applied to Light Water Reactors, Heavy Water Reactors, and hybride systems with different moderators.

Preface

Development of the VSOP code system resulted from continuous work over decades. It was stimulated by numbers of problems of reactor development and safety research. An intimate coupling existed between the developmental work, application of the code, and comparison with findings obtained elsewhere. Therefore, a great variety of hidden contributions is involved of so many colleagues and institutions to whom we want to express our gratitude in the first place.

Originally, the code emerged out of the MAFIA-II code being developed by L.Massimo. In the early years various useful contributions in view of Heavy Water Reactors and High Temperature Reactors have been included by T.Babac, J.Darvas, and V.Maly. In the scope of the European HTR-DRAGON Project, U.Hansen essentially promoted the development of the neutronics, fuel management, and economics evaluation, which led to a first completed version of the VSOP code as edited in the year 1980.

Since that time the development of modular reactors by the INTERATOM-SIEMENS-Group gave most important impulses for improvements of the code because of the inherent accident control and licensing demands. In this connexion also many contributions entered into the code which resulted from ideas of guest scientists and doctorands. Further, thanks are turned to professor R.Schulten and professor K.Kugeler as directors of our Institute. Their suggestions and ideas stimulated strong promotion in the developmental work.

And further, the authors would like to address their thanks to the Central Institute of applied Mathematics and to its crew who operates the IBM computers. Their cooperative help was really instrumental in setting up this second edition of the VSOP.

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1.0 Synopsis

1.1 Introduction

V.S.O.P. (Very Superior Old Programs) is a system of proven computer codes linked together for the numerical simulation of the nuclear reactor physics performance. Its applicability is directed to all types of thermal reactors, including reactors of smaller size as being developed for modular power plants or for direct heat utilization. As the code has widely been used for developmental work of the High Temperature Reactor with spherical fuel elements, it has preferably been extended to cover the specific features of this type of reactor.

The calculation comprises the processing of the cross sections, reactor and fuel element design, neutron spectrum evaluation, 2- or 3-dimensional diffusion calculation, burnup, fuel shuffling, control, and - just for the pebble bed HTR - thermal hydraulics of steady states and transients (Fig. 1).

The VSOP code allows to follow the reactor life from its startup through the running-in phase towards an equilibrium cycle. Repeated calculation of the different physics features ensures consistency in their feedback effects during the different burnup periods, fuel shuffling, and changes of power rating, which can optionally be defined. Accidental transients can be followed under repeated criticality evaluation. Characteristics of the reactor life history are preserved for calculating the individual decay power functions of the fuel elements. Explicite evaluation of fuel cycle costs over the reactor life time is made by the present worth method. Further, reprocessing and closure of the fuel cycle can be followed under consistent control of the fuel mass flow, including times of intermediate storage for the isotopic decay.

Over the last ten years new demands came up upon the VSOP code: For example the conception of smaller reactors, research of inherent safety features, explicite follow of accidental transients, improved accuracy of the results, adaption to new FORTRAN-compilers and the need of easy handling of the code by less experienced users. Consequently, many changes have been implemented over the years. This report explains the new features of the code and gives the new input manual.

The full size of the VSOP comprises about 60000 FORTRAN statements requiring the storage capacity of 17 M-Bytes. The running time of reactor life from start up to equilibrium ranges between 10 and 45 minutes of CPU-time at the IBM E/9000-620 computer, depending on the degree of subdivisions.

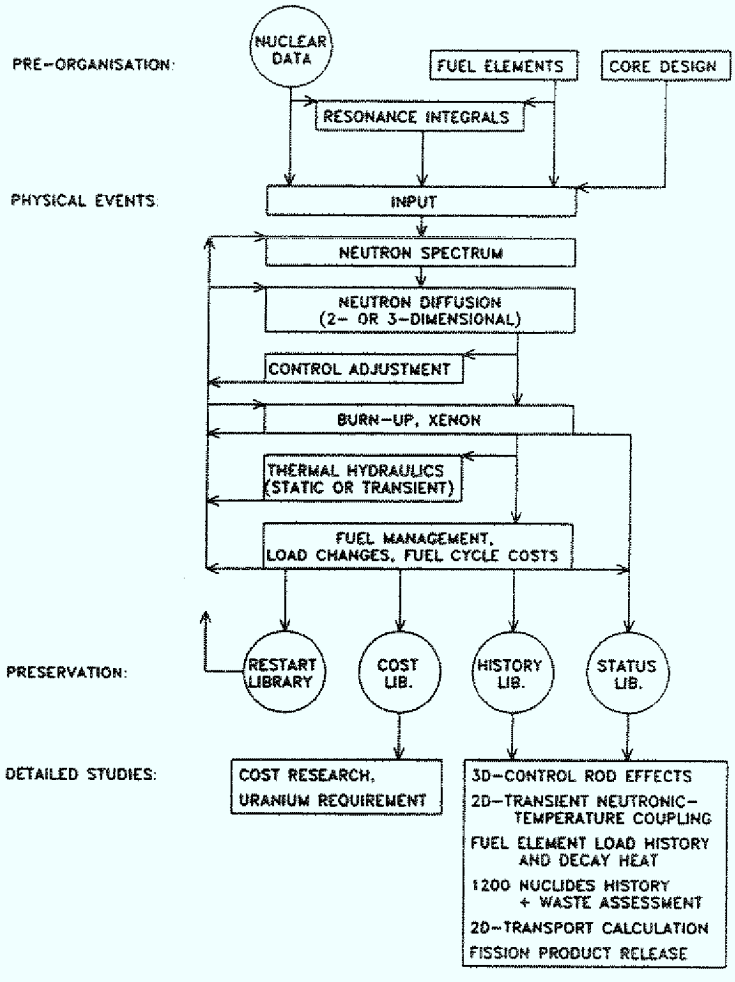

Fig. 1. V.S.O.P.-Physics Simulation

1.2 New Features of the Code

The older version of the VSOP code as introduced in JÜL-1649 /1/ has been made to follow the typical features of thermal reactors and fuel cycles. It has widely been applied for their comparison and assessment. The new version maintains these properties. Beyond that, it is directed to the more sophisticated evaluation of the details of the reactor performance, as it is required for the design and safety analysis. Over the last years the following new features have been incorporated into the code:

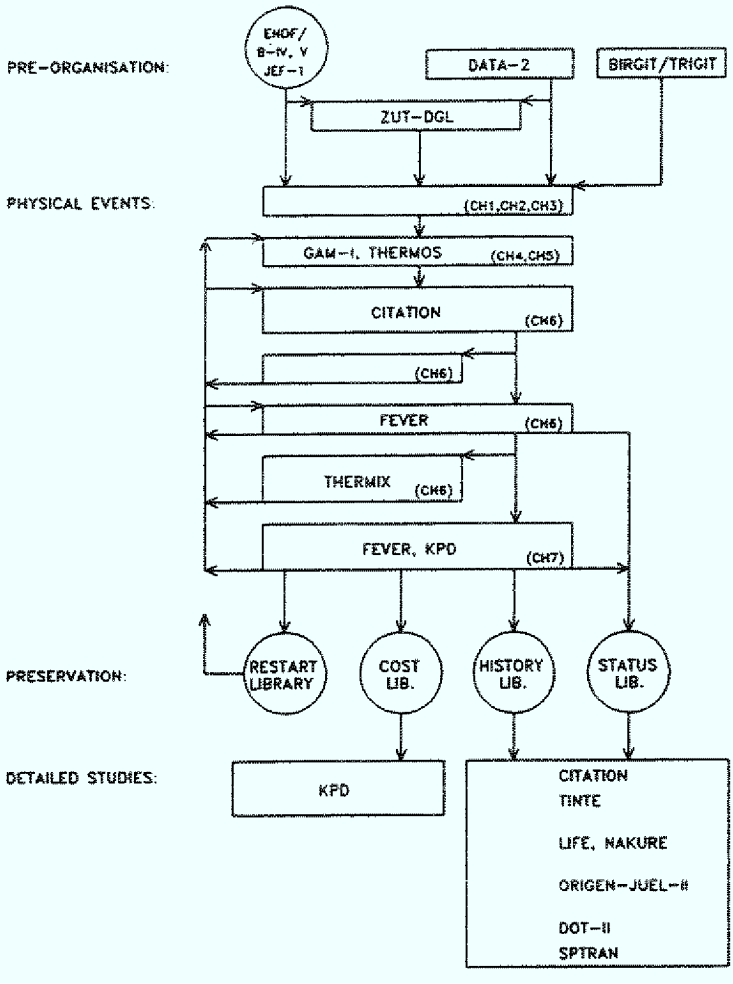

Fig. 2. V.S.O.P. The Basic Programs

- Variable dimensioning for the number of isotopes, layers, batches, energy groups, spectrum zones, storage boxes, and periods in cost calculation
- 2-dimensional finite mesh diffusion calculation in r-z
- 3-dimensional finite mesh diffusion calculation in x-y-z
- Simulation of any experimentally given flow pattern of the pebbles for the follow of burnup
- Leakage feedback for the spectrum zones
- New libraries out of ENDF/B-IV, -V, and JEF-I
- Fission yields of ENDF/B-IV, -V
- Providing of selfshielding factors depending on energy and space

- Temperature calculation of equilibrium or transients over the whole reactor, and feedback to the neutronics
- Decay heat evaluation for the individual fuel batches in their local positions, according to their preceding history of burnup and shuffling
- Effective thermal conductivity of the bed of pebbles as a function of temperature and fast neutron flux exposure
- Preservation of reactor life data for the joint external evaluation
- Simplified input.

The way of handling these new features of the code can be perceived from the description of the input in chapter 2. A more detailed review of the new features and the necessary data information are given in chapter 3.

1.3 Program Organisation

Compared with the former version of the VSOP, the new one is more adequately adapted to the capability of newer computers and newer compilers. At present it is adapted to the VS-FORTRAN-language level 66, and it is being run at the IBM E/9000-620. The high storage capability of that machine made it possible to load all members of the code simultaneously, thus dropping the overlay structure of the older version. By this way the extended shuffling of subroutines and common blocks became superfluous, which makes the construction of the program simpler. It allows the variable dimensioning and easy linking of new members into the system. Combined with the high speed of newer computers the present version of the code allows to achieve the necessary and sufficient accuracy in the reactor layout and in the simulation of the reactor performance. The code is applicable for the reactor design and for the detailed research of safety features.

In Fig. 2 the basic libraries and codes are given, of which the VSOP is made. The epithermal library is due to the 68 group structure of the GAM-I code, and the thermal one contains a 30 group structure of THERMOS. The library set is made of ENDF/-B-IV, -V, and JEF-I /3/. Cross sections of the resolved and unresolved resonances are generated by the ZUT-DGL code /4,5/ basing on resonance data by J.J. Schmidt /7/ and ENDF/B-IV, -V. Graphite scattering matrices are based on the Young phonon spectrum in graphite /8,9,10/.

The auxiliary code DATA-2 /11/ prepares the fuel element input data out of its geometric design. The BIRGIT code prepares the 2-dim. geometric design of the reactor. It accepts experimentally gained flow pattern of the spherical fuel elements through the reactor, and it is made to generate a flow pattern of finite batches of elements which

stepwise move towards the disloading tubes. Further it prepares a mesh pattern for the 2d-diffusion calculation, and it provides the transformation between the two patterns for the macroscopic cross sections and for the neutron flux. Similarly it provides the necessary transformations to the thermal hydraulics calculation. The 3-dim. geometric design is prepared by the auxiliary code TRIGIT.

Spectrum calculations are made by the GAM-I /12/ and THERMOS /13,14/ for an unlimited number of spectrum zones. Diffusion calculation is made by the CITATION /15/ in its 2- or 3-dimensional version. The burnup and the fuel shuffling is covered by a further development of the FEVER code /16/ for an unlimited number of burnup batches. Different burnup chains are available. Up to 45 fission products are included as a standard, and they can optionally be supplemented. Collapsing of the cross sections into broader energy groups can be made for all 184 nuclides of the source libraries, as desired as for the detailed burnup follow by ORIGEN-JÜL-II /20/.

The THERMIX code /17/ is included for the thermal hydraulics evaluation both static and time dependent, respectively. The temperatures of the fuel and moderator regions are turned back to the spectrum zones for subsequent core neutronics calculation.

The KPD /18/ provides the fuel cycle cost evaluation at every step of fuel management. It is based on the present worth method. For parametric cost research the relevant data of the reactor life are transmitted to a data unit.

Similarly the status of the reactor can be preserved for later restart. Further preservation of reactor data is provided for the purpose of joint evaluations beyond the capability of the VSOP. The full irradiation history of the many fuel batches is preserved for the calculation of the decay power function by means of the LIFE routine, which is needed for the explicite follow of reactor heatup under accidents.

The subdivision of the VSOP into seven chains CH1-CH7 is a relic of the former overlay structure. It has been retained as a pattern of organisation for the different members of the program, and it prints out the computing time of the individual members. It is a useful help in optimization of the computer runs.

Internal restart facilities have been included for the THERMOS and CITATION : After convergency of the first run of these code members the neutron flux fields are preserved as startup vectors for the repeated runs at later time steps. By this way an efficient reduction has been achieved for the computing time: Depending on the changes of the isotopic concentrations over the intervening burnup interval, the computing time of these two code members reduces by a factor between 0.2 and 0.02, respectively.

2.1 DATA-2, Fuel Element Design. D1 - D19

Cards D1 - D19

2.1.1 Specifications. D1 - D4

Card D1		Format (18I4)
1	KMAT	Number of nuclides to be considered in the VSOP. Specified on card(s) D2.
2	KOSTDA	> 0: Input data for fabrication and reprocessing will be specified on cards D3, D4. ≤ 0: Drop cards D3, D4.
3	NHOM	= 0: Normal. = 1: Drop heterogeneous evaluation of fuel elements. Just read homogenized atom densities on cards D19.

Card D2		Format (18I4)
1 : KMAT	IMAT(I), I = 1,KMAT	GAM-library identification number for the I. nuclide in VSOP. **Note:** Nuclide id.numbers beyond the library can be used (i.e. IMAT(I) > 184), but these nuclides must be identified on the VSOP-card(s) V6.

Cards D3 and D4 only when KOSTDA > 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. (≤ 6)
3	NF	Number of different fuel element fabrication cost data. (≤ 3)
4 : 9	FC(I), I = 1,6	Fabrication costs of the I. coated particle variant. (MU/kg_{HM})
10 : 12	FF(I), I = 1,3	Fabrication costs of the I. fuel element variant. (MU/ball)
13	DK	Fabrication costs of dummy elements. (MU/ball)

Card D4		Format (6E12.5)
1	HK	Costs of head end and transportation. (MU/kg_C)
2	AK	Costs of reprocessing. (MU/kg_{HM})
3	EK	Costs of waste treatment and disposal per 10% Fima. (MU/kg_{HM})

2.1.2 Design of fuel element-types and -variants. D5 - D19

(Limited to 27 different sets in combination with VSOP).

Card D5		Format (18A4)
1 :	TITLE(I), I = 1,18	Literal description of case.

Card D6		Format (6I4,E12.5)
1	NTYP	= 0: Ball type fuel elements. = 1: Prismatic block fuel element.
2	NFUTP	Identification of fuel element in 4 digits IJKL: IJ : Type (characterizes design and cost data). KL : Variant (e.g. for different enrichments).
3	NFCP	Input option for the coated particle: = 2: Cards D7 - D11. = 1: Card D7 only. = 0: Data from preceding design.
4	NFBZ	Input option for the fuel element: = 1: Cards D12 - D13 or D14 - D16, respectively. = 0: Data from preceding design.
5	NCORE	= 0: No effect. = 2: Reactor power evaluation, cards D17 - D18.
6	NZUS	= 0: No effect. > 0: Number of nuclides for which atom densities will be specified on cards D19. ($\leq$ 30)
7	FF3	= 0.: Volumetric filling fraction of spherical fuel elements in the core will be defined as 0.61 . > 0.: New filling fraction.

2.1.2.1 Coated particles. D7 - D11

Card D7 only when NFCP > 0 on card D6.

Card D7		Format (6E12.5)
1	ANR	Enrichment N_{fiss}/N_{HM} (as fraction).
2	FIMA	Envisaged heavy metal burnup for reprocessing cost calculation. (Fima)

3 . .	FRC(I), I = 1,NC	> 0.: Fraction of coated particle variant I in this fuel element. = 0.: Coated particle variant I (card D3) is not present.

Cards D8 - D11 only when NFCP = 2 on card D6.

Card D8		Format (18I4)
1	INDBS	Fuel identification: |1| = UO_2 |2| = UC |3| = UC_2 |4| = UO_2-ThO_2 |5| = UC-ThC |6| = UC_2-ThC_2 |7| = Pu-O_x-C_y (x, y given at card D10) |8| = Pu-O_2-ThO_2 |9| = Pu-O_2-UO_2 > 0: Fissile uranium = ^{235}U. < 0: Fissile uranium = ^{233}U.
2	NCT	Total number of coating layers (≤ 5), to be numbered with increasing radius.
3	NSIC1	Number of the 1. SiC coating layer.
4	NSIC2	Number of the 2. SiC coating layer.
5	IU8TH	When INDBS = 4, 5, 6 , ZUT uses: = 0: ^{232}Th as resonance absorber. = 1: ^{238}U as resonance absorber.

Card D9		Format (6E12.5)
1	RK	Radius of the coated particle kernels. (cm)
2	ROBR1	Density of the kernels. (gr/cm^3)
3	ROBR2	Density of 2. type of kernels if present. (gr/cm^3) Only if |INDBS| = 4, 5, 6, 8, 9 on card D8.
4	BETA	Enrichment of the uranium $N_{U5}/(N_{U5}+N_{U8})$ if |INDBS| = 4, 5, 6, 9 on card D8.

		For INDBS < 0 program uses ^{233}U instead of ^{235}U.

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

Card D10		Format (6E12.5)
1 : 4	PU(I), I = 1,4	Fraction of the isotopic composition in plutonium: ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu.
5	X	Oxygen in Pu-O_x-C_y, if INDBS = 7 on card D8.
6	Y	Carbon in Pu-O_x-C_y, if INDBS = 7.

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

2.1.2.2 Ball fuel elements. D12, D13

Cards D12 - D13 only when NTYP = 0 and NFBZ = 1 on card D6.
Only a selected set of the following parameters of the cards D12 and D13 is required.
Possible sets are given in Table I.

Card D12		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 ball. (cm)

3	FFI	Volume fraction: coat.part. / (coat.part. + matrix).
4	VMOD	Moderation ratio N_C/N_{HM}.
5	INDBK	= 0: No dummy balls. = 1: With dummy balls.
6	BK	Volume fraction: dummy balls/(fuel + dummy) balls.

Table I: Alternative specifications of ball shaped 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	x	x
FFI		x			x		x		x		x
VMOD			x	x	x	x	x	x	x		
ROSM	x			x		x		x		x	
BK										x	x

Card D13		Format (4E12.5,4E6.1)
1	ROSM	Density of heavy metal in fuel zone. (gr/cm^3)
2	ROMTX	Density of graphite in the matrix. (gr/cm^3)
3	ROSCH	Density of graphite in the outer shell. (gr/cm^3)
4	ROBK	Only relevant for INDBK = 1: > 0.: Density of graphite in the dummy balls. = 0.: Density of graphite in the dummy balls equal ROSCH.
4	SR0	Inner radius of the matrix. (cm) (> 0 for shell ball design).
5 . .	FRF(I), I = 1,NF	= 0.: Fabrication costs of the I. fuel element variant (card D3) are dropped. > 0.: Fabrication costs of the I. fuel element variant are used

		and multiplied by FRF(I). (Usually = 1.) Use continuation cards, if needed.

2.1.2.3 Prismatic fuel elements. D14 - D16

Cards D14 and D15 only when 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 sets are given in Table II.

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.: Normal. > 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 (6E12.5)
1	ROSM	Density of heavy metal in fuel zone. (gr/cm^3)
2	ROMTX	Density of graphite in the matrix. (gr/cm^3)
3	ROSTR	Density of graphite in the cooling channel. (gr/cm^3)
4	ROHR	Density of graphite in the tubes. (gr/cm^3)

Table II: Alternative specifications of rod shaped elements

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

2.1.2.4 Core design. D17, D18

Card D17 only when NCORE > 0 on card D6.

Card D17		Format (6E12.5)
1	QK	Power per fuel element. (W/(ball or block))
2	QI	Specific power. (KW/kg_{HM})

3	Q2	Specific power. (KW/kg_{fiss})
4	QV	Power density. (MW/m^3)
5	P	Power per fuel rod (W/cm). If NTYP = 1 on card D6. Only one of these 5 parameters must be specified.

Card D18 only when NCORE = 2 on card D6.

Card D18		Format (6E12.5)
1	WE	Total electric power. (MW_e)
2	ETA	Thermal efficiency.
3	ALFA	Ratio of core height/core diameter.
4	DREF	Thickness of reflectors.
5	ROREF	Density of graphite in the reflector. (gr/cm^3)
6	FF2	Volume fraction: (fuel + dummy) balls/core volume (if NTYP = 0 on card D6).

2.1.2.5 Additional nuclides. D19

Card D19 only when NZUS > 0 on card D6.

Card D19		Format (I4,4X,E12.5)
1	NRGAM	GAM-lib. identification of nuclide with additionally given atom density (e.g. Xenon, absorber, ...).
2	DENG	> 0.: Atom density (per barn cm, 10^{-24}), homogenized. < 0.: Program makes DENG = |DENG| * DENG(Carbon). **Note:** Use 1 card for each of the NZUS (≤ 30) additional nuclides.

2.2 ZUT-DGL, Resonance Integral Calculation. Z1 - Z20

Cards Z1 - Z20

Note:
When fuel element data are provided from DATA-2 and when resonance parameters are provided from a library, the input is reduced to the cards Z1 - Z6.

For definition of more detailed input see NNRESO = 5 and NNDATA = 0 on card Z1.

For opening of a new direct access data set for storing the resonance absorption cross sections read cards Z18 - Z20, Z6.

2.2.1 Short-input. Z1 - Z6

Cards Z1 - Z5 can be repeated for N different cases. The input stream is terminated by the card Z6. Fuel element design must be provided by DATA-2.

Card Z1		Format (I1,I5,I1,7E9.4)
1	IEND	9
2	JI	00000
3	KI	5 (Number of items on this card).
4	NNRESO	Data set number of the resonance parameter library: = 26.: U-235 = 27.: Th-232 = 28.: U-238 = 5.: Read resonance parameters from the input: after card Z4 read cards Z7 - Z9, after card Z5 read card Z10.
5	NNDATA	= 29.: No. of data set on which DATA-2 fuel element specifications are provided. Only short-input Z1 - Z6 is required. = 0.: Fuel element specification to be provided by input. Read the cards: Z1 - Z2, Z4 - Z5, Z11 - Z17.

6	NNSIGA	Data set number (30) for the resonance data library being generated in GAM-groups.
7	NNRESI	= 0.: Normal. = -NNRESO: Create a resonance parameter library on data set NNRESO. Read the cards Z7 - Z10.
8	NWING0	> 0.: Drop the wing correction in the GAM-group library because it is included in background cross sections. = 0.: Include the wing correction.

Card Z2		Format (6E12.5)
1	TEMP	Temperature of the resonance absorber. (°K)
2	ENRGU	Lower energy boundary for the set of resonance data to be respected. (eV)
3	ENRGO	Upper energy boundary for the set of resonance data to be respected. (eV)
4	SOLVE	Five digits IJKLM.0 as specification of the desired calculation method: I = 0: Infinite medium, or numerical computation of the geometric escape probability $P(\sigma_a)$. = 1: Cylindrical geometry of the absorbing material. = 2: Slab. = 3: Spherical (analytic formular of $P(\sigma_a)$). J = 1: Down scattering in the absorber based on the computed neutron flux. = 2: NR-approximation. = 3: IM-approximation. K = 0: Moderator no. 1 is not present. (The coating of the coated particles must be defined and treated as moderator in the case of unresolved resonances). = 1: Down scattering in moderator no. 1 uses the computed neutron flux. = 2: Down scattering assumes 1/E flux. L = 0: Moderator no. 2 is not present (cp. K). = 1: Down scattering in moderator no. 2 uses the computed neutron flux. = 2: Down scattering assumes 1/E flux.

		M = 0: Normal output option. > 0: More output.
5	TESTA	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 $P(\sigma_a)$ - calculation. K ≥ 1: Mesh points of $P(\sigma_a)$, Dancoff factors and data of homogenization of the matrix zone.
6	EW(13)	Number of mesh points for $P(\sigma_a)$-calculation. (≃ 20)

Card Z3		Format (6E12.5)
1	FUTYP	Fuel type and -variant specification to be read from data set 29 (cp. NFUTP at DATA-2-card D6).
2	EAMOD1	Atomic weight of moderator material 1, being admixed with the absorber. (e.g. Carbon)
3	ESIGM1	σ_s of the moderator 1.
4	EAMOD2	Atomic weight of moderator material 2, being admixed with the absorber. (e.g. Oxygen)
5	ESIGM2	σ_s of the moderator 2.
6	ECDANC	Dancoff factor. = 0.: To be used for infinite medium or numerical computation of $P(\sigma_a)$ for the spherical fuel elements. > 0.: Dancoff-Ginsburg factor. Required for the cylindrical fuel elements. This ECDANC has higher priority than the internally calculated one, which can optionally be ordered by the card Z11.

Card Z4		Format (12I6)
1	IDENT	Identification number of data set 30, where the calculated resonance integrals will be stored in GAM-group-σ_a-structure.
2	IDSATZ	Identification number of the calculated σ_a-cross section set to be stored on data set 30 for further use in GAM-calculations.
3	IDNUCL	GAM-library identification no. of the absorber nuclide.
4 : 12	LOESCH(J) J = 1,9	Id.-numbers of existing resonance data on data set 30 to be deleted prior to creating the new set.

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,I5,I1,7E9.4)
1	IEND	9
2 : 8	DUMMY	Blanc: Terminates the sequence of ZUT-DGL cases.

2.2.2 Resonance parameters. Z7 - Z10

Note:
The input of resonance parameters on cards Z7 - Z9 must be terminated by a blanc-card.
Cards Z7 - Z9 must be read after card Z4.
Card Z10 must be read after card Z5.

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

Card Z7		Format (I1,I5,I1,7E9.4)
1	IEND	2
2	JI	00005
3	KI	5
4	EZERO	Energy at the center of the resonance. (eV)
5	GAMN	Γ_n (eV)
6	GAGM	Γ_γ (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.

Cards Z8, Z9 for the unresolved resonances.

Card Z8		Format (I1,I5,I1,7E9.4)
1	IEND	6
2	JI	00000
3	KI	6
4	EC	Lower energy of the range of unresolved resonance evaluation. (eV)

5	GAMNO	Avg. [Γ_n^o] (eV)
6	GMGM	Avg. [Γ_γ] (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 only when any of the input figures is different from the figures on cards Z3 and Z10.

Card Z9		Format (I1,I5,I1,7E9.4)
1	IEND	6
2	JI	00000
3	KI	4
4	SIGPZ	σ_s , Potential scattering cross section of the absorber.
5	SIGM1	σ_s of moderator 1.
6	SIGM2	σ_s of moderator 2.
7	C	Dancoff factor. = 0.: To be used for infinite medium or numerical computation of $P(\sigma_a)$ for the spherical fuel elements. > 0.: Dancoff-Ginsburg factor. Required for the cylindrical fuel elements. This C has higher priority than the internally calculated one, which can optionally be ordered by the card Z11.

Card Z10		Format (I1,I5,I1,7E9.4)
1	IEND	1

2	JI	00001
3	KI	4
4	AZERO	Atomic weight of the absorber.
5	G	Statistical weight factor. (= 1 for ^{232}Th and ^{238}U)
6	SIGPZ	σ_s , Potential scattering cross section of the absorber.
7	TEMP	Temperature. (°K)

2.2.3 Explicite fuel element design. Z11 - Z17

Card Z11 only when Dancoff factor calculation by subroutine DANC3 is desired.

Card Z11		Format (I1,I5,I1,7E9.4)
1	IEND	7
2	K	Type of lattice: 10: Square lattice up to the 4. neighbour. 14: 4 x 4 bundle. 15: 5 x 5 bundle. 16: 6 x 6 bundle. 20: Triangular lattice up to the 4. neighbour. 22: 2 - rods bundle. 23: 3 - rods bundle. 27: 7 - rods bundle. 29: 19 - rods bundle.
3	KI	7
4	A	Radius of the rod.
5	B	Pitch.
6	DHUE	Cladding thickness.
7	DSP	Thickness of the gaps between the bundles (for K = 14, 15, 16).

8	SMOD	Σ_{tot} of the moderator.
9	SHUE	Σ_{tot} of the cladding.
10	SSP	Σ_{tot} in the gaps.

Card Z12		Format (I1,I5,I1,7E9.4)
1	IEND	1
2	JI	00010
3	KI	3
4	SOLVE	Same as on card Z2 must be given here.
5	ABAR	Radius (cm), for cylindrical or spherical fuel. Half thickness (cm), for slab. = 0.: Infinite medium, or explicite calculation of $P(\sigma_a)$.
6	C	Dancoff factor. = 0.: To be used for infinite medium or numerical computation of $P(\sigma_a)$ for the spherical fuel elements. > 0.: Dancoff-Ginsburg factor. Required for the cylindrical fuel elements. This C has higher priority than the internally calculated one, which can optionally be ordered by the card Z11.

Card Z13		Format (I1,I5,I1,7E9.4)
1	IEND	1
2	JI	00013
3	KI	7
4	EDZERO	N_{abs} atom density of absorber.
5	EAMOD1	Atomic weight of moderator no. 1.

6	ESIGM1	σ_s of moderator 1.
7	EDIQU1	$N_{mod\ 1}$ / N_{abs} ratio.
8	EAMOD2	Atomic weight of moderator no. 2.
9	ESIGM2	σ_s of moderator 2.
10	EDIQU2	$N_{mod\ 2}$ / N_{abs} ratio.

Cards Z14, Z15 only when numerical evaluation of $P(\sigma_a)$ is required (I = 0 in SOLVE).

Card Z14		Format (I1,I5,I1,7E9.4)
1	IEND	5
2	JI	00018
3	KI	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	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).
9	H	Fraction of graphite spheres in the pebble bed.

Card Z15		Format (I1,I5,I1,7E9.4)
1	IEND	5
2	JI	00025

3	KI	4
4	SI2	Avg. Σ_{tot} of the coatings.
5	SI4	Σ_{tot} in outer shell of a spherical element.
6	SI5	Σ_{tot} in graphite spheres.
7	ALPH	Ratio of densities: ρ(graphite in matrix) / ρ(graphite in coatings).

Card Z16		Format (I1,I5,I1,7E9.4)
1	IEND	8: Termination of ZUT-DGL input.

Card Z17		Format (A3, ...)
1	HEAD(1)	REP: Another input case will follow. END: Termination of the run.

2.2.4 Opening of a new resonance data library. Z18 - Z20

Card Z18		Format (1X,I5)
1	JI	= -30: Opening of direct access data set no. 30 for the resonance absorption cross sections in GAM-group-σ_a-structure.

Card Z19		Format (12I6)
1	IDENTI	< 0: |IDENTI| will be the identification number of the new data set 30.
2 .	IZAHL	Number of sets to be reserved for the σ_a cross section sets. (Use 170)

Card Z20		Format (10I2)
1 : 3	K(I), I = 1,3	= -1-1-1: Special key word.

2.3 Geometric Reactor Design.

2.3.1 BIRGIT, 2-dimensional. BI1 - BI10

Starter card BI1

Card BI1		Format (5I6)
1	NVSOP	Data set number for the data transfer to VSOP (use 25).
2	NGEOM	> 0: Data set number for the data transfer to CITATION (use 37). = 0: Drop the VSOP - CITATION layout.
3	NTHX	> 0: Data set number for the data transfer to THERMIX (use 43). = 0: Drop the VSOP - THERMIX layout.
4	IWRC	= 0: Volume matrix VSOP - CITATION is calculated and used. > 0: It is calculated, stored to data set IWRC, and used. < 0: It is not calculated, read from data set |IWRC|, and used.
5	IWRT	= 0: Volume matrix VSOP - THERMIX is calculated and used. > 0: It is calculated, stored to data set IWRT, and used. < 0: It is not calculated, read from data set |IWRT|, and used.

Cards BI2 - BI10

If NGEOM > 0 one set of cards for the VSOP - CITATION case,
if NTHX > 0 another set of cards for the VSOP - THERMIX case.

Card BI2		Format (4I6,E12.5,2I6,2E12.5)
1	IPUT	= 0: Normal output. = 1: Testoutput in addition.

2	IPLOT	= 0: Normal. > 0: Data set number for plotting.
3	IZFEIN	Number of Z meshes of a superposed fine grid.
4	JRFEIN	Number of R meshes of a superposed fine grid.
5	EP	(1.-EP) defines the position of the reference point in a fine mesh. (E.g. in the mesh $\Delta R * \Delta Z$ a given value EP = 0.1 means that the reference point is located at $0.9 * \Delta R$, $0.9 * \Delta Z$).
6	KANAL	Number of channels in the VSOP layout of the core. A conus must be regarded as an extra channel. Reflector zones can optionally be regarded as channels.
7	MDIREC	= 0: Calculation of the volume matrix by means of the superposed fine mesh grid. > 0: Calculation of the volume matrix by the direct method (only when the flow channels are vertical).
8	EPSY	Convergency criterion for the iteration on the radial position of the mesh points defining the flow channel curves. (about 0.00003)
9	RINTHX	= 0.: Normal. > 0.: Inner radius of the core. Only required when the BIRGIT design for THERMIX (see NTHX on card B11) does not include the inner part of the reactor.

For each of the KANAL channels one set of cards B13 - B15 required.

Card B13		Format (4I6,3E12.5)
1	KANTYP	= 0: This is an inner channel of the core. Layer id.numbers are assigned by the code. = 1: This is the outer core channel. Optionally the design of an outer conus can be defined below. = -1: This is a channel of the reflector for which the layer id. numbers are also assigned by the code. If a conus has been defined before, the first reflector channel adjacent to the outer core channel applies to the conus.
2	KAN	> 0: Number of layers in this channel.

		= 0: One layer over the whole channel.
3	IBATCH	> 0: Number of batches per layer. = 0: One batch per layer.
4	IJR	> 0: Number of axial mesh points (= MESH) for defining the outer limiting curve of this channel. Only for the inner core channels KANTYP = 0. IJR = 1 defines a straight vertical line. = -1: Same axial mesh points as for the preceding channel. Drop card BI4. = 0: Drop cards BI4, BI5. Limiting curves of the reflector channel and of the last core channel are internally defined by the information of card BI6.
5	VEKA	> 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. = 0.: No adaption of the limiting curve. If an inner conus and/or an outer conus is present, separate channels with KANTYP = -1 must be defined for these conus areas adjacent to the core. For an inner conus, the radial thickness RKONUS must be given by negative value. For an outer conus, its thickness and height must be given on card BI3 of the last core channel preceding to the conus channel.
6	RKONUS	= 0.: Core - reflector interface is vertical. No conus is present. < 0.: Inner conus. |RKONUS| is radial thickness of the conus. (cm) > 0.: The subsequent channel defines an outer conus with radial thickness RKONUS. (cm)
7	ZKONUS	Height of the conus. (cm)

Card BI4 only when IJR > 0

Card BI4 Format (6E12.5)

1 .	XWE(J), J = 1,MESH	Axial position (abscissa) of the coarse mesh points for the outer limiting curve of this channel. (cm)

Card BI5 only when IJR ≠ 0		
Card BI5		Format (6E12.5)
1 . .	YWE(J), J = 1,MESH	Radial position of the coarse mesh points for the outer limiting curve of this channel. (cm) (Ordinates for the interpolation). In case of an annular core, YWE(J) must be given as the distance from the inner limiting curve of the first core channel.

Cards BI6 - BI8 define the overall coarse mesh grid. Of course, it is only relevant for the outer parts of the reactor, in which the VSOP layers and CITATION compositions are congruent. For the area of the core, and optionally for the inner part of the reflector, for which the composition id.numbers are internally defined by the code, a finer mesh grid is defined on cards BI9 - BI10. For the THERMIX the definition of the grid is only required for the core, because the volume transfer matrix must only be made for the area of the core and conus.

Radial meshes

Card BI6		Format (6(I3,F9.3))
1	MR(I)	> 0: Number of fine radial meshes in the I-th coarse mesh. = 0: This radial coarse mesh is in the area of the core. Finer subdivision to be defined on card BI9.
2 . . .	DR(I) . . I = 1, ...	> 0.: Thickness of the I-th radial coarse mesh. (cm) = 0.: End of the input of radial coarse meshes. The number of given radial coarse meshes defines IMAX.

Axial meshes

Card BI7		Format (6(I3,F9.3))
1	MZ(N)	> 0: Number of fine axial meshes in the N-th coarse mesh. = 0: This axial coarse mesh is in the area of the core. Finer subdivision to be defined on card BI10.
2	DZ(N)	> 0.: Thickness of the N-th axial coarse mesh. (cm)

.	.	= 0.: End of the input of axial coarse meshes.
.	.	
.	N = 1, ...	The number of given axial coarse meshes defines NMAX.

Each of the NMAX axial coarse meshes requires one card BI8.

Card BI8		Format (18I4)
1 . . .	LAYVC (I,N) I = 1, IMAX	> 0: Composition id.number of the radial meshes I in the row N. (The numbers are preliminary and will be renamed successively after the id.numbers of the VSOP layers and CITATION compositions have been internally defined.) = 0: Core area. id.numbers are defined by the code for the finer grid of the cards BI9, BI10. = -1: Internally defined reflector area. Finer axial meshes according to card BI10.

Cards BI9, BI10 define the mesh grid of the core.

CITATION: Coarse meshes define the compositions, the fine meshes define the grid of the neutron flux calculation.

THERMIX: The fine mesh grid of the core must be identic to that of the THERMIX input on the cards TX7 - TX8, because the volume matrix is made for the transformation from VSOP layers to THERMIX meshes.

Radial meshes

Card BI9		Format (6(I3,F9.3))
1	MGR(I)	> 0: Number of fine meshes in the radial coarse mesh I. = 0: End of the radial mesh input.
2 . .	DGR(I) . I = 1, ...	Thickness of the radial coarse mesh I. (cm)

Axial meshes

Card BI10		Format (6(I3,F9.3))
1	MGZ(N)	> 0: Number of fine meshes in the axial coarse mesh N. = 0: End of the axial mesh input.
2 . .	DGZ(N) . N = 1, ...	Thickness of the axial coarse mesh N. (cm)

2.3.2 TRIGIT, 3-dimensional. TR1 - TR5

Card TR1		Format (15I5)
1	NVSOP	Data set number for the data transfer to VSOP (use 25).
2	NGEOM	Data set number for the data transfer to CITATION (use 37).
3	N200C	Number of layers in the power generating core. **Note:** The TRIGIT code defines the 3-dim. pattern of compositions in the reactor. VSOP-layer, VSOP-batches, and CITATION-compositions must be identic. They are assigned with the same id.numbers.
4	IPL	= 0: Normal. > 0: Plotting of geometry is provided for the plane no. IPL.
5	ICORE	= 0: Normal. > 0: Just for plotting: = 2: Input of 1/2 core-plane is transmuted to 1/1 core-plane. = 4: Input of 1/4 core-plane is transmuted to 1/1 core-plane.

Meshes in X-direction

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

Meshes in Y-direction

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

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.
2 . . .	DZ(K) . . .	≠ 0.: |DZ(K)| gives the thickness of the K-th coarse Z-mesh. (cm) < 0.: Core regions. > 0.: Non-core regions (e.g. reflectors). = 0.: End of the input of coarse Z-meshes.
	K = 1, ...	The number of given coarse K-meshes defines KMZ.

Definition of the pattern of compositions:

For each of the planes (Z) K = 1,KMZ one set of cards TR5.
For each of the rows (Y) J = 1,JMY one card TR5.

Card TR5		Format (15I5)
1 . . .	LAY3(I,J,K) I = 1,IMX	Only for the core: > 0: Composition id.number of the I-th mesh (X) in this row and plane. In the upper plane the code evaluates the maximum number NPL of core compositions. = 0: Id.no. of this composition is internally defined by adding NPL to the LAY3(I,J,K-1) of the foregoing plane. Only for the non-core-compositions (reflectors etc.): < 0: Id.no. of this composition is internally defined by adding the maximum number of core compositions (N200C) to the absolute of |LAY3(I,J,K)|. Reflector id. numbers must be given in an unbroken sequence starting with -1.

2.4 VSOP, Reactor and Fuel Cycle. V1 - R36

Cards V1-V23, G1-G11, T1-T11, C0-1 - CX-1, K1-K12, R1-R36

2.4.1 Starter cards. V1 - V2

Card V1		Format (72H...)
1	COL.2-72	Literal description of case.

Card V2		Format (18I4)
1	JTPE7	= 0: Normal start. > 0: Restart. Identification number of restart data to be read. Define IPRIN(8) and IPRIN(11). The next cards must be: optionally R8 (see IRR9 below), R9 - R36. (See Section 3.4.2).
2	JTPE9	= 0: No effect. > 0: Prepare restart data with id. no. JTPE9 from this case. Define IPRIN(9) and IPRIN(11). Data will be written after the last specified fuel management step. (IVSP(24) on card R9).
3	IPRIN(8)	= 0: No effect. > 0: Data set reference number of restart unit from which the burnup dependent data are retrieved. (Normally 14).
4	IPRIN(9)	= 0: No effect. > 0: Data set ref. no. of restart unit on which new burnup dependent data will be stored. (Normally = 15).
5	IPRIN(11)	= 0: No effect. > 0: Data set ref. no. of restart tape on which the library information is contained. The data are written after fuel management step no. 1 and they will be read in all re-

		starts of that case. (Normally = 20, both writing and reading)
6	IRR9	= 0: No effect. > 0: Only for restart: Card R8 will be given to redefine the options for the first cycle of the restart.
7	NVSOP	> 0: Unit number from which the BIRGIT data for the geometric design of the reactor are to be read. (Use 25) = 0: At Restart.
8	ITTT	= 0: No effect. > 0: Prepare a new 30 groups THERMOS library out of the 96 groups THERMALIZATION library. (NUTTE on card T1 must be 0).
9	I3D	= 0: 2-dimensional diffusion calculation in r-z. = 1: 3-dimensional diffusion calculation in x-y-z. (Ignored in restart)

2.4.2 Variable dimensions. V3

Card V3		Format (18I4)
1	KMAT	> 0: Number of nuclides (≤ 200). Use nuclide identification from data set 29 prepared in DATA-2. < 0: |KMAT| number of nuclides (≤ 200). Identification given on cards V5.
2	NXS	Number of different spectrum zones, comprising a combination of one or more batches.
3	NLB	= 0: No fixed cross section sets. > 0: Number of fixed microscopic cross section sets defined on cards V7A, V7B. The data are normally used for the nuclides in the reflectors for which no spectrum calculation is carried out. The data are refered to as spectrum calculation no. NXS+I (I=1,NLB).
4	N26	Number of energy groups in the diffusion calculation.

5	MMAF	Maximum number of burnup cycles.
6	MBATCH	Maximum number of batches to be filled into storage boxes.
7	MSTOB	Maximum number of storage boxes to be filled.
8	JTYP	No. of different fuel element types in the system ($\leq$ 10). Same as in cost input (MXTYP on card K1).
9	JCLAS	Total number of real burnup classes. For every fuel type the code automatically adds class 1 for the fresh fuel and class 0 for the scrap fuel. Limitation: JCLAS + 2*JTYP + MREP $\leq$ 40
10	MREP	Number of reprocessing mixtures. ($\leq$ 10).
11	JABOX	Total number of aging boxes and jumble boxes as explicitely specified on card R7 (only when MREP > 0).

2.4.3 Definition of materials. V4 - V9

Card V4		Format (18I4)
1	NO	Number of fission products ($\leq$ 49). If NO < IDKET the code drops the last surplus ones.
2	IDKET	Id.no. of fission product chain to be applied (29, 34, 39, 44, see Table VI).
3	KETT	= 0: No effect. > 0: Chain information of the last KETT fission products will be defined on cards V8. This option can be used to extend the chain structure or to define a new one.
4	NLT	= 0: No effect. > 0: Number of fission products, for which new yields and decay constants will be defined on card V9.
5	NLUM	Number of "lumped poison" nuclides. ($\leq$ 3)
6	NC	Number of control poison nuclides. ($\leq$ 2)

Card V5 only when KMAT < 0 on card V3.

Card V5		Format (1814)
I : KMAT	IMAT(I), I = 1,KMAT	Identification number of the VSOP nuclide I in the GAM-library. Use continuation cards. **Note:** Nuclide id.numbers beyond the library can be used (i.e. IMAT(I) > 184), but these nuclides must be identified on the card(s) V6.

Cards V6 only when some nuclides of the library shall be duplicated and used with new id.numbers IMAT(I) > 184. One card V6 for every new id.number.

Card V6		Format (1814)
1	JNEU	Id.no. of the new nuclide.
2	LMAT	Id.no. of the library nuclide of which the cross sections are to be duplicated.

Cards V7A and V7B only when NLB > 0 on card V3.
For each fixed microscopic cross section set one set of cards. 1 card V7A plus N26 cards V7B (for each energy group).

Card V7A		Format (I4,68H...)
1	HLA	VSOP identification number of the reflector nuclide.
2	LOC.5-72	Literal description.
Card V7B		Format (5E12.5)
1	FISIG(I)	$\nu * \sigma_f$ fission.

2	TOSIG(I)	σ_t transport.
3	ABSIG(I)	σ_a absorption.
4	OUSIG(I)	σ_s (I→I + 1) down scattering.
5	XNU(I)	ν neutrons/fission.
		I: Energy group index starting with 1 for the fast group.

Card V8 only when KETT > 0 on card V4.
A total of KETT cards required, starting with the card for the fission product nuclide N = NO - KETT + 1.

Card V8		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 V9 only when NLT > 0 on card V4.
A total of NLT cards is required, one for each fission product for which the yields are defined or altered.

Card V9		Format (16,6X,5E12.4)
1	N	VSOP identification no. of a selected fission product nuclide.
2	YIELD1(N)	^{233}U fission yield of nuclide N.
3	YIELD2(N)	^{235}U fission yield of nuclide N.
4	YIELD3(N)	^{239}Pu fission yield of nuclide N.

5	YIELD4(N)	^{241}Pu fission yield of nuclide N.
6	XLAM(N)	Decay constant of nuclide N. (1/sec)

2.4.4 Design and operations. V10 - V23

2.4.4.1 Case identification. V10

Card V10		Format (9I4,2E12.5,I4)
1	JSER	= 0: Diffusion calculation, control poison adjustment, burnup. = 1: Diffusion calculation, burnup. = 2: Diffusion calculation. = 3: Same as 0, but control poison adjustment in the reflector.
2	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 R31 - R34).
3	NXE	= 0: Start with time step -1 in order to find a starting distribution of Xenon. = 1: First step of calculation at time step 0. Starting Xe-concentration given at input.
4	NKOST	= 0: No effect. > 0: Fuel cycle cost calculations. (Cards K1-K12).
5	IBUCK	= 0: No feedback of leakage from diffusion to spectrum calculation. = 1: Feedback of broad group bucklings to GAM, and thermal leakage to THERMOS. = 2: Feedback of an average epithermal buckling to GAM, and thermal leakage to THERMOS.

6	MUHU(3)	= 0: Drop streaming correction in pebble bed. = 2: Streaming correction LIEBEROTH /34/ in power generating batches (only for pebble bed).
7	IXEN	= 0: Xe-135 equilibrium. > 0: Explicite ^{135}I - ^{135}Xe calculation (must be redefined for each burnup cycle by IVSP(28) on card R14).
8	LOBNEW	= 0: Normal. = 2: Life history is preserved for ORIGEN-JÜL-II on unit 39, starting from this cycle.
9	IBASCH	= 0: No effect. > 0: In 3-dim. design: Number of batches in the upper plane of the core (useful for automatic definition of KD18 on card V11).
10	SERCON	Convergency criterion for K_{eff} when adjusting control poison or other atom concentrations. ($\simeq$ 0.0001)
11	REFNO	= 0: No effect. > 0: Option for the reflector batches: With respect to NCH1 > 0 on card V11, the code uses the composition id.numbers of the BIRGIT input, instead of the real VSOP-batch numbers.
12	IPRIN2	$\geq$ 0: Print layout of batches at startup. = -1: No output.

2.4.4.2 Definition of reactor batches. V11 - V14

Each of the N200 batches requires one set of cards V11-V14, starting with batch no. 1.

Card V11		Format (6I4,E12.5,I4,20X,2I6)
1	NREAD	$\leq$ 100: Number of atom densities to be specified on subsequent cards V12. > 100: Read atom densities of fuel type IJ, variant KL from data set 29. (Compare NFUTP on card D6).
2	NCH1	> 0: Number of a previously specified batch with the same atom densities.

		Note: If conus batches are present, they must follow behind the core batches. For reflector batches see the option REFNO on card V10. < 0: Read new atom densities from direct access unit 28.
3	NCH3	> 0: Number of a previously specified batch with the same geometric data for lumped poison materials. Caution!
4	NCH5	> 0: Number of a previously specified batch with the same control poison data. = 0: Use data of batch no. 1. < 0: Read card V14.
5	NLUMPS	> 0: The densities of the lumped poison nuclides (on card V12) are lumped densities, and they will be homogenized. (Card V13) = 0: These densities are given homogenized.
6	NHOT	> 0: Number of spectrum zone for this batch. > NXS (on card V3): Fixed set of σ as defined by NLB on cards V3, V7A, V7B. = 0: Use NHOT of the preceding batch.
7	WPART	Fraction of the volume of this batch per layer: = 0.: In the batches of the first layer the code makes WPART = 1. / (no. of batches per layer). In the other batches of the core the code copies WPART of the corresponding batch of the preceding layer. In the batches 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 layer, and it holds for all subsequent layers until redefined).
8	NFTST	Definition of fuel type id.no. of this batch. Only when fuel is defined by cards V12, otherwise the id.no. is taken from batch no. NCH1. **Note:** If NREAD > 100 the id.no. is taken from DATA-2. In reflectors the id.no. is 0.
9	MULT	= 0: No effect. > 0: The id.no. of this batch is defined by KD18 = KD18 + MULT * IBASCH (useful in 3-dim. design for the batches in the lower planes).

10	KD18	= 0: No effect. > 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. Non power generating batches (e.g. reflectors) are counted from 1 ... (the number of core batches is automatically added). < 0: Last card V11, holding for the batch |KD18|.

Atom densities: Card V12 only when $0 < NREAD \leq 100$. A total of NREAD cards is required.

Card V12 Format (I4,4X,E12.5)

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. Lumped poison materials can be given in lumped density (cp. NLUMPS on card V11).

Control rods: Card V13 only when NLUM > 0 on card V4, and when NCH3 = 0 on card V11.

Card V13 Format (6E12.5)

		The lumped poison nuclide in all batches of one layer has the same poison-selfshielding specification.
1	RODS	Number of absorber rods in this layer.
2	DILP	Inner diameter of one rod. (cm)
3	DOLP	Outer diameter of one rod. (cm)
4	HLP	Height of one rod. (cm)
5	VLP	Volume of all rods in this layer. = 0.: It will be calculated from the other data. > 0.: The other data are not required.
6	SSLUMP	Selfshielding factor of the lumped poison at the thermal en-

		ergy group.

Control poison: Card V14 only when NC > 0 on card V4, and when NCH5 < 0 on card V11. One card V14 for each control poison nuclide. If NCH5 = 0 use data of batch no. 1.

Card V14 Format (6E12.5)

		The control poison nuclide(s) in all batches of one layer have the same min. and max. limitations.
1	POISM	Minimum atom density of control poison in this layer. (e.g. = 0.)
2	POISL	Maximum atom density of control poison in this layer.

2.4.4.3 Data for the burnup calculation. V15 - V16

Cards V15-V19 only when JSER $\leq$ 1 on card V10.

Card V15 Format (6E12.5)

1	DELDAY	Length of time steps between diffusion calculations (large burnup time step). Days
2	POWER	Thermal core power. Watt
3	FIWATT	Fissions/Ws for varying isotopic compositions according to DIN 25463 /30/: = 0.: Starting value = 3.087E+10 (^{235}U). > 0.: Optional starting value.
4	ZKFIND	End of cycle K_{eff} for burnup calculations and for control poison adjustments.

Card V16		Format (18I4)
1	JNSTOP	Last large burnup time step in one burnup cycle. ($\leq$ 93 + NXE on card V10)
2	JNUM	Number of small time steps in one large step, i.e. between two subsequent diffusion calculations. Renormalization of the neutron flux is done at the small time steps.

2.4.4.4 Control poison search. V17 - V19

Cards V17-V19 only when JSER = 0 on card V10.

Card V17		Format (18I4)
1	JSMAX	Maximum number of control poison iterations for any layer at one time step. (All batches of the layer are treated simultaneously.) ($\simeq$ 50)
2	JSSMAX	Maximum number of control poison iterations for the total core at one time step. ($\simeq$ 200)
3	LSIM	Number of layers, for which the control poison is adjusted simultaneously. LSIM layers form a poison region for simultaneous poison adjustment.
4	KSS	Length of the list of layers for control poison adjustments. The ratio KSS/LSIM gives the number of poison adjustment regions.
5 . .	NPOIS(I), I = 1,KSS	The list gives the sequence of layers in which the adjustments are performed. In every poison adjustment region of LSIM layers the poison is adjusted simultaneously. A layer can appear more than once, i.e. it can be named in different poison adjustment regions. Continuation cards if required.

Card V18		Format (6E12.5)
I : KSS	PINMIN(I), I = 1,KSS	Minimum fraction of control poison insertion in the I. layer to be adjusted. (e.g. = 0.) Continuation cards if required.

Card V19		Format (6E12.5)
I : KSS	PINMAX(I), I = 1,KSS	Maximum fraction of control poison insertion in the I. layer to be adjusted. (e.g. = 1.) Continuation cards if required.

2.4.4.5 Selfshielding in lumped poison materials. V20

Card V20 only when NLUM > 0 on card V4. A set of N26 cards (energy groups) is required, fast group first. (Only for power generating batches).

Card V20		Format (6E12.5)
1 : 5	A(J), J = 1,6	Coefficients of the polynomal representation of the self-shielding factor G. $G = \left(\sum_{J=1,6} A(J) * S_{tot}^{J} \right)^{-0.5}$ with $S_{tot} = \sum_{I=1,NLUM} \sigma_{total}(I) * N(I)$ for each batch with N(I) = lumped atom density of the I. nuclide in the lump.

2.4.4.6 Print-out options and steerings. V21

Card V21		Format (1814)
1	IPRIN(1)	Spectrum calculation: = 0: Thermal selfshielding factors, only. = 1: Same as 0, plus averaged thermal cross sections. = 2: Same as 1, plus fine group neutron fluxes. = 3: Same as 2, plus broad groups averaged cross sections for materials with concentration > 0. = 4: Same as 3, for all materials.
2	IPRIN(2)	= 0: No output. = 1: Print layout of batches before shuffling. = 2: Same as 1, plus atom densities (only in combination with IPRIN(3) ≥ 0).
3	IPRIN(3)	Burnup calculation: = -1: Global neutron balance. = 0: Detailed neutron balance. = 1: Same as 0, plus characteristic data for all fuel batches.
4	IPRIN(4)	= 0: Skip spectrum calculation if a set of cross sections is available. Instructions on card V22 are neglected. = 1: Repeat spectrum calculation as defined on card V22. = 2: Same as 1, but only for the thermal spectrum. = 3: Same as 1, but not for zones without heavy metal (reflectors). = 4: Same as 2, but not for zones without heavy metal (reflectors).

2.4.4.7 Steering the performance for spectrum and diffusion calculation. V22 - V23

Card V22		Format (1814)
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. < 0: Same as > 0, but only for the thermal spectrum calcu-

		lation.
2 : 18	ISPEKT(I), I = 2,18	> 0: No. of further time steps for spectrum calculation. < 0: Same as > 0, but only for the thermal spectrum calculation. = 0: If all ISPEKT = 0, spectrum calculation is performed in every time step.

Card V23		Format (18I4)
1 : 18	IDIFF(I), I = 1,18	If all IDIFF(I) = 0: Diffusion calculation is performed at every time step. If at least one IDIFF(I) ≠ 0: The IDIFF(I) give the time steps at which diffusion calculation is to be performed.

2.4.5 Fast and epithermal neutron spectrum - GAM. G1 - G11

Card G1		Format (12I6)
1	IDGAM	Id.-no. of GAM-library. (5015)
2	IDZUT	Id.-no. of the resonance integral library. (180)
3	IDTHER	Id.-no. of THERMOS-library. (515) = 0: Calculate THERMALIZATION for TTTT. It shall be made only for one spectrum zone (see Section 2.4.10).
4	NGAM	Data set reference number of the resonance integral library. (30)
5	IDESIN	Number of different fuel element designs (≤ 10). Only for different resonance cross section data on cards G3, G4. The differentiation of fuel element designs for the resonance calculation is normally the same as for the thermal cell calculation, i.e. IDESIN = NBER on card T5.
6	IJGM	Geometry of the fuel element:

		= 1: Slab. = 2: Cylinder. = 3: Sphere.
7	MSTU	Fission source spectrum: = 3: ^{233}U. = 5: ^{235}U. = 11: ^{239}Pu. And others. (The library contains 18 different ones). = 0: Unit fission source in the GAM-group no. given by MGHUS.
8	MGHUS	= 0: In diffusion calculation the fission source is assigned to the broad groups corresponding to the source spectrum. = 1 and MSTU ≠ 0: Fission source is assigned just to the first broad group.
9	NSSS	= 0: No selfshielding factors applied. > 0: Number of sets of selfshielding factors (cards G6-G11). = -1: One single set of selfshielding factors to be applied in all spectrum zones (cards G7 - G11).
10	IPRSEL	Output option of the selfshielding factors: = 0: Broad energy group definition. = 1: Selfshielding factors for the different nuclides.

Card G2		Format (6E12.5)
1 : NXS	TEMZUT(I), I = 1,NXS	Temperature of the resonance absorbers in the NXS different spectrum calculations. (°C) (NXS on card V3) Continuation cards if necessary.

Card G3 only when IDESIN > 1 on card G1.

Card G3		Format (12I6)
1 :	NDES(I), I = 1,NXS	Fuel element design number in the spectrum calculation I.

NXS		Continuation cards if necessary.

For each design (IDESIN) a set of 2 cards G4.

Card G4		Format (12I6)
1	NZ	Number of resonance absorption cross section sets to be read from data set NGAM for this fuel element design. First card contains information for ^{232}Th, second card for ^{238}U. ($\leq$ 10)
2 . .	IZUT(K), K = 1,NZ	Id.-numbers of cross section sets which will be used for temperature calculation. IZUT = 0: Just background cross sections for σ_a (E).

Definition of broad energy groups.

Card G5		Format (6E12.5)
1 .	CEG(I), I = 1,N26-1	Desired lower energy limit of the fast energy group(s). (eV)

2.4.5.1 Individual epithermal selfshielding factors. G6 - G11

Card G6 only when NSSS > 0 on card G1 (see also Section 3.2.3).

Card G6		Format (12I6)
1 : NXS	NSET(I), I = 1,NXS	Id-no. of the set of selfshielding factors to be applied in the spectrum zone I. Continuation cards if necessary.

Cards G7 - G11 only when NSSS ≠ 0:
For each of the NSSS sets of selfshielding factors one set of cards G7 - G11.

Card G7		Format (12I6)
1	MOBG	> 0: Number of broad epithermal energy groups for input of selfshielding factors (card G8). (Up to 67 groups can be defined). = 0: Broad energy groups same as defined on card G5 (the code sets MOBG = N26 - 1). < 0: Same broad energy groups as defined before.
2	LSUB	> 0: Number of subsets of cross section-selfshielding factors SC (cards G9). (≤9) = 0: No input of SC.
3	NK	> 0: Number of cell zones for neutron flux-selfshielding factors SF (cards G10). (≤6) = 0: No input of SF.

Card G8 only when MOBG > 0 **and** MOBG < 67.

Card G8		Format (12I6)
1 : MOBG	MGBN(J), J = 1,MOBG	Id.number of the GAM group with the highest energy in the broader energy group J.

Cards G9 only when LSUB > 0.
A set of (J = 1,MOBG) cards G9 must be given for the MOBG broad energy groups.

Card G9		Format (6E12.5)
1 : LSUB	SC(L,J), L = 1,LSUB	Broad energy group J: Cross section-selfshielding factor of subset L.

Cards G10 only when NK > 0.
A set of (J = 1,MOBG) cards G10 must be given for the MOBG broad energy groups.

Card G10		Format (6E12.5)
1 : NK	SF(K,J), K = 1,NK	Broad energy group J: Neutron flux-selfshielding factor of cell zone K.

A card G11 is required for each nuclide (simplification of input can be defined on the cards).

Card G11		Format (I6,2I2,6E10.4)
1	IDG	> 0: Id-no. of nuclide in the GAM 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 G11.
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) to be applied for this nuclide.
4 :	ANT(K), K = 1,NK	Fraction of the homogenized atom density to be assigned to the cell zone no. K (only when NK > 0)

2.4.6 Thermal cell spectrum - THERMOS. T1 - T11

Card T1		Format (12I6)
1	NKER	Number of different scattering nuclides. (≤ 5)

2	NKERAB	Number of absorber materials for which a scattering matrix is calculated (Brown St. Johnes). ($\leq$ 10)
3	NUTTE	= 0: Calculate THERMALIZATION for preparing of a THERMOS library (see Section 2.4.10). = 1: THERMOS calculation, no subsequent calculation of selfshielding factors. = 2: Print-out selfshielding factors.
4	NUCT	Maximum number of scattering nuclide id-numbers per one scattering nuclide to be read for temperature calculation (cards T2). ($\leq$ 11)
5	ITY	Identification of fuel element type (see card T5) of which the geometry data are used for streaming correction and for the performance data list. = 0: Use the first fuel element type (for which the first set of cards T6-T10 is given). > 0: Use the ITY-th fuel element type. = -1: Define the geometry data on card T11. This is necessary if THERMOS cell definition is different from fuel element size.
6	MUP	= 0: Normal. > 0: Number of broader thermal groups (to be read on card T1A) for given individual selfshieldings.

Card T1A only when MUP > 0 on card T1.

Card T1A		Format (6E12.5)
I : MUP	EMU(I), I = 1,MUP	Upper limit (eV) of the I-th thermal broader group for the given individual selfshieldings, starting with the lowest thermal group.

For each of the NKER scattering nuclides one set of cards T2-T3, in sequence of VSOP nuclides on card V5.

Card T2		Format (12I6)
1	IKER(J),	Id.-no. of the J. scattering matrix which will be used in the

: NUCT	J = 1,NUCT	temperature interpolation for this scattering nuclide.
NUCT + 1	KBLIND	Number of dummy scattering matrices to be stored on data set 10. Must be specified on the last card T2. This reserves storage if additional scattering matrices will be given in re-start cases.

Card T3		Format (6E12.5)
1 : NXS	TCELS(J), J = 1,NXS	Temperature of this scattering nuclide for spectrum calculation J. (°C)

Card T4 only when NKERAB > 0 on card T1.

Card T4		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	Identification no. of nuclide I for which scattering matrix is calculated.

Card T5		Format (12I6)
1	NGEOM	= 0: Cylindrical fuel element. = 1: Spherical fuel element.
2	NBER	Number of different fuel element types for the thermal cell calculation. Normally same as IDESIN on card G1. See also NFUTP on card D6.
3 .	NTYSP(I), I = 1,NXS	Identification no. of fuel element type used for spectrum calculation I.

For each fuel element type one set of cards T6-T10 required.

Card T6		Format (6E12.5)
1	TKG	Temperature for the initial guess of Maxwell neutron spectrum. °K/T0. (≃ 1.5, see also STRT0 on this card).
2	FUELL	Ratio: Volume of the cell / homogenized volume. (E.g. volumetric filling fraction of fuel balls in the core).
3	FUTYP	> 0.: Fuel element type identification IJ to be read from data set 29 (compare NFUTP on card D6). = 0.: All design specifications must be given on cards T7, T8
4	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 V5, T2). = 0.: T0 = 293.6 °K.
5	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. (This option is recommended).
6	TLEAK	= -1.: Isotropic boundary condition. Read card T10. = 0.: Reflecting boundary condition. = 1.: White boundary condition.

Card T7		Format (20I1,2I2,4E12.5)
1 : 20	MTBL(J), J = 1, 20	Cell zone no. in which mesh point J is located. E.g. 11122223330000. The highest digit defines the number of cell zones NCZ. (≤ 5)
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 heterogenity.
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: Density of matrix/density of coating.

Card T8 only when FUTYP = 0. on card T6.

Card T8 Format (6E12.5)

1 : 5	RED(I+1), I = 1, 5	Outer radius of cell zone no. I. (cm) Inner radius of cell zone no. 1 is set to 0.

A card T9 is required for each nuclide. For simplified input see below.

Card T9 Format (I5,I4,I1,6E10.4)

1	IDISO	> 0: Id. no. of nuclide in the THERMOS-library, starting with absorber nuclides in sequence of increasing 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 V5 and T2. < 0: -IDISO terminates the input of cards T9.
2	MUPO	= 0: Normal. > 0: Individual thermal selfshieldings of this isotope are given on cards T9A.
3	JT	= 0: The fractional densities VB specified on this card are also valid for all subsequent nuclides, unless revised. = 1: The VB are valid only for this nuclide.

4	VB(1)	≥ 0.: Fraction of the homogenized atom density to be assigned to the 1. cell zone. < 0.: Fractions are read from data set 29. = -1.: Nuclide distributed like fuel. = -2.: Nuclide distributed like moderator.
5 .	VB(L), L = 2,NCZ	Fraction of the homogenized atom density to be assigned to the L. cell zone. L = 2...NCZ.
. .	VB(NCZ+1)	The fraction of the nuclide assigned to the coated particle fuel zone ICOAT on card T7 must be further subdivided between kernel and coating-matrix. VB(NCZ+1) gives the fraction in the kernels.

Card T9A only when MUPO > 0 on card T9.

Card T9A Format (6E12.5)

1 : MUP	SFMU(K), K = 1,MUP	Individual selfshieldings of this isotope in the MUP broader thermal energy groups as defined on card(s) T1A.

Card T10 only when TLEAK = -1. on card T6.

Card T10 Format (6E12.5)

1	ALBEDO(1)	Albedo at the outer edge of the cell for the lowest energy group no. 1. = 1.: Reflection. = 0.: Vacuum boundary condition.
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. Use continuation cards if necessary.

Card T11 only when ITY = -1 on card T1.

Card T11		Format (6E12.5)
1	FF(1)	Volumetric filling fraction of fuel elements in the core.
2	FF(2)	Inner radius of the fuel zone of the elements (normal = 0.).
3	FF(3)	Outer radius of the fuel zone. (cm)
4	FF(4)	Outer radius of the element. (cm)
5	FF(5)	Fraction of graphite balls (only spherical elements).

2.4.7 CITATION, Joint diffusion calculation. C0-1 - CX-1

The diffusion code CITATION is applied for calculation of criticality and neutron flux distribution. It is fed with macroscopic cross sections being prepared from collapsed microscopic cross sections and from atom densities at any time step defined by the input. Actually the input for CITATION is described in Ref. /15/. A great deal of the input, however, is prepared internally by the VSOP, BIRGIT (2-dim.), TRIGIT (3-dim.). Just few input data must be given by the user, and we describe them in the following. They must be given only for the first call of CITATION in a VSOP run (or in a restart case), and they are internally preserved for the repeated calls of CITATION during the run.

2.4.7.1 Memory location. C0-1 - C0-3

Card C0-1		Format (2I6)
1	N	> 0: Dimension reserved for data storage (words). < 0: |N| gives the dimension in units of 1000 words.
2	NGEO	> 0: Unit number from which the BIRGIT data for the geometric design of the reactor are to be read. = 0: Unit number = 37 (compare BIRGIT-Input card BI1)

Each individual case is to have two title cards at the beginning.

Card C0-2		Format (18A4)
1 : 18	B(I), I = 1,18	First literal description of case.

Card C0-3		Format (18A4)
1 : 18	B(I), I = 1,18	Second literal description of case.

2.4.7.2 General options. C1-1 - C1-5

Card C1-1		Format (I3)
1	IOPT	001

Control options

Card C1-2		Format (24I3)
1	NGC1	0
2	NGC2	0
3	NGC3	= 0: No effect. > 0: Option to write data on logical device 35 to permit re-start.

4	NGC4	0
5	NGC5	= 0: No effect. = 1: Save macroscopic cross sections on logical device 31.
6	NGC6	= 0: No effect. > 0: Option to write neutron flux map on I/O logical device 21.
7	NGC7	= 0: No effect. = 1: Option to write power density map on I/O logical device 32.
8	NGC8	0
9	NGC9	0
10	NGC10	Type of eigenvalue problem. = 0: Effective multiplication factor calculation. = -5: Fixed source (read cards C26-1, 2, 3, 6).
11 : 14	NGC11 : NGC14	0 0
15	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 cards C1-3 and C1-4 below). = 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.
16 : 18	NGC16 : NGC18	0 0
19	NGC19	Macroscopic cross section option. = 0: No effect. > 0: Only macroscopic cross sections input in section 008 will be used.
20 : 22	NGC20 : NGC22	0 0

23	NGC23	= 0: No effect. > 0: Used to force I/O for iterative problems, generally not used.
24	NGC24	= 0: No effect. = -1: Define unisotropic diffusion constants on the cards C7-1 - C7-6. This allows diffusion calculation in void areas as present in the pebble bed reactor.

Edit Options.

Card C1-3		Format (2413)
1	IEDG1	0
2	IEDG2	0
3	IEDG3	= 0: No effect. > 0: Print macroscopic group-to-group transfer cross sections.
4	IEDG4	= 0: No effect. > 0: Print macroscopic reaction rate cross sections.
5	IEDG5	= 0: No effect. > 0: Print gross neutron balance over system by group.
6	IEDG6	= 0: No effect. > 0: Print gross neutron balance by zone by group.
7	IEDG7	0
8	IEDG8	0
9	IEDG9	= 0: No effect. > 0: Print zone average flux values by group. (IEDG6 = 0)
10	IEDG10	= 0: No effect. > 0: Print point flux values by group.
11	IEDG11	0
12	IEDG12	= 0: No effect. > 0: Print zone average power densities.

13	IEDG13	= 0: No effect. > 0: Print relative power density traverses through peak.
14	IEDG14	= 0: No effect. > 0: Print point power densities.
15 : 24	IEDG15 : IEDG24	0 0

General Iteration Count and Machine Time Limits.

The first numbers on this card C1-4 are the iteration count limits for the various loop calculations. Problems are terminated when the iteration count reaches the limit and the calculation proceeds as per NGC15 (see card C1-2). For a statics problem (no depletion or dynamics) only the items ITMX1, ITMX19 and ITMX21 apply.

Card C1-4		Format (24I3)
1	ITMX1	> 0: Maximum number of initial eigenvalue problem iteration. If the demand is greater than 999 iterations, it can be redefined: ITMX1 = IJK. If I = 8 and JK > 0 it is redefined as ITMX1 = I * 100 * JK. = 0: Default value = 200
2 : 18	ITMX2 : ITMX18	0 0
		The following items are the machine time limits (min) for the various loop calculations and also total computer time limit; generally calculations continue if time is exceeded as if convergence criteria had been satisfied.
19	ITMX19	> 0: Limit for the initial eigenvalue problem. = 0: Default value = 60
20	ITMX20	> 0: Limit for all other eigenvalue problems. = 0: Default value = 30
21	ITMX21	> 0: Limit of any reactivity loop. = 0: Default value = 60

22	ITMX22	0
23	ITMX23	0
24	ITMX24	> 0: Limit of total machine time. = 0: Default value = 120

General Restraints

Card C1-5		Format (6E12.0)
		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 = 0.5
3	GLIM3	0.
:	:	
6	GLIM6	0.

2.4.7.3 Description of neutron flux problem. C3-1 - C3-4

Card C3-1		Format (I3)
1	IOPT	003

General Description.

Card C3-2		Format (24I3)
1	NUACI	Type of flux approximation.

		= 0: Finite-difference diffusion theory.
2	NUAC2	= 0: Use available flux, multiplication factor and acceleration parameters from the previous calculation.
3	NUAC3	0
4	NUAC4	0
5	NUAC5	Geometry option. = 7: Two-dimensional cylinder. (r,z) = 11: Three-dimensional slab. (x,y,z)
6	NUAC6	0
7	NUAC7	0
8	NUAC8	Indicator of two-dimensional diagonal symmetry (on planes if 3-D). Set to 0 if NUAC11 = -1. = 0: No effect. > 0: There is symmetry about the diagonal starting at the upper lefthand corner and there are the same number of rows and columns. < 0: There is inverted diagonal symmetry.
9	NUAC9	Indicator of two-dimensional symmetry along column slices for 3-D problems only, see options above (NUAC8).
10	NUAC10	0 **Note:** 2-dim.: r = left → right z = top → bottom 3-dim.: x = left → right y = front → back z = top → bottom
11	NUAC11	Left boundary condition (required for 1-D, 2-D, 3-D). = -1: Periodic. = 0: Extrapolated (vacuum). = 1: Reflected.
12	NUAC12	Top boundary condition (required for 2-D, 3-D). = 0: Extrapolated. = 1: Reflected.
13	NUAC13	Right boundary condition (required for 1-D, 2-D, 3-D). Set to -1 if NUAC11 is -1.

		= 0: Extrapolated. = 1: Reflected. = 3: Inverted reflection (180 ° rotational symmetrie).
14	NUAC14	Bottom boundary condition (required for 2-D, 3-D). = 0: Extrapolated. = 1: Reflected.
15	NUAC15	Front boundary condition (required for 3-D). = 0: Extrapolated. = 1: Reflected.
16	NUAC16	Back boundary condition (required for 3-D). < 10: Extrapolated. ≥ 10: Reflected.
17	NUAC17	Number of zone to be an internal black absorber and have the non-return boundary condition applied at its edges (see XMIS2 on card C3-4; this zone will be black to all groups unless additional data are supplied). NUAC17 can be > 999, since NUAC16 has been modified in its format to ≷ 10.
18	NUAC18	= 0: Only positive neutron flux allowed. > 0: Option to allow negative neutron flux.
19	NUAC19	= 0: No effect. > 0: Override use of Chebychev polynomials in adjusting the acceleration parameters.
20	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 relax 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.
21	NUAC21	0
22	NUAC22	0
23	NUAC23	Specified number of inner iterations. Normally not specified (see NUAC20 above).
24	NUAC24	0

Iteration Convergence Criteria.

Card C3-3		Format (6E12.0)
1	EPI1	Maximum relative flux change for the last iteration of each initialization eigenvalue problem. (0.0001)
2	EPI2	Maximum relative change in the eigenvalue for the last iteration of eigenvalue problems. This applies to the multiplication factor calculation. (0.00001)
3	EPI3	0.
4	EPI4	Replaces EPI1 for all eigenvalue problems except those for initialization or static calculations. (0.0001)
5	EPI5	0.
6	EPI6	0.

Miscellaneous Data.

Card C3-4		Format (6E12.0)
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 C3-2).
2	XMIS2	Internal black absorber boundary constant for the zone NUAC17. *) = 0.: In connection with NUAC17 > 0 on card C3-2 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	XMIS3	Core power level. (MW_{th}) Use 0, because the core power is an internal data transfer from VSOP to CITATION.
4	XMIS4	Conversion factor, ratio of thermal energy to fission energy.

5	XMIS5	1.
6	XMIS6	Initial overrelaxation factor. Normally calculated by the code and not specified here.

*) $-\frac{D}{\phi} \cdot \frac{\partial \phi}{\partial x}$

2.4.7.4 Diffusion calculation in void areas. C7-1 - C7-6

Cards C7-1 - C7-6 only when NGC24 = -1 on card C1-2.

Card C7-1		Format (2I6)
1	JH	Number of void areas (card C7-2). (≤ 6)
2	KH	Number of different sets of void cross sections (cards C7-3, C7-4). (≤ 5)

Card C7-2		Format (18I4)
1	IZONE(J),	Id.no. of void cross section set to be inserted into the J. void area.
2	M1(J,1),	First CITATION zone located in the J. void area.
3 .	M1(J,2), J = 1,JH	Last CITATION zone located in the J. void area.

One set of cards C7-3 - C7-6 for each of the K = 1,KH void cross section sets.

Card C7-3		Format (6E12.5)
1	SGA(K,I),	Macroscopic absorption cross sections of the energy groups

:	I = 1,N26	I.

Card C7-4		Format (6E12.5)
1 :	SGR(K,I), I = 1,N26	Macroscopic removal cross sections of the energy groups I.

Card C7-5		Format (3E12.5,I3)
1	RDK(K)	Thickness of this void in radial dimension. (cm)
2	V2(K,1)	Factor to be multiplied to the diffusion coefficient in radial dimension.
3	V2(K,2)	Factor to be multiplied to the diffusion coefficient in axial dimension.
4	IKEN	= 0: No effect. > 0: Group dependent factors will be defined on card C7-6.

Card C7-6 only when IKEN > 0 on card C7-5.

Card C7-6		Format (6E12.5)
1 : N26	FKEN(K,I), I = 1,N26	Energy group dependent factors to be multiplied to the V2 of card C7-5.

2.4.7.5 Fixed source. C26-1, 2, 3, 6

Cards C26-1, 2, 3, 6 only when NGC10 = -5 on card C1-2.

Card C26-1		Format (I3)
1	IOPT	026

Card C26-2		Format (2I3)
1	NFX1	= -1: Fixed source is specified by zones (drop the cards C26-4 and C26-5).
2	NFX2	= 0: Short output. > 0: Source (n/sec) will edited by mesh points.

Card C26-3		Format (6E12.5)
1 : N26	V1F(I), I = 1,N26	Fraction 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.

Card C26-6		Format (6(I3,E9.3))
1	N2F(I),	> 0: Zone number. = 0: End of the input of section 26.
2 . .	V2F(I), . I = 1, ...	Fixed source. (n/sec-cm^3)

2.4.7.6 Location of the reflector edges. CX-1

Card CX-1 defines the location of the edges of the reflectors in order to print the maximum neutron dose.

Card CX-1		Format (12I6)
1	ITR	No. of the lowest mesh of the top reflector.

2	IBR	No. of the upper mesh of the bottom reflector.
3	JRR	No. of the inner mesh of the outer radial reflector.
4	JIR	No. of the outer mesh of the inner reflector column.

2.4.8 Fuel cycle costs calculation. K1 - K12

Cards K1-K12 only when NKOST > 0 on card V10.

Card K1		Format (10I4,A4,I4,A4)
1	IDCOST	Identification number for the cost library to be prepared. It will contain the reactor burnup history for KPD-cost calculations.
2	NCD	= 0: No cost library will be prepared. > 0: Data set reference number for the cost library. (Sequential data set on magnetic tape or private disk) = 40: Direct access data set must be //G.FT40F001.
3	NMAF	Number of burnup cycles for which burnup data are supplied. The length of approach to equilibrium phase is assumed to be equal to NMAF burnup cycles. NMAF may be overridden by information contained within burnup data.
4	MXTYP	Number of different fuel types in the system (≤ 10). For each type a set of cards K7-K10 is required.
5	ND2O	= 0: Normal. > 0: Heavy water moderated reactor and D_2O expenditures included in cost calculation. Card K12 required. (This option may be used to simulate capital costs of power plant).
6	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.
7	IPRINT	= 0: Print-out without materials balance for each batch.

		= 1: Print-out includes materials balance.
8	ICARD	= 0: Normal, only of significance for restart cases.
9	IQ	= 0: Normal. > 0: Calculate average equilibrium FCC over the last IQ periods (Ref/18/, Section 3.5).Recommended when the accounting period is shorter than the irradiated time of the fuel to obtain representative FCC for the equilibrium cycle.
10	NEWCO	= 0: Neglect financing cost of fresh out-of-pile batches class = 1. (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 R3.
11	$	Monetary unit in which input is supplied. The user specifies the 4 character alphanumeric designation to be used in print-out, e.g. DM or US$.
12	X	The energy cost is calculated in units of $$ (see below) and X is the conversion from $ to $$. E.g. 100 means $ = 100 $$.
13	$$	Monetary unit in which energy costs is calculated and printed in output, e.g. Dpf or Mill.

Card K2		Format (6E12.5)
1	F	Annual load factor. Same as AAAA on card R2.
2	ETA	Net efficiency of power plant.
3	GLD	> 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 is defined to be the equilibrium period and repeated till the end of plant operation. For D_2O cost calculation GLD is taken as amortisation time for heavy water investments. < 0.: Drop average FCC calculation.

4	GMZ	Number of instalments 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_2O 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 levelising 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 (6E12.5)
1	SS	Tax rate (1/a) on fissile investments.
2	RES	Reserve factor (RES = 1 + 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. Blanc = 1.0 .
3	VERL	Recovery factor for reprocessing. (0.97 - 0.99)

4	YPA	Fraction of discharged ^{233}Pa decaying into ^{233}U during out-of-pile storage (normally = 1.0). When using VSOP and having defined storage and reprocessing time, the amount of ^{233}U reaching the reprocessing plant has already been explicitely accounted for, then YPA = 0. (^{239}Np is assumed to decay completely into ^{239}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. Normally the out-of-pile time will be the same as cycle length and TOUT = -1. Will cause 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}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 U_3O_8 ($/lb U_3O_8). The price is given as per lb corresponding to common use in literature.
2	CO8F6	Cost of conversion of U_3O_8 to UF_6 ($/kg U). The enriched end product is in the form UF_6, the costs of converting the hexafluoride into UO_2 or any other compound, are included in the fabrication costs.
3	CTRENN	Separation cost. ($/SWU)
4	TAIL	Tail enrichment, i.e., ^{235}U content in discarded uranium from diffusion plant; at present = 0.003, but likely to be 0.0025 in the future.
5	XLOSS1	Losses in conversion of U_3O_8 to UF_6 (typically 0.5 - 1.0%).
6	XLOSS2	Losses in conversion of enriched UF_6 to UO_2 or UC and in fabrication (typically 0.5 - 1.0%).

Card K6 is always required. The costs of fresh ^{232}Th, ^{233}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 utilisation and for each fuel type depreciation factors are specified on cards K8.

Card K6		Format (6E12.5)
1	CTH232	Cost of ^{232}Th ($/kg), at present 10 $/kg.
2	CU233	≥ 0.: Cost of fissile ^{233}U. ($/kg) < 0.: Cost of ^{233}U is calculated relative to cost of 93% enriched ^{235}U with ABS(CU233) as parity value. Cost(^{233}U) = ABS(CU233) * Cost(93% ^{235}U)
3	CPUFIS	≥ 0.: Cost of fissile ^{239}Pu and 241. ($/kg) < 0.: Cost of Pu-fission relative to cost of 93% ^{235}U with parity value ABS(CPUFIS).

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

Card K7		Format (6E12.5)
1	ANSM	Type of heavy metal: 1.: Th(met.), 2.: ThO_2, 3.: ThC, 4.: ThC_2, 5.: U(met.), 6.: UO_2, 7.: UC, 8.: UC_2.
2	CU5	Initial reference enrichment of ^{235}U, in uranium (next word CU8 ≤ 0.). 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. Cost of ^{235}U ($/kg) when next word CU8 > 0. Price kept constant during calculation.
3	CU8	≤ 0.: Cost of ^{238}U = 0., and cost of ^{235}U calculated from batch enrichment and card K5. > 0.: Cost of ^{238}U ($/kg). Supply ^{235}U cost as specified above. This option operates only when CU8 > 0. for all types!
4	CFAB	≥ 0.: Fuel fabrication cost ($/kg HM) excluding cost of heavy metal. Monetary unit is $ as specified on card K1 and given per kg initial HM in fuel element.

		< 0.: Use data which are given on data set 29 for this fuel element type.
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.: Use data which are given on data set 29 for this fuel element type. 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 (6E12.5)
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 ^{233}U has no value. > 0.: Discharged ^{233}U cost depreciated by factor CHIU3.
3	CHIU	= 0.: Discharged ^{235}U has no value. > 0.: Discharged ^{235}U cost - for actual enrichment in depleted fuel - depreciated by factor CHIU.
4	CHIPU	= 0.: Discharged fissile ^{239}Pu and 241 has no value. > 0.: Discharged Pu-fissile cost depreciated by factor CHIPU.
Card K9		Format (6E12.5)
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 (typically 1 - 1.5 y).
2	TIN	Lead-time (d) for payment of enrichment service and conversion costs for fuel replacement relative to fuel loading (typically 0.5 - 1.0 y). Also lead-time for purchase of ^{233}U and

		fissile plutonium.
3	TFAB	Lead-time (d) for payment of fabrication costs for replacement fuel relative to fuel loading (typically 0.5 - 1.0 y). The lead time for D_2O 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 (typically 0.5 - 1.0 y).
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. (Typically 0.5 - 1.0 y).

Card K10		Format (6E12.5)
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 when NPUFD > 0 on card K1.

Card K11		Format (6E12.5)
1 : NMAF	UUKOST(1) . .	Fuel cycle cost ($\$/KW_h$) 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).
	UUKOST (NMAF)	The FCC for the U-cycle must be specified for all periods NMAF. This calculation allows for NMAF < 30 only. Continuation cards if necessary.

Card K12 only when ND2O > 0 on card K1.

Card K12		Format (6E12.5)
1	DOUTIN	Weight (kg) of total D_2O in-pile and out-of-pile inventory. (D_2O cost calculations may be used to simulate amortization of capital investment for the plant. The capital is then paid in instalments at the beginning of each cycle or accounting period, in such a way that the instalments levelised over the life-time GLD give the total present worth value at the time of start-up. In this case DOUTIN could be interpreted as KW(e) of the power plant.)
2	CDNEU	Cost ($/kg) of new D_2O. (Capital cost including interest during construction at time of start-up in $/KW(e).)
3	CDALT	Cost ($/kg) of old D_2O (0., i.e., no value of station end-of-life).
4	ZD	Interest rate (1/a) on D_2O investments (or capital costs).
5	SD	Tax rate (1/a) on D_2O investments (or capital costs).
6	VD	D_2O losses per year (normally 0.01). It is assumed that the D_2O replacement expenditures have the same lead-time and interest rate as fabrication costs. (0.0 in case of plant cost).

2.4.9 Fuel management. R1 - R36

Cards R1-R36 only when NRSTRT > 0 on card V10.

2.4.9.1 General definitions. R1 - R3

Card R1 only when NRSTRT = 3 or 4 on card V10, i.e. for fuel management with reprocessing.

Card R1		Format (6E12.5)
1	XREPRO(I),	Reprocessing factor for material no. I.

: KMAT	I = 1,KMAT	The reprocessing plant is simulated by reprocessing factors multiplied to the different nuclides. The decay of ^{233}Pa and ^{239}Np is calculated for period TREPRO (card R2). The reprocessing factors are defined as: 1.00 = No losses. 0.00 = Complete removal. 0.95 = 5% loss during reprocessing, etc. Data must be specified for all KMAT (card V3) nuclides. The same reprocessing factors apply to all batches. Continuation cards if necessary.

Card R2		Format (6E12.5)
1	TDOWN	> 0.: Length of downtime during reload (days). The decay of ^{233}Pa, ^{239}Np and ^{135}Xe are calculated for all in-core batches. < 0.: The fraction |TDOWN| of the duration of the preceding burnup cycle is used as downtime.
2	TSTORE	> 0.: Length of out-of-pile storage time (days) before reusing the fuel. Decay is calculated for all out-of-pile batches, except those of class 1 (fresh) and class 0 (scrap). Financing costs are paid during time TSTORE. The irradiation age of a batch is increased by TSTORE /AAAA, i.e. in full power days. < 0.: TSTORE is set equal to the period between two successive reloads, so that out-of-pile fuel is reloaded after one cycle.
3	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.
4	AAAA	Load factor of power plant. When fuel cycle costs are evaluated, same as F on card K2 in cost input.
5	BRUCH	Failure rate of discharged fuel (pebble bed reactor only). In each discharged batch a fraction BRUCH is assumed non-reusable and added to the scrap batches.
6	AGEBOX	= 0.: No effect. = 1.: Aging boxes for reprocessing mixtures will be specified.

		Card R7 is required.

Card R3		Format (1814)
1	KUGL	= 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, check on discharge burnup, and handling of discarded scrap fuel. = 2: Reactor with out-of-pile cycle: As above, fuel may be replaced in any core position.
2 . .	KLASSE(J), J = 1,JTYP	> 0: No. of burnup classes of fuel type J. The fuel of each type is subdivided into burnup classes. Class 1 is fresh fuel. A total of 20 classes are allowed for all 10 types, this means that either one type with 20 classes or many types with a variable number of classes may be specified. = 0: Code assumes one class and defines Fima limit = 0. No cards R4 are required.

2.4.9.2 Data for individual fuel types. R4 - R6

Cards R4-R6 only when KUGL > 0 on card R3. The cards are supplied as a set for each fuel type, i.e. JTYP sets.

Card R4 is skipped, if for this fuel type the number of burnup classes, KLASSE on card R3, has been specified = 0. The code assumes KLASSE = 1 and FIMAKL(1) = 0.

Card R4		Format (6E12.5)
1	FIMAKL(1)	Upper Fima limit for burnup class 1 of this fuel type. The lower limit for class 1 is defined as 0. by the code. The Fima values are used only to discriminate the classes and not to determine fuel burnup in MWd/t. The definition of Fima in a batch at time t:

		Fima(t) = |HM(t) - HM(0)| / HM(0).
2	FIMAKL(2)	Upper Fima limit class 2.
. .	FIMAKL (KLASSE)	Upper Fima limit last class, KLASSE, of this fuel type.

Definition of fresh fuel store, class = 1.

Card R5 Format (4(I6,E12.5))

1	NTP1	Fuel type no.
2	PARVL1	Volume (cm^3) of fuel store. The choice of fuel volume is arbitrary as long as no financing cost of fresh fuel store is calculated (see KPD report). 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. When requiring more fuel from the store than actually present, the store is regarded as unlimited. Fuel removed from the store does not change the remaining volume, neither does the isotopic composition change during reactor life.
3	NISO	> 0: Number of isotopes on the following cards R6. The composition of fresh fuel is specified by NISO and the cards R6. Isotopic concentrations are zero, except those mentioned on cards R6. = 0: Cards R6 are skipped for this fuel type, and PARVL1 = 0. < -100: Composition of fresh fuel store is defined in DATA-2 (cp. NFUTYP on card D6). ABS(NISO) specifies fuel with 4 digits IJKL: IJ = Fuel type id.no. KL = Variant of type IJ characterizing enrichment variant.
4	XMARX	No. of the reprocessing mixture to which scrapped fuel of this type belongs. Discharged fuel is combined to reprocessing mixtures, 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 used for refuelling. XMARX ≤ 10.

		If AGEBOX > 0. (card R2) this reprocessing mixture is transfered to its corresponding aging box(es). If for all types XMARX = 0., no reprocessing mixtures are prepared.

Card R6 only when NISO > 0 on card R5.

Card R6		Format (4(I6,E12.5))
1	L	Id.no. according to VSOP list of first nuclide with atom density ≠ 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.
		Continuation cards if necessary.

2.4.9.3 Aging boxes for discharged fuel. R7

Card R7 only when AGEBOX > 0. on card R2.

Card R7		Format (18I4)
1 : MREP	NAJB(J), J = 1,MREP	Number of aging boxes plus one jumble box to be defined for the J. reprocessing mixture. MREP is the total number of reprocessing mixtures being defined by the XMARX sequence on card R5. NAJB ≤ 10. Note: 1. Discarded scrap fuel from the reactor is loaded into the reprocessing mixture box J. 2. It is transfered to the corresponding first aging box. 3. Aging boxes are stepwise transfered to the next higher ones.

		4. Those with an age ≥ TREPRO (card R2) are transfered to the corresponding jumble box J. 5. If NAJB(J) = 1, the reprocessing mixture box J is immediately given to the jumble box. 6. A fraction FOJB(J) (card R15) of the jumble box is inserted into the reprocessing mixture box J. It is ready for use at the next reload, which will be performed after the following burnup cycle. 7. That fraction which is not used, is returned to the jumble box J.

2.4.9.4 Instructions for one burnup cycle. R8 - R36

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 R8 only when IRR9 > 0 on card V2, 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 have been given at the last card R9 of the preceding run.

Card R8		Format (12I3,3E12.5)
1	IPRIN(1)	Same as on card R9.
2	IPRIN(2)	Same as on card R9.
3	IPRIN(3)	Same as on card R9. (-2: Doesn't work).
4	IPRIN(4)	Same as on card R9.
5	NNSTOP	= 0: No effect. > 0: Number of large time steps per burnup cycle, i.e. redefinition of JNSTOP (cards V16 and R14).
6	NNUM	= 0: No effect. > 0: Number of small time steps per large time step, i.e. redefinition of JNUM (cards V16 and R14).
7	IXEN	= 0: ^{135}Xe equilibrium. > 0: Explicite ^{135}I and ^{135}Xe calculation.

8	NIAVC	= 0: No Change of the option of average fuel cycle cost calculation. = 1: Drop average FCC calculation. = -1: Calculate average FCC.
9	IBUC	= 0: Leakage feed back option unchanged. = 1: Feedback of broad group bucklings to GAM and thermal leakage to THERMOS. = 2: Feedback of average epithermal buckling to GAM and thermal leakage to THERMOS. = 3: No feed back at all.
10	MUHU3	= 0: Streaming correction option unchanged. = 2: Streaming correction LIEBEROTH /34/ in power generating batches (only for pebble bed). = 3: No streaming correction at all.
11	NOCPA	= 0: Option of control poison adjustment unchanged. < 0: If in the preceding cycle control poison adjustment was calculated, it can be stopped here. (Code sets JSER = 1).
12	IVSP11	= 0: No change of diffusion calculation option. > 0: Repeat diffusion calculation as defined by the IDIFF on cards V23/R17. < 0: Drop diffusion calculation. **Note:** Prior to the first diffusion calculation of a restart the code requires cards C0-1 - CX-1 (Section 3.4.2).
13	XDAY	Same as DELDAY on cards V15 and R14.
14	XPOW	Same as POWER on cards V15 and R14.
15	XKAY	Same as ZKFIND on cards V15 and R14.

Card R9		Format (24I3)
1	IVSP(1)	≤ 1: The information of this card holds only for this shuffling and for the following burnup cycle. > 1: The information of this card holds for IVSP(1) shufflings and burnup cycles. The items 2 ... 11 are kept, the others are set to 0.

		Output options:
2	IPRIN(1)	Spectrum calculation (same as on card V21): = 0: Thermal selfshielding factors, only. = 1: Same as 0, plus averaged thermal cross sections. = 2: Same as 1, plus fine group neutron fluxes. = 3: Same as 2, plus broad groups averaged cross sections for materials with concentration > 0. = 4: Same as 3, for all materials.
3	IPRIN(2)	= 0: No output. = 1: Printout of the irradiation time of the batches. = 2: Same as 1, plus atom densities (only in combination with IPRIN(3) ≥ 0).
4	IPRIN(3)	Burnup calculation (same as on card V21): = -2: All output dropped (submitted to a dummy data set 4) except K_{eff}. = -1: Global neutronic balance. = 0: Detailed neutronic balance. = 1: Same as 0, plus characteristics of the N200 fuel batches
5	NPRINT	Fuel management operations at this reload: = -1: No fuel management output. = 0: Short summary. = 1: List of all operations (recommended). = 2: Detailed printout including atom densities in all batches before and after reload (very much!).
6	IPRINT	Fuel cycle costs calculation (same as on card K1): = 0: Printout without materials balance for each batch. = 1: Printout includes materials balance.
7	JTIK	VSOP - THERMIX: = 0: Minimum output. = 1: Thermal properties of the VSOP - layers.
8	IN2	= 0: No effect. > 0: No. of the burnup time step for which a list of performance data will be printed. < 0: Print neutron balance averaged over the cycle.
		Steering the calculational performance:
9	IPRIN(4)	= 0: Skip spectrum calculation if a set of cross sections is available. Instructions on cards V22/R16 are neglected. = 1: Repeat spectrum calculation as defined on cards V22 R16.

		= 2: Same as 1, but only for the thermal spectrum. = 3: Same as 1, but not for zones without heavy metal (reflectors). = 4: Same as 2, but not for zones without heavy metal (reflectors).
10	IVSP(11)	= 0: Drop diffusion calculation. > 0: Repeat diffusion calculation as defined by the IDIFF on cards V23/R17.
11	N44	= 0: No effect (2-dim. cases). > 0: Data set number for ATLAS-library (only for 3-dim. cases). It must be defined when MUHU(8) > 0 at the end of this card.
12	NKEEP	NKEEP = L I J: J = 0: Use the previously defined fuel management scheme. = 1: Read a new fuel management scheme on the cards R24. = 2: Generate a new fuel management scheme with all batches staying in their position (no cards R24 are required). = 3: Generate a new fuel management scheme. Batches with individual fuel management instructions will be identified on cards R24. Non identified power generating batches will be shuffled to the next layer. Non-power generating batches (e.g. reflectors) stay in their position. = 4: Same as 3. Also the 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 R24 are due for all subsequent batches until redefined by a new card R24. Non-power generating batches (e.g. reflectors) stay in their positions. I = 0: Normal. = 1: Fuel management is preserved for ORIGEN (equilibrium cycle treatment) and explicite afterheat in THERMIX. = 2: Life history is preserved for afterheat calculation, starting from next cycle, on unit 60. = 3: Stop the preservation of the data for afterheat calculation. Last preserved data are from preceding cycle. L = 0: Normal. = 2: Life history is preserved for PRIOR/ORIGEN-JÜL-II on unit 39, starting from next cycle.

		= 3: Stop the preservation of the data for PRIOR/ORIGEN-JÜL-II. Last preserved data are from preceding cycle.
13	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 burn-up cycle. Read card R15.
		Redefinitions:
14	IVOID	= 0: No effect. = 1: Redefinition of void areas for CITATION on card R10.
15	IREDEF	= 0: No effect. = 1: Redefinitions of time steps, power, criticality constraints etc. on card R14.
16	IVSP(16)	= 0: No effect. = 1: Redefinition of time steps for spectrum calculation. Give ISPEKT on card R16 (same as card V22).
17	IVSP(17)	= 0: No effect. = 1: Redefinition of time steps for diffusion calculation. Give IDIFF on card R17 (same as card V23).
18	IRETEM	= 0: No effect. = 1: Redefinition of temperatures of the spectrum zones. Read cards R19, R20 (same as card G2 and NKER cards T3). = 2: Read new resonance integral definition on cards R21 (same as cards G4). = 3: Includes both options 1 and 2.
19	NTIK	NTIK = I J K: K = 0: No effect. > 0: Perform temperature calculation. = 1: Read new time steps ITEMP on card R18, and read new input for THERMIX on cards TX1-TX23, KX1 - KX5. = 2: Read new ITEMP on card R18, use previous THERMIX input. = 3: Use previous ITEMP, and give new THERMIX input. = 4: Use previous ITEMP, previous THERMIX input. J > 0: THERMIX calculation. = 1: One single THERMIX calculation at each time step

		given by the ITEMP. > 1: Time dependent THERMIX parallel to the VSOP (input sequence: cards TX1 - TX4, TX17 - TX23, KX1 - KX5). = 2: Apply the power distribution of the individual time step and the afterheat. = 3: Power for THERMIX is only the afterheat. = 5: Same as under 2, read cards R11, R12, R13, but R13 only at the beginning of THERMIX. Adjustment of the power for given K_{eff}. = 6: Same as under 5, but read card R13 anyway (the counting of THERMIX-runs starts again from ITIK(1) = 0). I = 0: No effect. Use the information of the given THERMIX-KONVEK input. = 1: Submit new KONVEK input.
20	LIB	= 0: No effect. > 0: Write library 'status of core' for TINTE /6/ on data set 19 at time step LIB prior to the spectrum and diffusion calculation. Read card R35. < 0: For each batch write atom densities on direct access unit 28.
21	LOB	Dummy.
22	MUHU(1)	= 0: No effect. > 0: Extracted number of nuclides (≤ 20) for the output of atom densities at the end of the burnup cycle. Read id.-numbers NUPRI(I) on card(s) R36. **Note:** Printout according to the option IPRIN(2) (for all cases). Transfer to unit N44 according to MUHU(8) (only for 3-dim. cases).
23	IVSP(24)	= 0: No effect. > 0: Terminate the run after this fuel shuffling. The following burnup cycle will be the first cycle in a restart case.
24	MUHU(8)	= 0: No effect (2-dim. cases). > 0: No. of burnup time step. Batch data of 3-dim. cases are written to unit N44 which can be evaluated in the display code ATLAS (Section 2.9). Power, burnup, and thermal flux are written for the given burnup time step, atom densities (see MUHU(1)) and weight of materials for the end of the burnup cycle.

Card R10 only when IVOID = 1 on card R9 (only for the CITATION diffusion calculation).

Card R10		Format (18I4)
1	JII	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.void area (the void cross section sets are defined on the cards CZ-1 - CZ-6 of the CITATION).
.	MI(I, 1),	First CITATION layer located in the I. void area.
.	MI(I, 2), I = 1, JII	Last CITATION layer located in the I. void area.

Only for the time dependent THERMIX and adjustment of the power to achieve a given K_{eff}. Definition of the unit 58 is necessary.

Cards R11, R12 and R13 only when J = 5 or 6 in NTIK on card R9.

Card R11		Format (6E12.5)
1	ENDK	= 0.: Target K_{eff} of the beginning of the time dependent run is the last K_{eff} of VSOP. > 0.: New target K_{eff}.
2	QVOLLL	Power at the start of the time dependent run. (Watt)
3	QREMAX	Upper limitation of the power fraction in the power variation procedure (relative to the QVOLLL).
4	EPQ	Minimum of the power fraction.
5	EPC	Minimum of change of K_{eff} in two subsequent time steps for steering of recalculation of DQDDC (card R12).
6	URZ	= 0.: No effect. < 0.: Minimum THERMIX output.

Card R12		Format (6E12.5)
1	DQDDC	Starting guess for DQ/DC. DQ = Change of the relative power fraction in two subsequent time steps, DC = Corresponding change of the K_{eff} /DELDAY, i.e. Delta K_{eff} per day. (E.g. -0.02)
2	DELC	Starting guess for Delta K_{eff} per day. (E.g. -0.0019)
3	DCN	Starting guess for (K_{eff} - K_{eff} (linear extrapolation from the former time steps)) divided by DELDAY. (E.g. 0.025)
4	DQCMAX	Limitation of the free internal recalculation of DQDDC (see Subroutine QFIX).
5	PSPALT	= 0.: No effect. > 0.: Redefinition of the pressure in the gap compositions of THERMIX.
6	DMOT	> 0.: Factor of maximum change of DQDDC per time step. = 0.: Default value = 0.5 .

Card R13 only at the beginning of time dependent THERMIX.

Card R13		Format (2I3,5E12.5,I6)
1	JRESTW	= 0: No effect. > 0: Data set no. to which THERMIX restart data are to be written.
2	JRESTR	= 0: No effect. > 0: Data set no. from which THERMIX restart data are to be read.
3	Q0	Nuclear power fraction at the beginning.
4	QMI	Minimum of the nuclear power fraction during the transient.
5	QMA	Maximum of the nuclear power fraction during the transient.
6	QRAT	= 0.: No effect.

		≠ 0.: Relaxiation for the adjustment of EPQ (see Subroutine QFIX).
7	DAEM	Relaxiation for the DQDDC adjustment (see Subroutine QFIX). (E.g. 1.25)

Card R14 only when IREDEF = 1 on card R9.

Card R14		Format (4I3,3E12.5,4E6.0)
1	JNSTOP	= 0: No effect. > 0: Redefinition of the number of large burnup time steps per burnup cycle (card V16).
2	JNUM	= 0: No effect. > 0: Redefinition of small burnup time steps in one large step (card V16).
3	IVSP(27)	= 0: Streaming correction as defined before. = 2: Streaming correction by LIEBEROTH /34/.
4	IVSP(28)	= 0: ^{135}Xe equilibrium. > 0: Explicite ^{135}I - ^{135}Xe calculation, to be defined in each cycle, if desired.
5	DELDAY	= 0.: No effect. > 0.: Redefinition of the length of one large time step, days (card V15).
6	POWER	= 0.: No effect. > 0.: Redefinition of thermal core power, Watt (card V15).
7	ZKFIND	= 0.: No effect. > 0.: Redefinition of end of cycle - K_{eff} (card V15).
8	HNUC	= 0.: No effect. > 0.: Number of new atom densities to be read on card R22. (≤ 12)
9	HPOS	> 0.: Number of batches to be loaded with the new atom densities. (Read card(s) R23). = 0.: Insert additional materials in all power generating batches. = -1.: Read simplified input for control rods in x-y-z - cases

		on the cards R23a - R23d.
10	XTDOWN	= 0.: No effect. > 0.: Redefinition of length of down time during reload (TDOWN on card R2). < 0.: Set TDOWN = 0.
11	CONPOI	= 0.: No effect. > 0.: Read control poison adjustment data on cards R27 - R30. CONPOI gives the number of layers with control poison data. < 0.: Stop the control poison adjustments (JSER = 1).

Card R15 only when NCYC = 1 on card R9.

Card R15		Format (6E12.5)
I : MREP	FOJB(I), I = 1,MREP	≥ 0.: Volumetric fraction of the I. 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 to be removed from the I. jumble box is calculated by the code. ABS(FOJB(I)) gives the ratio: Volume to be loaded into the reprocessing mixture I/volume of the scrap fuel being sent to the first aging box.

Card R16 only when IVSP(16) = 1 on card R9.

Card R16		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. < 0: Same as > 0, but only for the thermal spectrum calculation.
2 : 18	ISPEKT(I), I = 2, 18	> 0: No. of further time steps for spectrum calculation. < 0: Same as > 0, but only for the thermal spectrum calculation. = 0: If all ISPEKT = 0, spectrum calculation is performed

		in every time step.

Card R17 only when IVSP(17) = 1 on card R9.

Card R17		Format (18I4)
1 : 18	IDIFF(I), I = 1, 18	If all IDIFF(I) = 0: Diffusion calculation is performed at every time step. If at least one IDIFF(I) ≠ 0: The IDIFF(I) give the time steps at which diffusion calculation is to be performed.

Card R18 only when NTIK (Digit K) = 1 or 2 on card R9.

Card R18		Format (18I4)
1 : 18	ITEMP(I), I = 1, 18	If all ITEMP(I) = 0: THERMIX-temperature calculation at every time step. If at least one ITEMP(I) ≠ 0: The ITEMP(I) give the time steps at which temperature calculation is to be performed.

A set of cards R19, R20 only when IRETEM = 1 or 3 on card R9.

Card R19		Format (6E12.5)
1 : NXS	SEMZUT(I), I = 1,NXS	> 0.: Temperature of the resonance absorbers in the NXS different spectrum calculations. °C (See NXS on card V3). = 0.: Temperature of the I. spectrum calculation stays unchanged. Continuation cards if necessary.

For each of the NKER scattering nuclides one set of cards R20.

Card R20		Format (6E12.5)
1 : NXS	SCELS(I), I = 1,NXS	> 0.: Temperature of this scattering nuclide for spectrum calculation I. °C (See NKER on card T1). = 0.: Temperature of the I. one stays unchanged. Continuation cards if necessary.

Cards R21 only when IRETEM = 2 or 3 on card R9. For each design a set of 2 cards R21.

Card R21		Format (12I6)
1	NZ	Number of resonance absorption cross section sets to be read from data set NGAM (card G1) for this fuel element design. First card contains information for ^{232}Th, second card for ^{238}U. (NZ ≤ 10)
2 . .	IZUT(K), K = 1,NZ	Id.-numbers of cross section sets which will be used for temperature interpolation. IZUT = 0: Just background cross sections for σ_a (E).

Card R22 only when HNUC > 0. on card R14.

Card R22		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. Continuation cards if necessary.

Card R23 only when IIPOS > 0. on card R14.

Card R23		Format (12I6)
I : IIPOS	IBAE(I), I = 1,IIPOS	New materials only in the individual batches IBAE(I). ($\leq$ 999) Continuation cards if necessary.

Cards R23a - R23d only when IIPOS = -1. on card R14.

Card R23a		Format (12I6)
1	NUCO	Number of control rods to be provided. ($\leq$ 30)
2	NUPL	Number of planes in the core for possible insertion of control rods.
3	NUFU	Number of fuel batches for which insertion of control materials (as given on card(s) R22) is treated simultaneously. ($\leq$ 5)
4	NURE	= 1: Control material is also inserted in reflector batches. = 0: No control material insertion in reflectors.
5	NUBPP	Number of batches per plane in the core.

Card R23b		Format (6E12.5)
1	FULENG	Height of a batch (z-direction) in which control materials can be added. (cm)
2	REFTH	Height of the reflector batch (cm). (Only when NURE = 1).
3	SPRING	Length of a non-absorbing part at the tips of the control rods (cm). This length must be included in the insertion depth given on card(s) R23d.

One card R23c for each of the I = 1,NUCO control rods.

Card R23c		Format (12I6)
I	ITOP(I)	< 0: Id.no. of reflector batch for insertion of control materials.
.	ITOC(I,N), N = 1,NUFU	Id.no. of fuel batches in the upper core plane for simultaneous loading of control materials. The id.no.'s of the corresponding batches in the lower planes (J = 2,NUPL) are prepared by the code by adding (J-1) * NUBPP.

Card R23d		Format (6E12.5)
I : NUCO	DEPTH(I), I = 1,NUCO	Insertion depth of the control rods, starting from the upper edge of the core (cm) (including the non-absorbing parts at the tips).

When NKEEP (Digit J) = 1 (on card R9) one full set of cards R24 - R26 for each of the NRESHZ different reload batches is required. This defines the FM-scheme. When NKEEP = 3 or 4, these cards are only required for batches with important instructions. Batches which are only shuffled downwards (NKEEP = 3) or stay in their position (= 4) do not need the card R24.

FM means "Fuel management".
TBP means "This batch position".
OPB means "Out of pile box".

Card R24		Format (2I5,I2,6I4,3E12.5)
1	IX1	= 0: Normal. > 0: When NKEEP = 3, 4 or 5: No. of batch position to which this card R24 (and R25, R26) refers. < 0: Last card R24 holding for the batch |IX1|.
2	NRX	= 0: Refuelling of this batch position TBP with fuel specified by I7, I8.

		> 0: Id.no. of a batch which is shuffled into TBP. > 10000: Load storage box no. (NRX - 10000) into TBP. (This storage box must have been filled up at a previous reload!). < 0: New atom densities are loaded into TBP. A set of ABS(NRX) densities are defined on cards R25. The fuel type identification is unchanged (not a recommended option).
3	NSB	= 0: Normal. > 0: No. of storage box into which this batch is to be filled. Data can be retrieved in all following reloads, until over-written by data stored in same box.
4	IX4	Four digits IJKL: IJ = MANAGE, KL = NREP. MANAGE = 0: Load fuel without any change into TBP. > 0: Fuel of an out of pile box OPB is used and treated (i.e. reprocessed and/or reenriched) and loaded into TBP. NREP = 0: No reprocessing. = 1: Reprocessing before loading into TBP. This option only when NRSTRT = 3 or 4 on card V10 and after having supplied cards R1.
5	MAKEUP	If NREP > 0 and/or NSPALT > 0: VSOP-id.no. of the isotope used as make up material in reprocessed and/or reenriched fuel. The heavy metal density of the new batch is adjusted to the initial value of the loaded fuel type. If MAKEUP = 0: No material is added thus defining a new heavy metal loading.
6	NSPALT	Number of materials for enrichment or reenrichment. A card R26 must follow.
The following part of card R24 is dependent on the option of **MANAGE**:		
MANAGE = 0:		
7	I7	= 0: Fuel type no. same as batch NRX. > 0: Fuel type to be loaded into TBP (only with out of pile

		FM, KUGL > 0 on card R3).
8	I8	If NRX > 0, I7 = 0, I8 = 0: In-core fuel shuffling or loading from a storage box. The fuel of the batch position NRX is loaded into TBP. NRX ≤ NRESHZ: In-core batch. NRX > NRESHZ: Storage box. If NRX = 0, I7 > 0, I8 = 1: Load fresh fuel of type I7. Storage unlimited. If NRX = 0, I7 > 0, I8 > 1: Load fuel of type I7, burnup class I8 (defined on card R4). Available amount is the disloading of the last reload. If more requested than available, fresh fuel of class 1 is added. If NRX = 0, I7 > 0, I8 = 0: Load scrap fuel of the last reload.
9	IR	= 0: Normal.
10	R1	= 0.: Fissile enrichment stays unchanged. > 0.: R1 defines a new enrichment for the loaded fuel. Only relevant if fresh fuel (class 1) is used.
11	R2	When NRX > 0, NRX ≤ NRESHZ (use of in-core batches): = 0.: New volume for TBP is given by the inserted batch NRX. > 0.: R2 is the fraction of the in-core batch to be inserted into TBP. When NRX > NRESHZ (use of storage boxes): = 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 of the layer's volume. > 0.: R2 is the fraction of the storage box to be inserted into TBP. When NRX = 0: > 0.: Fraction of the total volume of the out of pile fuel of type I7, class I8 to be loaded into TBP. If KUGL = 1 (on card R3) the volume of all batch positions in the upper layer is automatically limited to the layer's volume. The fresh fuel store (class 1) is unlimited. For other OPB's the total volume reused for the present reload is limited to the volume of elements being available. Therefore, check the sum of all volumes of a given

		class for each reload. If not enough available, additional fuel of the same type and class is used for filling up. < 0.: ABS(R2) gives the fraction of that part of the volume of the out of pile fuel, which has been left over from the loading of preceding batch positions.
12	R3	= 0.: Normal. > 0.: New cross section set no. to be used for TBP. The option should be used when the fuel type in a batch position is exchanged by another type for which a different spectrum and cross section set is required.
MANAGE = 1:		
		Treated is the fuel disloaded at the last reload. Each fuel type I7, burnup class I8 forms a separate OPB. The available amount is the disloading of the last reload. Fresh fuel class 1 is unlimited. The new formed fuel type is also I7.
7	I7	No. of the fuel type.
8	I8	No. of the burnup class.
9	IR	= 0: Normal.
10	R1	Enrichment N_{fiss}/N_{HM} for the new formed elements.
11	R2	> 0.: Fraction of the total OPB volume to be treated and loaded into the volume of TBP. < 0.: The OPB volume fraction ABS(R2) is related to that part of the OPB volume, which has been left over from preceding loadings during the present fuel management step. If depletion would be necessary, the program reduces the OPB volume fraction R2 instead.
12	R3	= 0.: New volume of TBP is that one which has been made available from the OPB. > 0.: New volume of TBP is R3 * volume of the upper layer of the presently considered batch. = 1.: The upper layer is filled up. The new definition of the TBP volume immediately causes a corresponding change in the used OPB volume fraction R2. < 0.: The specified fraction of the OPB 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 = ABS (R3) * volume of the upper layer 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.
MANAGE = 2:		
		Treated is the content of a reprocessing mixture which is the considered OPB. It can optionally be loaded from a jumble box (comp. card R7 and NCYC on card R9). The content has been formed from the disloaded fuel of several fuel types (XMARX on card R5) and has been summed up over previous cycles.
7	I7	Id.no. of fresh fuel type of which the identification number, the heavy metal density and the atom densities of the new heavy metal nuclides are assigned to the here formed new fuel elements.
8	I8	Id.no. of the used reprocessing mixture.
9	IR	= 0: Normal.
10	R1	Same as under MANAGE = 1.
11	R2	Same as under MANAGE = 1.
12	R3	Same as under MANAGE = 1.
Card R25 only when NRX < 0 on card R24.		
Card R25		Format (4(I6,E12.5))
1,3,5 ...	NPX(J), J = 1,|NRX|	VSOP - id.no. of the J. nuclide with the atom density ≠ 0.
2,4,6 ...	CPX(J), J = 1,|NRX|	Atom density of the J. nuclide. If = 0. the nuclide needs not to be specified. Continuation cards if necessary.

Card R26 only when NSPALT > 0 on card R24.

Card R26 Format (4(I6,E12.5))

1,3,5 ...	IDFISS(J), J = 1,NSPALT	VSOP - id.no. of the J. nuclide used for reenrichment.
2,4,6 ...	FICOMP(J), J = 1,NSPALT	Relative fraction of the J. nuclide in the enrichment composition. The sum of all FICOMP in the composition must be 1. Only the fissile isotopes in FICOMP are used to calculate enrichments, so the composition may also contain fertile materials, for instance 0.93 ^{235}U and 0.07 ^{238}U. The original fissile/HM ratio in the batch before reenriching be YSPALT, the code distinguishes two different cases: Case 1: R1 > YSPALT, new material with the relative composition specified in FICOMP is added to make up the difference (R1 - YSPALT). Case 2: 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 R24) 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 reenrichment. 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 R24). For some types of reactors the heavy metal loading in a particular batch position may have to be varied during the lifetime of the reactor, for instance during the running-in phase.
		Continuation cards if necessary.

Cards R27 - R30 only when CONPOI > 0. on card R14.
One card R27 for each of the CONPOI layers with control poison data.

Card R27		Format (I12,2E12.5)
1	KR	Id. number of the considered layer.
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).
		Continuation cards if necessary.
Card R28 same as card V17.		
Card R29 same as card V18.		
Card R30 same as card V19.		

2.4.9.5 Criticality search for the reloads. R31 - R34

Cards R31 - R34 only when NRSTRT = 2 or 4 on card V10.

Card R31		Format (18I4)
1	JARIT	= 0: No iteration for this reload, skip cards R32 - R34. > 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 R33 are iterated to give reactivity K-search.
2 .	NCOL(I), I = 1,JARIT	Batch id.no. of the I. batch.
...	ITVAR	= 0: Normal. > 0: Use different sets of materials to increase resp. decrease enrichment to obtain correct K_{eff}. Two sets of cards R32 - R33: First set in case K-search > K_{eff} core, second set in case K-search < K_{eff} core. Code reads both sets of cards and selects in each case the required one.

...	IR16	= 0: Normal. > 0: Read card R34 with new heavy metal densities for iteration batches. IR16 is the number of batches in which 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 running-in phase.

If JARIT > 0 on card R31: At least one set of cards R32 - R33.
If ITVAR > 0 on card R31: Two sets of cards R32 - R33.

Card R32		Format (4(I6,E12.5))
1	ITMAT	Total number of materials iterated, i.e. length of materials list on card R33 ($\leq$ 13).
2	XKEFF	> 0.: k(o), reactivity specification for iteration search in cycle i. = 0.: Use same k(o) as beginning of last cycle, $k^i(o) = k^{i-1}(o)$. < 0.: Determine a k(o) value for beginning of next cycle so that the end of cycle reactivity k(min) is reached after the specified number of time steps JNSTOP. The extrapolation is made from $k^i(o) = (k^{i-1}(o) - k^{i-1}(JNSTOP)) + k(min) * ABS(XKEFF)$ and k(min) = ZKFIND (card V15). The value of XKEFF may be used to adjust for uncertainties in k(min). This is black magic.
3	MAKEUP	Material id.no. of nuclide to adjust heavy metal density in batches to either initial value in batch or as specified on card R34.
4	XTYPE	= 0.: Fuel type no. of batches is not altered (normal). > 0.: New fuel type no. for batches. Same no. is given to all batches for which iteration is performed.

Card R33		Format (4(I6,E12.5))
1	IDIT(1)	Material id.no. of first nuclide used in iteration.
2	COMPIT(1)	Relative fraction of first nuclide.

3	IDIT(2)	Material id.no. of second nuclide.
4	COMPIT(2)	Relative fraction of second nuclide.
.	.	
.	.	
		The relative fractions of all ITMAT (card R32) nuclides must be equal 1. If all COMPIT = 0., the existing relative fractions in the batches remain unaltered during iteration.

Card R34 only when IR16 > 0 on card R31.

Card R34		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.
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

2.4.9.6 "Status of core" for TINTE. R35

Card R35 only when LIB > 0 on card R9.

Card R35		Format (17A4,2I2)
1 : 17	TITEL(I), I = 1, 17	Literal description of the case to be transfered to the TINTE /6/ data set no. 19 .
18	MIX	= 0 or 1: Normal. > 1: Number of batches in each layer. Atom densities will be averaged and the data of the layers are given to the library.

2.4.9.7 Extracted nuclides for printout and/or transfer to unit N44 (3-dim. display code ATLAS). R36

Card R36 only when MUHU(I) > 0 on card R9.

Card R36		Format (12I6)
1 . .	NUPRI(I), I = 1,MUHU(i)	VSOP id.no. of nuclide for which printout and/or transfer to unit N44 is desired. Up to 20 nuclides can be specified.

2.4.10 TTTT, Preparing THERMOS-library. V1 - TTTT3

Sequence of input cards:

V1 - G5: VSOP input of case identification, use IDTHER = 0 on card G1

TERTT1, TERTT2: THERMALIZATION input without selfshielding factors.

T1: VSOP input, insert NUTTE = 0.

TTTT1 - TTTT3: Preparing new THERMOS library.

THERMALIZATION: Cards TERTT1 - TERTT2

Card TERTT1		Format (12I6)
1	JNTAPE	Id.no. of the thermal 96 groups library (THERMALIZATION).
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. Use continuation cards if necessary.

Card TERTT2		Format (6E12.5)
1	TOM	Temperature in calculation of Maxwellian neutron energy distribution for starting iterations of thermal spectrum. (°K)
2	EPSI	Criterion of convergency of flux iteration. (≈ 0.0001)
3	WAT	Acceleration of convergency: 0. = no, 1. = yes.
4	SSOPT	= 0.: No selfshielding factors are defined.

TTTT: Cards TTTT1 - TTTT3

Card TTTT1		Format (7I6,6X,E12.5)
1	JNTAPE	Id.no. of THERMALIZATION library.
2	IDTP	Id.no. of the THERMOS library to be generated.
3	ITTTT	> 0: Reduced output.
4	IEBE	Nuclide no. with full output.
5	ITUTEU	> 0: Print out of scattering matrices.
6	KERNE	Number of scattering matrices to be condensed for the THERMOS library. = 1000: Condensing of all scattering matrices.
7	ITOT	> 0: All absorbers.
8	T	Temperature (°K) for Maxwellian flux for eventually condensing absorbers.

Card TTTT2 only when KERNE ≠ 1000 on card TTTT1.

Card TTTT2		Format (12I6) ((IDKER(I,J), I = 1,2), J = 1,KERNE)
1	IDKER(1,ν)	GAM-id.no. of the ν-th scattering matrix.
2	IDKER(2,ν)	VSOP-id.no. of the ν-th scattering matrix.

Card TTTT3		Format (10I5/10I5/10I5) (3 cards)
1 .	NG(ν)	Number of the lower fine group for the new ν-th broad group to be formed.

2.5 THERMIX/KONVEK, 2d-Thermal Hydraulics. TX1 - KX5

Cards TX1 - TX23, KX1 - KX5

Card TX1		Format (F4.1,4X,16A4)
1	TXNEW	= 0.: New THERMIX input corresponding to subsequent input cards. = 1.: Old input cards (before the year 1994).
2 : 17	TITLE(I), I = 1,16	Literal description.

Card TX2		Format (18I4)
		Steering of the calculation:
1	IFKON	= 0: THERMIX calculation only, no KONVEK. **Note:** The input of KONVEK is needed anyway. ≠ 0: THERMIX-KONVEK coupling: = -1: Coupling between the temperatures of gas and solid material by heat transfer coefficient α. Recommended for steady state calculations, not valid in transient runs. = 1: Coupling via the source/sink distribution. = 2: Internal decision of coupling (not recommendable).
2	IIMAX	= 0: Temperature calculation in fuel elements by matrix-elimination (Gauss). > 0: Approach by iteration (Gauss-Seidel). Not valid for graphite spheres in transient runs.
3	IPRINT	= -2: Minimum output. = 1: Recommendable output. = 2: Maximum output. ≥ 3: In addition distribution of heat sources.
4	IPUN	= 0: No effect.

		= 3: Write restart on the data set no. IREST.
5	IFRSTA	= 0: No restart. > 0: Restart. Starting temperature distribution is read from data set IREST. (In case IREST = 0 the code requires the former input cards TH20 - TH22). Homogenized structure of fuel elements: = 1: Time starts at T = 0. = 2: Time scale continues. Heterogeneous structure of fuel elements: = 3: Time starts at T = 0. = 4: Time scale continues.
6	INTVAL	= 0: Steady state run. > 0: Number of time steps for the transient run. ($\leq$ 50) = 1: Coupling with VSOP: The time steps are given by the VSOP-burnup scheme (JNSTOP, DELDAY on card R14).
7	KOMVAR	= 0: Normal.
8	IFRED	= 0: Power distribution independent of the time. = 3: Explicite calculation of the decay heat according to the explicite life history of the fuel elements and to the DIN 25485. = 1: Decay heat function of OTTO scheme. = 2: Decay heat function of MEDUL or implicite formular $0.0622 * (T^{-0.2} - (T+T_0)^{-0.2})$.
		Iterations:
9	MITMAX	> 0: Maximum number of iterations of temperature calculation. = 0: Default value = 2000
10	IKORM	> 0: Maximum number of changes of the relaxiation factor. = 0: Default value = 100
11	IFREL	= 0: Inner iteration in radial direction (I). = 1: Inner iteration in axial direction (N).
12	ITLAM	> 0: Drop recalculation of temperature dependent material data for ITLAM−1 time steps (only for steady state THERMIX-KONVEK iteration). = 0: Default value = 10

13	NLOOP	> 0: Maximum number of THERMIX-KONVEK ("Loop") iterations (steady state). = 0: Default value = 100
		Datasets:
14	IREST	= 0: No effect. > 0: Data set no. for storing the temperature field of steady state THERMIX runs. Must also be defined in transient THERMIX run, starting from this temperature field.
15	IEXPR	= 0: No effect. > 0: Data set no. for temperature field for the 2D-plots.

Card TX3		Format (12F6.1)
1	QNORM	> 0.: Total power (MW). Input power field is normalized to QNORM. In transient run the QNORM defines the reactor power to which the decay heat is related. = 0.: Drop normalization.
2	Z0	Axial position of the upper edge of the reactor fuel zone (cm). (Normally = 0.)
3	ZU	Axial position of the lower edge of the reactor fuel zone (cm). (Height of the core)
4	ETHA	> 0.: Convergence criterium for local THERMIX temperature field. (°C) = 0.: Default value = 0.01
5	OVMAX	> 0.: Maximum relaxiation factor. = 0.: Default value = 1.7
6	OVMIN	> 0.: Minimum relaxiation factor. = 0.: Default value = 0.6
7	TDIFF	> 0.: Relative convergence criterium of the time independent THERMIX-KONVEK iteration. = 0.: Default value = 0.0005
8	EFAK	> 0.: Multiplication factor for maximum allowable error le-

		vel, which stops the run. = 0.: Default value = 1.
9	DTVOR	> 0.: Maximum of the relative temperature change $\Delta T / T$ < DTVOR in a time interval Δt of a transient run. The time intervals Δt are correspondingly adapted. = 0.: Default value = 0.05
10	ZEITMI	Minimum length of the time intervals Δt in the transient run.

Card TX4 only when INTVAL > 0 on card TX2.

Card TX4		Format (3(F6.1,2I2,E10.3))
1	DZEIT(1)	Length of the first little time interval. (sec)
2	NPRIN(1)	> 0: Print the fields of temperature and streaming for all NPRIN little time steps. = 0: Default value = 50
3	NKONV(1)	> 0: Run the KONVEK every NKONV little time step (only when IFKON ≠ 0 on card TX2). = 0: Default value = 1
4	ZEI(1)	End of this 1. large time interval. (hours) Same for the next large time interval:
5	DZEIT(M)	= 0.: Free choice of the little intervals. < 0.: Also free choice, but maximum = |DZEIT(M)|. (sec) > 0.: Constant length of the little time intervals. (sec)
6	NPRIN(M)	As above.
7	NKONV(M)	As above.
8	ZEI(M) M = 2,INTVAL	As above. **Note:** In coupling with VSOP (INTVAL = 1) only the first large time interval must be defined, and DZEIT(2) holds for the further time history, which is steered by the VSOP burn-up time steps.

Card TX5		Format (2E12.5,12I4)
1	RAD0	Position of the first radial mesh point I = 1. (cm) (Normal = 0.).
2	PHI0	Position of the first axial mesh point N = 1. (cm) (Normal = –height of compositions above the core). **Note:** The upper edge of the core must be located at the position 0. The axial core dimension is counted from top to bottom.
3	IFRFI	= 0: Normal. = 1: Adiabatic boundary condition in the first radial mesh.
4	IFRFA	= 0: Normal. = 1: Adiabatic boundary condition in the last radial mesh.
5	IFRFL	= 0: Normal. = 1: Adiabatic boundary condition in the first axial mesh.
6	IFRFR	= 0: Normal. = 1: Adiabatic boundary condition in the last axial mesh.

Card TX6		Format (18I4)
1	KMAX	Number of compositions to be defined on cards TX10. ($\leq$ 31)
2	NTHX	Data set no. of BIRGIT-library (see Section 2.3, card B11).
3	IFTEST	= 0: Normal. = 1: Testoption. For checking the input, the code runs without iterations.

Cards TX7 - TX9 define the coarse mesh grid, a subdivision of the fine grid, and the positions of KONVEK- and THERMIX-compositions in the coarse grid.

Card TX7		Format (6(I3,F9.0))
1	IC(1)	Number of fine mesh intervals in the 1. coarse radial interval.

2	C(1)	Width of the 1. coarse radial interval. (cm)
.	.	
.	.	
	IC(I)	> 0: Number of fine mesh intervals in the I. coarse radial interval. = 0: End of radial mesh definition.
	C(I)	Width of the I. coarse radial interval. (cm)

Card TX8		Format (6(I3,F9.0))
1	NC(1)	Number of fine mesh intervals in the 1. coarse axial interval.
2	C(1)	Width of the 1. coarse axial interval. (cm)
.	.	
.	.	
	NC(I)	> 0: Number of fine mesh intervals in the I. coarse axial interval. = 0: End of axial mesh definition.
	C(I)	Width of the I. coarse axial interval. (cm)

Two sets of cards TX9:

First set with KONVEK compositions as defined on cards KX3. One card TX9 is required for each axial coarse mesh "N" (even when no KONVEK composition is present in this mesh).

Second set of cards TX9 is to be given subsequently, containing THERMIX compositions as defined on cards TX10 - TX13.

Card TX9		Format (24I3)
1	KOC(1,N)	> 0: Id. no. of composition in the 1. radial coarse mesh. = 0: No composition is present.
.	.	
.	.	
I	KOC(I,N)	> 0: Id. no. of composition in the I. radial coarse mesh.

		= 0: No composition is present.

One card TX10 (optionally followed by TX11 - TX13) for each of the KMAX different THERMIX compositions.

Card TX10		Format (A3,7I3,8E6.0)
1	BEM	XYZ: Literal description of this composition. HET: Temperatures are calculated in the inner of the fuel elements. Analysis of temperature/volume. COR: Analysis of temperature/volume for this composition.
2	II	Id. no. of this composition.
3	IFTV	= -1: "Solid material zone". Temperature calculation comprises the heat exchange with the coolant of KONVEK by source/sink heat transfer. = 0: "Solid material zone". No heat exchange with the coolant is involved. = 1: "Fluid zone". No temperature calculation is performed for this zone. Coupled with the neighbours by the heat transfer coefficient ALP on this card. **Note:** For instance these zones are used as the heat sink of the liner. At the top and right of the reactor one mesh is sufficient for this zone. At the bottom two meshes are required.
4	IFWKT	= 0: Heat capacity given by C on this card. > 0: Identification no. of the material function for temperature dependent heat capacity (see Tab. VIII).
5	IFLT	= 0: Thermal conductivity λ given by LAM on this card. > 0: Identification no. of the material function for temperature and dose dependent λ (see Tab. IX). = 7: The temperature dependent function of id.no. = 7 uses LAM0 of this card as $\lambda(T = 0°C)$. = 4: In case of EPS > 0. (see below) the function uses LAM0 of this card as pressure (bar) of the gas in the gap. In case of EPS = 0. the function uses helium at the pressure 1 bar.
6	IDIR	Only when EPS > 0.:

		= 0: Radiation in radial direction. = 10: Exclusively in radial direction. = 1: Radiation in axial direction. = 11: Exclusively in axial direction.
7	NTVAR	= 0: No effect. > 0: In case of fluid zone (IFTV = 1) provide time dependent temperatures on card TX13.
8	IDUM	Dummy.
9	RHO	Volumetric fraction of solid material in this composition. RHO is used for calculation of the heat capacity.
10	C	= 0.: When IFWKT > 0. > 0.: Heat capacity of the solid material. ($J/cm^3/°K$)
11	LAM	= 0.: When IFLT > 0. > 0.: Thermal conductivity in solid material zones (only when IFTV = 0 or -1). ($W/cm/°K$)
12	LAM0	= 0.: Normal. > 0.: When IFLT = 7, LAM0 is λ(T = 0°C). When IFLT = 4 and EPS > 0., LAM0 is the pressure of the gas in this composition.
13	EPS	= 0.: No heat radiation. > 0.: Coefficient of emission for the heat radiation between the side walls of the composition. (Maximum number of compositions with heat radiation = 19).
14	TVOR	= 0.: Start up temperature field results from the input temperature field of the cards TX14 - TX16. > 0.: Start up temperature of this composition (°C) superior to the startup temperatures of the cards TX14 - TX16.
15	WPRR	= -1.: Field of power density results from VSOP. It will be normalized to QNORM (card TX3). ≥ 0.: Power density of this composition. (W/cm^3)
16	ALP	= 0.: No effect. > 0.: Heat transfer coefficient in fluid zones ($W/cm^2/°K$) (only when IFTV = 1). **Note:** ALP ≃ 0.5: Temperature at the boundary close to that of this fluid zone. ALP ≃ 0.01: Temperature at the boundary close to that of the adjacent zone.

Cards TX11, TX12 only when BEM = "HET" on card TX10.

Card TX11 Format (2E10.3,I5)

1	HEPS	> 0.: Void fraction in the pebble bed. = 0.: Default value = 1 - RHO (on card TX10).
2	HKUG	Diameter of the spherical fuel element. (cm)
3	NHZON	Number of radial mesh intervals in the sphere. (≤ 5)

I = 1,NHZON cards TX12.

Card TX12 Format (E10.3,2I5,E10.3)

1	DI(I)	Inner diameter of the Ith radial mesh interval. (cm) **Caution:** I = 1 ... counts from the outer shell towards the inner!
2	NH1(I)	Id.no. of temperature dependent thermal conductivity (see IFLT on card TX10).
3	NH2(I)	Id.no. of temperature dependent heat capacity (see IFWKT on card TX10).
4	XFW(I)	Shielding factor of the power density in the Ith shell (in the fuel shells normally = 1.).

Card TX13 only when NTVAR > 0 on card TX10.

Card TX13 Format (14F5.2)

1	TKV(I)	Temperature. (°C)
2 .	ZEIV(I) I = 1,NTVAR	Time. (h)

Card TX14		Format (2I5,6E10.3 / 7E10.3)
1	IPOLI	= 0: Linear interpolation of temperature input of cards TX16. = 1: Logarithmic interpolation (radial).
2	IE	= 0: Drop reading of cards TX15, TX16. > 0: Number of radial mesh points for startup temperature input.
3 .	RE(I), I = 1,IE	Radial mesh points for startup temperature input on cards TX16. Continuation cards according to given FORMAT.

Cards TX15 - TX16 only when IE > 0 on card TX14.

Card TX15		Format (2I5,6E10.3 / 7E10.3)
1	IPOLN	= 0: Linear interpolation of temperature input of cards TX16. = 1: Logarithmic interpolation (axial).
2	NE	Number of axial mesh points for startup temperature input.
3 .	PHE(I), I = 1,NE	Axial mesh points for startup temperature input on cards TX16. Continuation cards according to given FORMAT.

One card TX16 for each of the N = 1,NE axial mesh points.

Card TX16		Format (7E10.3)
1 : IE	T(I,N), I = 1,IE	Startup temperature at mesh point I,N.

Card TX17		Format (I6,2I3,5E12.5)
1	MZNORM	= 0: No effect. > 0: Start the time counting from the present THERMIX-restart.
2	MC2	= 0: No effect. > 0: Read card TX18 with definition of Thermix-compositions for time dependent output of the "heat storage".
3	NGEOM	Data set no. of CITATION geometry input as prepared in BIRGIT (normally 37).
4	CIZET0	Difference between the axial zero points of CITATION and THERMIX.
5	SIG	= 0.: Default value = 1. > 0.: Factor to be multiplied with the explicitely evaluated decay heat function.
6	RL	Avg. power density. (MW/m^3)
7	SM	Avg. heavy metal content per fuel element (incl. graphite spheres). (g/sphere)
8	BURN	Avg. burnup of spent fuel. (MWd/kg_{HM})

Card TX18 only when MC2 > 0 on card TX17.

Card TX18		Format (3I1)
1 : KMAX	IKO(I), I = 1,KMAX	"Heat storage" id.-no. to which the heat of THERMIX-composition I shall be added up. Possible "heat store" id.numbers: 5, 6, 7, 8, 9.

Card TX19		Format (5E12.5,E10.3,2I1)
1	DELTAT	Desired temperature interval (ΔT) for the numerical integra-

		tion inside the fuel elements (°C). 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.: Various test output of temperature integration inside of the fuel elements. < 0.: Thermal conductivity as a function of fast neutron dose and temperature will be given on the cards TX20-TX23.
5	R0	= 0.: No effect. > 0.: Inner radius of the fuel matrix (if shell ball is considered).
6	A0	Initial enrichment of the fuel. (%)
7	ISTANZ	= 0: No effect. > 0: Punch T and relative fuel matrix volume in the corresponding ΔT averaged over the total core.
8	IFUGRA	= 0: Fuel element temperature calculation by direct integration. > 0: Fuel element temperature calculation from THERMIX.

Cards TX20 - TX23 only when WRIT < 0. on card TX19.

Card TX20		Format (1216)
1	NSCH	Number of different functions of the thermal conductivity. (≤ 2)
2 .	KTEM(N), N = 1,NSCH	Number of temperature mesh points for which the thermal conductivity will be given. (≤ 10)
. .	LFAD(N), N = 1,NSCH	Number of fast neutron dose mesh points for which the thermal conductivity will be given. (≤ 10)

For each thermal conductivity function one set of cards TX21 - TX23.

Card TX21		Format (6E12.5)
1 .	TSTUE(K), K = 1,KTEM	Temperature mesh points.
Card TX22		Format (6E12.5)
1 .	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 TX23.		
Card TX23		Format (6E12.5)
1 .	WLSTUE(K), K = 1,KTEM	Thermal conductivity at the temperature mesh points. (W / cm / °C)

Card KX1		Format (5E10.3,4I5)
1	EPSI1	> 0.: Relative criterion of convergency for gas temperature. = 0.: Default value = 1.E-5
2	EPSI2	> 0.: Criterion of convergency 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	OVM2	> 0.: Relaxation factor for iterations on mass flow. = 0.: Default value = 1.0
5	EPSI4	> 0.: Relative criterion of convergency of the avg. gas tem-

		perature in the outer iterations between gas temperature and mass flow. = 0.: Default value = 0.02
6	ITM1	> 0: Maximum number of iterations for gas temperature. = 0: Default value = 100
7	ITM2	> 0: Maximum number of iterations for mass flow. = 0: Default value = 200
8	ITM3	> 0: Maximum number of outer iterations between gas temperature and mass flow. = 0: Default value = 5

Card KX2		Format (5E10.3,4I5)
1	DKUG	> 0.: Diameter of the spheres. (cm) = 0.: Default value = 6.0
2	EPSI	> 0.: Void fraction in the core. = 0.: Default value = 0.39
3	CP	> 0.: Specific heat capacity of the gas. (J/Kg/°K) = 0.: Default value = 5195.
4	PRAN	> 0.: Prandtl-constant of the gas. = 0.: Default value = 0.66
5	DRUCK	> 0.: Pressure of the gas. (bar)
6	IFZDR	= 0: Pressure of the system is constant. = 2: Pressure changes according to temperature. Gas inventory is constant.

One card KX3 for each of the KONVEK compositions as defined on the first set of cards TX9.

Card KX3		Format (5I6,7E6.0)
1	KR	Id.no. of this composition.

2	IFBQ	= 0: When IFTV = -1 on card TX10. Convective heat source is computed in the meshes of this composition. = -1: No convective heat source evaluation (e.g. in voids).
3	IFBR	Type of composition: = 0: No gas streaming. = 1: Pebble bed. = 2: Vertical pipes. (≤ 8) = 5: Horizontal void (no more than one mesh over its thickness).
4	IFZST	= 0: No time dependent mass flow. = 1: Given by input on cards KX4, KX5. = 2: Mass flow according to conservation law.
5	IFZTF	= 0: No time dependent gas inlet temperature. = 1: Given by input on cards KX4, KX5.
6	PVOR	> 0.: Pressure at beginning of iterations. (bar) = -1.: Pressure = pressure of the gas (see DRUCK on card KX2).
7	XKON	Additional pressure drop relative to computed pressure drop over the length of the channel (only when IFBR = 2). (1/cm)
8	ALPHA	> 0.: Coefficient of heat transition between gas and solid material (W/cm^2K). In pebble beds α is internally calculated, use ALPHA = 1. as an internal multiplication factor. = 0.: Internal calculation of α. In voids (IFBR = 5) use α = 0.
9	EPSIL	Volumetric fraction of void in this composition.
10	DHYD	Hydraulic diameter (cm). Only when IFBR $\geq$ 2.
11	STZUK	Source of mass flow. (kg/s)
12	TFLVOR	Temperature of inlet gas. (°C)

Cards KX4, KX5 only when at least one of the IFZST and/or IFZTF = 1 on cards KX3.
Up to 100 time steps can be defined by cards KX5. Linear interpolation is provided between the time steps.

Card KX4		Format (4I10)
1	IZK1	Number of compositions with time dependent input of mass flow and/or gas inlet temperature. (≤ 3)
2 .	IZKOM(I), I = 1,IZK1	Id.no. of the I-th composition.

Card KX5		Format (8F9.3)
1	ZVOR	> 0.: Time. (min) = 0.: End of the input of cards KX5.
2	ZDR	Pressure. (bar)
3	ZST(I)	Source of mass flow of the composition no. IZKOM(I). (kg/s) (Only when IFZST(I) = 1).
4 . .	ZTF(I) I = 1,IZK1	Temperature of inlet gas of the composition no. IZKOM(I). (°C) (Only when IFZTF(I) = 1).

2.6 LIFE, Fuel Life History for Decay Power Evaluation. LF1 - LF4

Card LF1 sets up the dimensions.

Card LF1		Format (6I6)
1	M50	Number of storage boxes being filled in VSOP plus number of batches which are loaded into these boxes.
2	M200	Number of batches of VSOP.
3	KMAX	Number of VSOP burnup cycles being required for setting up the full irradiation history of the individual batches (compare KT5 > 0 on card LF3).
4	LMAX	Number of all VSOP time steps of the KMAX burnup cycles.
5	MTMAX	Number of graded time steps to be generated ($\leq$ 49).
6	MEDUL	Number of passes of elements through the core.

Card LF2		Format (8I6)
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	N61	Id.-no. of the unit to which the new library is to be copied.

5 . . 8	M60(1) . . M60(4)	Id.-no. of the 1. VSOP-unit (up to 4 VSOP-units can be used which have been prepared in a sequence of restart runs). Id.-no. of the 4. VSOP-unit.

Card LF3		Format (5I6)
1	KT3	= 0: Normal. Precursory life evaluation starts with the last cycle of the given VSOP libraries. > 0: Number of VSOP cycle from which the precursory history evaluation begins.
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	KT1	= 0: Read all cycles from VSOP given on the units M60. ≥ 2: Drop VSOP cycles from the units M60 with cycle id.no. < KT1.
4	KT5	= 0: No effect. = 1: Preserve only the last VSOP cycle and prepare KMAX identic cycles out of it. > 1: Preserve only VSOP cycle with id.-no. KT5 and prepare KMAX identic cycles out of it.

Card LF4		Format (4E12.5)
1	TN	Time span (days) to be covered by the coarse new intervals (≥ 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	Out of pile residence time in the storage boxes. (days) (days)

4	TEPS	> 0.: Convergency limit for iterative calculation of the incremental parameter of the coarse time steps. = 0.: The code uses 0.1 .

2.7 PRIOR, Fuel Life History for Entire Isotope Generation. P1 - P2

Used for ORIGEN evaluation.

Card P1 sets up the dimensions.

Card P1		Format (12I6)
1	N200C	Number of batches in the core.
2	NXSC	Number of spectrum zones in the core.
3	LXS	Number of time steps with spectrum calculations.
4	KMAX	Number of burnup cycles.
5	LMAX	Total number of large burnup time steps.
6	IMAT	Number of nuclides.
7	NGRP	Number of energy groups.

Card P2		Format (12I6)
1	KT3	= 0: Normal. Precursory life evaluation starts with the last cycle of the given VSOP library. > 0: No. of the VSOP burnup cycle from which the precursory history evaluation begins.
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	N61	Id.-no. of the unit to which the new library is to be submitted.

5	M60(1)	Id.-no. of the 1. VSOP-unit (up to 4 VSOP-units can be used which have been prepared in a sequence of restart runs).
.	.	
.	.	
8	M60(4)	Id.-no. of the 4. VSOP-unit.

2.8 ATLAS, Map of 3-Dim. VSOP Results. A1 - A3

Cards A1 - A3

Card A1		Format (24I3)
1	ISEQ	= 0: Display given data fields individually for every plane. = 1: Display of each data field for all specified planes in sequence.

Card A2		Format (24I3)
1 . .	IPL(I), I = 1,KMZ	> 0: Id.numbers of the planes to be displayed. (KMZ = total numbers of planes as defined in TRIGIT). = 0: End of the planes to be displayed. If all IPL(I) = 0, all planes are to be displayed (including reflectors).

If ISEQ = 0: One set of cards A3 for every plane.
If ISEQ = 1: The set of cards A3 is due for all given planes.

Card A3		Format (3I6,E12.5)
1	IDS	= 0: End of information for this plane (ISEQ = 0) or all planes (ISEQ = 1). = 1: Display of general batch information (burnup, power). = 2: Display of atom densities. = 3: Display of weights of materials (uranium and plutoni- = 4: Display of thermal batch flux.
2	LL	When IDS = 1: LL = 0: Burnup, LL = 1: Power. When IDS = 2: LL = VSOP-id.no. of the nuclide. When IDS = 3: LL = GAM-id.no. of the nuclide. When IDS = 4: LL = 0

3	IAD	= 1: Beyond display, preserve this data field and add it up with the other fields with IAD = 1 (only for nuclides with IDS = 2 or 3). = 0: Normal. If previous fields have been added up, the field of the sum is displayed prior to the present one.
4	PFAK	> 0.: Factor of normalization to be multiplied to the field. (E.g. avg. power / fuel element) = 0.: PFAK = 1.

3.0 Useful Comments

For many parts of the VSOP package explainations are required beyond the descriptions of the input manual. Minor and major changes have been implemented in the code since the first VSOP report was edited in 1980 /1/. They are listed in the section 1.2 and will further be outlined here. We learnt from questions of the users about the need of comments and we'll give our answers to them here. We wish the comments will improve the understanding and help in simulating the reactor features.

3.1 Nuclear Data

3.1.1 Libraries

Spectrum calculations are based on the GAM-I /12/ and THERMOS /13,14/ code. Correspondingly, the code needs the two respective libraries. They have been extracted from the basic nuclear data sets ENDF/B-V and JEF-I. Testing has been reported in Ref. /32/, and will be continued in PROTEUS-experiments in the future /33/.

The GAM-library is given in 68 energy groups ranging from 10 MeV to 0.414 eV. The presently used library has the identification number 5015. It contains 181 materials. From the listing of Table III the reader recognizes the source of the respective nuclides.

The THERMOS-library is given in 30 energy groups ranging from 0 to 2.05 eV. The identification number is 515. The library (Tab. IV) is subdivided into 2 parts: (1) The absorbers with identification numbers being the same as in the GAM-library. (2) The scatterers with identification numbers out of four digits. For the scattering nuclides scattering kernels have formerly been prepared with application of different scattering laws and for different temperatures. The second part of Tab. IV gives the respective information.

Actually, the basic thermal source library is given in 96 energy groups in the group structure of the THERMALIZATION spectrum code (which is a precursor of the GATHER). Condensing of the THERMALIZATION library to a THERMOS library must be based on a specific thermal neutron energy spectrum being adequate for the considered reactor and fuel elements. Such condensing can be made by the subroutine TTTT which is outlined in section 3.1.4. An auxiliary program MAKI /19/ is available which allows easy modification of the THERMALIZATION-library.

Table III: GAM-Library

No.	Id.-no.			
1	1	H-1	Mat 1301	ENDFB-V
2	2	H-2	Mat 4012	JEF-1
3	3	Be-9	Mat 1289	ENDFB-IV
4	4	B(nat)		JEF-1
5	5	C	Mat 1306	ENDFB-V
6	6	Th-232	Mat 4902	JEF-1
7	7	Pa-233	Mat 1391	ENDFB-V
8	8	U-233	Mat 4923	JEF-1
9	9	U-234	Mat 4924	JEF-1
10	10	U-235	Mat 4925	JEF-1
11	11	U-236	Mat 4926	JEF-1
12	12	U-238	Mat 4928	JEF-1
13	13	Np-239	Mat 4939	JEF-1
14	14	Pu-239	Mat 1264	ENDFB-IV
15	15	Pu-240	Mat 4940	JEF-1
16	16	Pu-241	Mat 4941	JEF-1
17	17	Pu-242	Mat 1342	ENDFB-V
18	18	Fission-Product		
19	19	Fiss.Prod.U-235		GAMJUL
20	20	Fiss.Prod.U-233		GAMJUL
21	21	Fiss.Prod.Pu-239		GAMJUL
22	22	N-14	Mat 4074	JEF-1
23	23	O-16	Mat 4086	JEF-1
24	24	Mg	Mat 4120	JEF-1
25	25	Al-27	Mat 4137	JEF-1
26	26	Si	Mat 4140	JEF-1
27	27	Cr	Mat 4240	JEF-1
28	28	Mn-55	Mat 4255	JEF-1
29	29	Fe(nat)	Mat 4260	JEF-1
30	30	Co-59	Mat 4279	JEF-1
31	31	Ni	Mat 4280	JEF-1
32	32	Cu	Mat 4290	JEF-1
33	33	Se-82	Mat 4342	JEF-1
34	34	Br-81	Mat 4351	JEF-1
35	35	Kr-83	Mat 4363	JEF-1
36	36	Kr-84	Mat 4364	JEF-1
37	37	Kr-85	Mat 4365	JEF-1
38	38	Kr-86	Mat 4366	JEF-1
39	39	Rb-85	Mat 4375	JEF-1
40	40	Rb-87	Mat 4377	JEF-1
41	41	Sr-88	Mat 4388	JEF-1
42	42	Sr-90	Mat 4380	JEF-1
43	43	Y-89	Mat 4399	JEF-1
44	44	Zr	Mat 4409	JEF-1
45	45	Zr-90	Mat 4400	JEF-1
46	46	Zr-91	Mat 4401	JEF-1
47	47	Zr-92	Mat 4402	JEF-1
48	48	Zr-93	Mat 4403	JEF-1
49	49	Zr-94	Mat 4404	JEF-1
50	50	Zr-96	Mat 4406	JEF-1
51	51	Mo	Mat 4420	JEF-1
52	52	Mo-95	Mat 4425	JEF-1
53	53	Mo-96	Mat 9283	ENDFB-V
54	54	Mo-97	Mat 4427	JEF-1
55	55	Mo-98	Mat 9285	ENDFB-V
56	56	Mo-100	Mat 9287	ENDFB-V
57	57	Tc-99	Mat 1308	ENDFB-V
58	58	Ru-100	Mat 4440	JEF-1
59	59	Ru-101	Mat 4441	JEF-1
60	60	Ru-102	Mat 4442	JEF-1
61	61	Ru-104	Mat 4444	JEF-1
62	62	Rh-103	Mat 1310	ENDFB-V
63	63	Pd-104	Mat 4464	JEF-1
64	64	Pd-105	Mat 4465	JEF-1
65	65	Pd-106	Mat 4466	JEF-1
66	66	Pd-107	Mat 4467	JEF-1
67	67	Pd-108	Mat 9386	ENDFB-V
68	68	Pd-110	Mat 4460	JEF-1
69	69	Ag-109	Mat 1373	ENDFB-V
70	70	In-115	Mat 4495	JEF-1
71	71	Cd	Mat 4480	JEF-1
72	72	Cd-110	Mat 4483	JEF-1
73	73	Cd-111	Mat 4484	JEF-1
74	74	Cd-112	Mat 4485	JEF-1
75	75	Cd-113	Mat 4486	JEF-1
76	76	Cd-114	Mat 4487	JEF-1
77	77	Te-126	Mat 4525	JEF-1
78	78	Te-128	Mat 4527	JEF-1
79	79	Te-130	Mat 4529	JEF-1
80	80	I-127	Mat 9606	ENDFB-V
81	81	I-129	Mat 9608	ENDFB-V
82	82	Xe-128	Mat 4542	JEF-1
83	83	Xe-130	Mat 4544	JEF-1
84	84	Xe-131	Mat 4545	JEF-1
85	85	Xe-132	Mat 4546	JEF-1
86	86	Xe-134	Mat 4548	JEF-1
87	87	Xe-135	Mat 4549	JEF-1
88	88	Xe-136	Mat 4551	JEF-1
89	89	Cs-133	Mat 4553	JEF-1
90	90	Cs-135	Mat 4555	JEF-1
91	91	Cs-137	Mat 9669	ENDFB-V
92	92	Ba-134	Mat 4564	JEF-1
93	93	Ba-136	Mat 4566	JEF-1
94	94	Ba-137	Mat 4567	JEF-1
95	95	Ba-138	Mat 4568	JEF-1
96	96	La-139	Mat 9707	ENDFB-V
97	97	Ce-140	Mat 4580	JEF-1
98	98	Ce-142	Mat 4582	JEF-1
99	99	Pr-141	Mat 9742	ENDFB-V
100	100	Nd-142	Mat 9763	ENDFB-V
101	101	Nd-143	Mat 4603	JEF-1
102	102	Nd-144	Mat 4604	JEF-1
103	103	Nd-145	Mat 9766	ENDFB-V
104	104	Nd-146	Mat 4606	JEF-1
105	105	Nd-148	Mat 9769	ENDFB-V
106	106	Nd-150	Mat 4600	JEF-1
107	107	Pm-147	Mat 9783	ENDFB-V
108	108	Sm-147	Mat 9806	ENDFB-V
109	109	Sm-148	Mat 9807	ENDFB-V
110	110	Sm-149	Mat 1319	ENDFB-V
111	111	Sm-150	Mat 9809	ENDFB-V
112	112	Sm-151	Mat 4621	JEF-1
113	113	Sm-152	Mat 9811	ENDFB-V
114	114	Sm-154	Mat 9813	ENDFB-V
115	115	Eu-151	Mat 4631	JEF-1
116	116	Eu-153	Mat 4633	JEF-1
117	117	Eu-154	Mat 4634	JEF-1
118	118	Eu-155	Mat 9832	ENDFB-V
119	119	Gd-154	Mat 4644	JEF-1
120	120	Gd-155	Mat 4645	JEF-1
121	121	Gd-156	Mat 4646	JEF-1
122	122	Gd-157	Mat 4647	JEF-1
123	123	Gd-158	Mat 4648	JEF-1
124	124	Tb-159	Mat 4659	JEF-1
125	125	Au-197	Mat 4797	JEF-1
126	126	Pb	Mat 4820	JEF-1
127	127	Bi-209	Mat 4839	JEF-1
128	128	Li-6	Mat 4036	JEF-1
129	129	Li-7	Mat 4037	JEF-1
130	130	B-10	Mat 4050	JEF-1
131	131	Nitrogen-14		GAMEFB
132	132	U-237	Mat 4927	JEF-1
133	133	Np-237	Mat 4937	JEF-1
134	134	V mit Cr-Streumatrix		GER
135	135	V	Mat 4230	JEF-1
136	136	Nb mit Zr-Streumatrix		GER
137	137	Ti	Mat 4220	JEF-1
138	138	Zry = Zr		GAMJUL
139	139	Ag-107	Mat 4477	JEF-1
140	140	Nb-93	Mat 4413	JEF-1
141	141	W(nat)		JEF-1
142	142	Ru-105	Mat 4445	JEF-1
143	143	Rh-105	Mat 4455	JEF-1
144	144	Cs-134	Mat 4554	JEF-1
145	145	Ce-144	Mat 4584	JEF-1
146	146	Pr-142	Mat 4592	JEF-1
147	147	Pm-148	Mat 4612	JEF-1
148	148	Pm-148m	Mat 4613	JEF-1
149	149	Zr-95	Mat 4405	JEF-1
150	150	Poison in C Dummy		
151	151	Ru-103	Mat 4443	JEF-1
152	152	Xe-133	Mat 4547	JEF-1
153	153	Ce-141	Mat 9725	ENDFB-V
154	154	Pr-143	Mat 4593	JEF-1
155	155	Pm-149	Mat 4614	JEF-1
156	156	I-131	Mat 4536	JEF-1
157	160	Fiss.Prod.U-235 Chain 44		
158	161	Fiss.Prod.U-235 Chain 39		
159	162	Fiss.Prod.U-235 Chain 34		
160	163	Fiss.Prod.U-235 Chain 29		
161	164	B-11	Mat 4051	JEF-1
162	165	Hf-174	Mat 4724	JEF-1
163	166	Hf-176	Mat 4726	JEF-1
164	167	Hf-177	Mat 4727	JEF-1
165	168	Hf-178	Mat 4728	JEF-1
166	169	Hf-179	Mat 4729	JEF-1
167	170	Hf-180	Mat 4720	JEF-1
168	171	W-182	Mat 4742	JEF-1
169	172	W-183	Mat 4743	JEF-1
170	173	W-184	Mat 4744	JEF-1
171	174	W-186	Mat 4746	JEF-1
172	175	Pm-151	Mat 4615	JEF-1
173	176	U-232	Mat 8232	ENDFB-V
174	177	Pu-238	Mat 1338	ENDFB-V
175	178	Am-241	Mat 1361	ENDFB-V
176	179	Am-242	Mat 8542	ENDFB-V
177	180	Am-242m	Mat 1369	ENDFB-V
178	181	Am-243	Mat 1363	ENDFB-V
179	182	Cm-242	Mat 8642	ENDFB-V
180	183	Cm-243	Mat 1343	ENDFB-V
181	184	Cm-244	Mat 1344	ENDFB-V

Table IV: THERMOS-Library

Id.-no.	Absorber		
4	Boron (nat)	JEF-1	Mat 4050/51 (20% B-10 + 80% B-11)
6	Thorium-232	JEF-1	Mat 4902
7	Protactinium-233	ENDFB-V	Mat 1391
8	Uranium-233	JEF-1	Mat 4923
9	Uranium-234	JEF-1	Mat 4924
10	Uranium-235	JEF-1	Mat 4925
11	Uranium-236	JEF-1	Mat 4926
12	Uranium-238	JEF-1	Mat 4928
13	Neptunium-239	JEF-1	Mat 4939
14	Plutonium-239	ENDFB-IV	Mat 1264
15	Plutonium-240	JEF-1	Mat 4940
16	Plutonium-241	JEF-1	Mat 4941
17	Plutonium-242	ENDFB-V	Mat 1342
22	Nitrogen-14	JEF-1	Mat 4074
24	Magnesium (nat)	JEF-1	Mat 4120
25	Aluminium-27	JEF-1	Mat 4137
26	Silicon (nat)	JEF-1	Mat 4140
27	Chromium (nat)	ENDFB-IV	Mat 1191
28	Manganese-55	JEF-1	Mat 4255
29	Iron (nat)	JEF-1	Mat 4260
30	Cobalt-59	JEF-1	Mat 4279
31	Nickel (nat)	JEF-1	Mat 4280
32	Copper (nat)	JEF-1	Mat 4290
33	Selenium-82	JEF-1	Mat 4342
34	Bromine-81	JEF-1	Mat 4351
35	Krypton-83	JEF-1	Mat 4363
36	Krypton-84	JEF-1	Mat 4364
37	Krypton-85	JEF-1	Mat 4365
38	Krypton-86	JEF-1	Mat 4366
39	Rubidium-85	JEF-1	Mat 4375
40	Rubidium-87	JEF-1	Mat 4377
41	Strontium-88	JEF-1	Mat 4388
42	Strontium-90	JEF-1	Mat 4380
43	Yttrium-89	JEF-1	Mat 4399
44	Zirconium (nat)	JEF-1	Mat 4409
45	Zirconium-90	JEF-1	Mat 4400
46	Zirconium-91	JEF-1	Mat 4401
47	Zirconium-92	JEF-1	Mat 4402
48	Zirconium-93	JEF-1	Mat 4403
49	Zirconium-94	JEF-1	Mat 4404
50	Zirconium-96	JEF-1	Mat 4406
51	Molybdenum (nat)	JEF-1	Mat 4420
52	Molybdenum-95	JEF-1	Mat 4425
53	Molybdenum-96	JEF-1	Mat 4426
54	Molybdenum-97	JEF-1	Mat 4427
55	Molybdenum-98	ENDFB-V	Mat 9285
56	Molybdenum-100	ENDFB-V	Mat 9287
57	Technetium-99	ENDFB-V	Mat 1308
58	Ruthenium-100	JEF-1	Mat 4440
59	Ruthenium-101	JEF-1	Mat 4441
60	Ruthenium-102	JEF-1	Mat 4442
61	Ruthenium-104	JEF-1	Mat 4444
62	Rhodium-103	ENDFB-V	Mat 1310
63	Palladium-104	JEF-1	Mat 4464
64	Palladium-105	JEF-1	Mat 4465
65	Palladium-106	JEF-1	Mat 4466
66	Palladium-107	JEF-1	Mat 4467
67	Palladium-108	ENDFB-V	Mat 9386
68	Palladium-110	ENDFB-V	Mat 9389
69	Silver-109	ENDFB-V	Mat 1373
70	Indium-115	JEF-1	Mat 4495
71	Cadmium (nat)	JEF-1	Mat 4480
72	Cadmium-110	JEF-1	Mat 4483
73	Cadmium-111	JEF-1	Mat 4484
74	Cadmium-112	JEF-1	Mat 4485
75	Cadmium-113	JEF-1	Mat 4486
76	Cadmium-114	JEF-1	Mat 4487
77	Tellurium-126	JEF-1	Mat 4525
78	Tellurium-128	JEF-1	Mat 4527
79	Tellurium-130	JEF-1	Mat 4529
80	Iodine-127	ENDFB-V	Mat 9606

Id.-no.	Absorber		
81	Iodine-129	ENDFB-V	Mat 9608
82	Xenon-128	JEF-1	Mat 4542
83	Xenon-130	JEF-1	Mat 4544
84	Xenon-131	JEF-1	Mat 4545
85	Xenon-132	JEF-1	Mat 4546
86	Xenon-134	JEF-1	Mat 4548
87	Xenon-135	JEF-1	Mat 4549
88	Xenon-136	JEF-1	Mat 4551
89	Cesium-133	ENDFB-V	Mat 1355
90	Cesium-135	JEF-1	Mat 4555
91	Cesium-137	ENDFB-V	Mat 9669
92	Barium-134	JEF-1	Mat 4564
93	Barium-136	JEF-1	Mat 4566
94	Barium-137	JEF-1	Mat 4567
95	Barium-138	JEF-1	Mat 4568
96	Lanthanum-139	ENDFB-V	Mat 9707
97	Cerium-140	JEF-1	Mat 4580
98	Cerium-142	JEF-1	Mat 4582
99	Praseodymium-141	ENDFB-V	Mat 9742
100	Neodymium-142	JEF-1	Mat 4602
101	Neodymium-143	JEF-1	Mat 4603
102	Neodymium-144	ENDFB-V	Mat 9765
103	Neodymium-145	ENDFB-V	Mat 9766
104	Neodymium-146	ENDFB-V	Mat 9767
105	Neodymium-148	ENDFB-V	Mat 9769
106	Neodymium-150	JEF-1	Mat 4600
107	Promethium-147	ENDFB-V	Mat 9783
108	Samarium-147	ENDFB-V	Mat 9806
109	Samarium-148	JEF-1	Mat 4628
110	Samarium-149	ENDFB-V	Mat 1319
111	Samarium-150	JEF-1	Mat 4620
112	Samarium-151	JEF-1	Mat 4621
113	Samarium-152	ENDFB-V	Mat 9811
114	Samarium-154	JEF-1	Mat 4624
115	Europium-151	JEF-1	Mat 4631
116	Europium-153	JEF-1	Mat 4633
117	Europium-154	JEF-1	Mat 4634
118	Europium-155	ENDFB-V	Mat 9832
119	Gadolinium-154	JEF-1	Mat 4644
120	Gadolinium-155	JEF-1	Mat 4645
121	Gadolinium-156	JEF-1	Mat 4646
122	Gadolinium-157	JEF-1	Mat 4647
123	Gadolinium-158	JEF-1	Mat 4648
124	Terbium-159	ENDFB-V	Mat 9857
125	Gold-197	JEF-1	Mat 4797
126	Lead (nat)	JEF-1	Mat 4820
127	Bismuth-209	JEF-1	Mat 4839
128	Lithium-6	JEF-1	Mat 4036
129	Lithium-7	JEF-1	Mat 4037
130	Boron-10	JEF-1	Mat 4050
131	Nitrogen-14	ENDFB 68	XA = 1.885*(VO/V) XS = 10.2
132	Uranium-237	JEF-1	Mat 4927
133	Neptunium-237	JEF-1	Mat 4937
135	Vanadium (nat)	JEF-1	Mat 4230
137	Titanium (nat)	JEF-1	Mat 4220
138	Zircaloy-4	XA nach GEMP-346 zus.gest. XS con Zircon Teu III.68	
139	Silver-107	JEF-1	Mat 4477
140	Niobium-93	JEF-1	Mat 4413
141	Wolfram	nach Resonanzd. BNL-325 mit Genex %-Ant. Nuklidk. 21.5.69 Bonka	
142	Ruthenium-105	JEF-1	Mat 4445
143	Rhodium-105	JEF-1	Mat 4455
144	Cesium-134	JEF-1	Mat 4554
145	Cerium-144	JEF-1	Mat 4584
146	Praseodymium-142	JEF-1	Mat 4592
147	Promethium-148	JEF-1	Mat 4612
148	Promethium-148m	JEF-1	Mat 4613
149	Zirconium-95	JEF-1	Mat 4405
150	Poison in C	Nukem A3,A2-B. Teu. I.70 B,U,Al,Si,Cr,Mn,Fe,Co,Ni,Cu etc.	

Id.-no.	Absorber		
151	Ruthenium-103	JEF-1	Mat 4443
152	Xenon-133	JEF-1	Mat 4547
153	Cerium-141	ENDFB-V	Mat 9725
154	Praseodymium-143	JEF-1	Mat 4593
155	Promethium-149	JEF-1	Mat 4614
156	Iodine-131	JEF-1	Mat 4536
160	Fiss.Prod.U235 Chain 44		
161	Fiss.Prod.U235 Chain 39		
162	Fiss.Prod.U235 Chain 34		
163	Fiss.Prod.U235 Chain 29		
164	Boron-11	JEF-1	Mat 4051
165	Hafnium-174	JEF-1	Mat 4724
166	Hafnium-176	JEF-1	Mat 4726
167	Hafnium-177	JEF-1	Mat 4727
168	Hafnium-178	JEF-1	Mat 4728
169	Hafnium-179	JEF-1	Mat 4729

Id.-no.	Absorber		
170	Hafnium-180	JEF-1	Mat 4720
171	Tungsten-182	JEF-1	Mat 4742
172	Tungsten-183	JEF-1	Mat 4743
173	Tungsten-184	JEF-1	Mat 4744
174	Tungsten-186	JEF-1	Mat 4746
175	Promethium-151	JEF-1	Mat 4615
176	Uranium-232	ENDFB-V	Mat 8232
177	Plutonium-238	ENDFB-V	Mat 1338
178	Americium-241	ENDFB-V	Mat 1361
179	Americium-242	ENDFB-V	Mat 8542
180	Americium-242m	ENDFB-V	Mat 1369
181	Americium-243	ENDFB-V	Mat 1363
182	Curium-242	ENDFB-V	Mat 8642
183	Curium-243	ENDFB-V	Mat 1343
184	Curium-244	ENDFB-V	Mat 1344

Id.-no.	Scatterer
1001	Carbon 300K P0 & P1 Summit to 1eV & Gas 739.32K 1/V 3.88mb
1002	Carbon 600K P0 & P1 Summit to 1eV & Gas 890.98K 1/V 3.88mb
1003	Carbon 900K P0 & P1 Summit to 1eV & Gas 1110.51K 1/V 3.88mb
1004	Carbon 1200K P0 & P1 Summit to 1eV & Gas 1363.14K 1/V 3.88mb
1005	Carbon 1350K P0 & P1 Gas kernel 1/V Absorption Sigma0 = 3.88mb
1006	Carbon 1500K P0 & P1 Gas kernel 1/V Absorption Sigma0 = 3.88mb
1007	Hydrogen 300K P0 & P1 Gas kernel 1/V Absorption Sigma0 = .332b
1008	Hydrogen in H_2O 300K P0 & P1 Gaker to 1eV & Gas 1153.26K 1/V .332b
1009	Hydrogen 589K P0 & P1 Gas kernel 600F 1/V .332b
1010	Hydrogen in H_2O 589K 600F P0 & P1 Gaker to 1eV & Gas 1269.37K 1/V .332b
1011	Hydrogen 1200K P0 & P1 Gas kernel 1/V Sigma0 = .332b
1012	Beryllium 980K P0 & P1 Gas kernel 1/V Sigma0 = 10mb
1013	Beryllium 1366K P0 & P1 Gas kernel 2000F 1/V Sigma0 = 10mb
1014	Beryllium 1422K P0 & P1 Gas kernel 2100F 1/V Sigma0 = 10mb
1015	Oxygen 589K P0 & P1 Gas kernel 600F
1016	Deuterium Gas-Kern T = 293.4K Teuchert 18.5.1967
1017	Deuterium Gas-Kern T = 493.4K Teuchert 18.5.1967
1018	Deuterium Gas-Kern T = 593.4K Teuchert 18.5.1967
1019	Deuterium Gas-Kern T = 693.4K Teuchert 18.5.1967
1020	Deuterium 593K Gaker-Kira for Gr.1-55, 22-75 & Gas kernel Teu/Ha.67
1021	Sauerstoff Gas-Kern mit BASK bei T = 900K
1022	Beryllium in BeO 900K Summit-BeO-Matr. minus O-Matr. Rest von 1012
1023	Berylliumoxyd 900K Summit-BeO-Matr. XA = 0.01/V XS = 9.69 S = S(O) & S(Be)
1101	Hydrogen Nelkin-Kern (Gaker-Kira) 293.6K IX.68 Darvas
1102	Hydrogen Nelkin-Kern (Gaker-Kira) 323.6K IX.68 Darvas
1103	Hydrogen Nelkin-Kern (Gaker-Kira) 373.6K IX.68 Darvas
1104	Hydrogen Nelkin-Kern (Gaker-Kira) 473.6K IX.68 Darvas
1105	Hydrogen Nelkin-Kern (Gaker-Kira) 573.6K IX.68 Darvas
1111	Deuterium Nelkin-Kern (Gaker-Kira) 293.6K IX.68 Darvas
1112	Deuterium Nelkin-Kern (Gaker-Kira) 323.6K IX.68 Darvas
1113	Deuterium Nelkin-Kern (Gaker-Kira) 373.6K IX.68 Darvas
1114	Deuterium Nelkin-Kern (Gaker-Kira) 473.6K IX.68 Darvas
1115	Deuterium Nelkin-Kern (Gaker-Kira) 573.6K IX.68 Darvas
1121	Oxygen Brown-St-John-Freigas 293.6K IX.68 Teuchert
1122	Oxygen Brown-St-John-Freigas 323.6K IX.68 Teuchert
1123	Oxygen Brown-St-John-Freigas 373.6K IX.68 Teuchert
1124	Oxygen Brown-St-John-Freigas 473.6K IX.68 Teuchert
1125	Oxygen Brown-St-John-Freigas 573.6K IX.68 Teuchert
1126	Oxygen Brown-St-John-Freigas 900.0K XII.70 Teuchert
1127	Oxygen Brown-St-John-Freigas 1200.0K XII.70 Teuchert
1128	Oxygen Brown-St-John-Freigas 1350.0K XII.70 Teuchert
1500	Weisser Riese 1000K Atomgewicht 1000000 22.XII.70
1600	Carbon 300K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1601	Carbon 400K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1602	Carbon 500K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1603	Carbon 600K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1604	Carbon 700K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1605	Carbon 800K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1606	Carbon 900K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1607	Carbon 1000K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1608	Carbon 1100K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1609	Carbon 1200K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1610	Carbon 1300K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1611	Carbon 1350K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70
1612	Carbon 1500K Young Phon.-Spektr. Colli Punktwerte 2eV Schroeder 4.7.70

Table V: Sequence of Nuclides

	VSOP-Id.no.		GAM-Id.no.	
1.	Heavy metal isotopes are firmly assigned:			
	1	^{232}Th	6	
	2	^{233}Pa	7	
	3	^{233}U	8	
	4	^{234}U	9	
	5	^{235}U	10	
	6	^{236}U	11	
	7	^{238}U	12	
	8	^{239}Np	13	
	9	^{239}Pu	14	
	10	^{240}Pu	15	
	11	^{241}Pu	16	
	12	^{242}Pu	17	
	13	^{237}Np	133	Insert what you consider to be more important for your study.
		or ^{243}Am	181	
2.	Fission products of any chain definition:			
	14	^{135}Xe		
	15	Non-saturating fission product		
	16 ...	Further isotopes of the chain NO ≤ 49 fission products are allowed.		
3.	Lumped poison:			
	subsequent	NLUM = 0-3 different nuclides are possible with self shielding factors depending on their concentration		
4.	Control poison:			
	subsequent	NC = 0-2 different nuclides are possible with concentrations adjustable to achieve given K_{eff}		
5.	Non burning absorbers:			
	subsequent	Absorbers for which concentrations remain unchanged during burnup, e.g. structural materials		
6.	Scatterers:			
	subsequent	NKER = 1-5 scatterers must be given at the end		

3.1.2 Identification Numbers of the Nuclides

In spite of variable dimension, in VSOP the number of materials (KMAT) is limited to KMAT $\leq$ 200. That limitation is due to the dimensions of some data sets and can easily be extended, if required.

Identification of the nuclides is defined by the cards D2 (Section 2.1) or by the cards V5 (Section 2.4.3). Every nuclide I of the VSOP run is defined by the number IMAT(I), which is its Id.-no. at the GAM-library, as given in Table III.

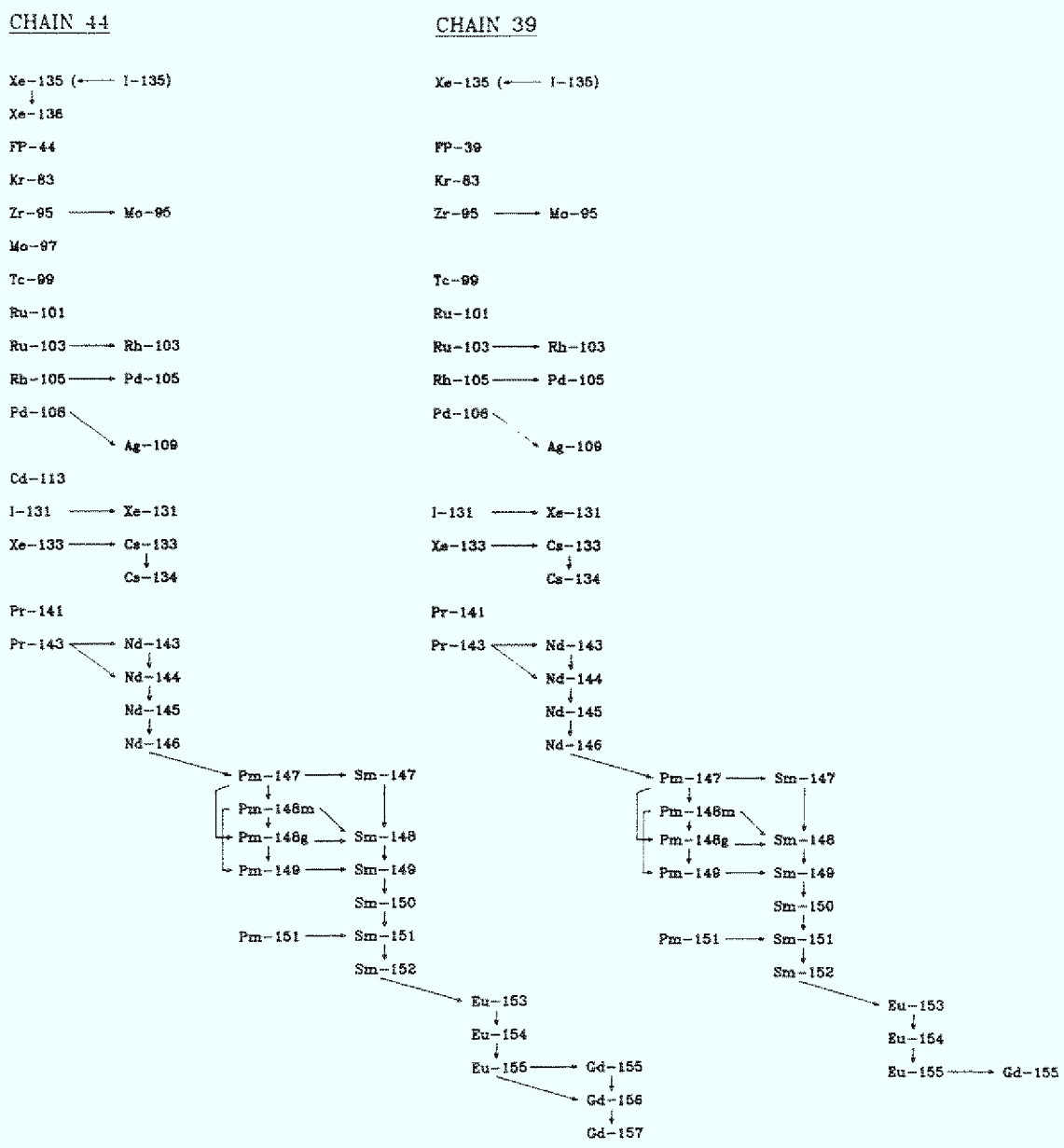

Fig. 3. Fission Product Chains 44 and 39

A certain sequence must be observed for the designation of the nuclides, which is outlined in Table V: The first 13 nuclides must be the fissionable heavy metal isotopes in the given order. They are followed by the fission products, with ^{135}Xe and cumulative fission product in the positions 14 and 15, respectively. The order of the explicitely treated fission products must correspond with the chain definition (Tab.VI). Subsequently, lumped poison and adjustable poison represent absorbers of variable concentration. They are followed by absorbers of fixed concentrations.

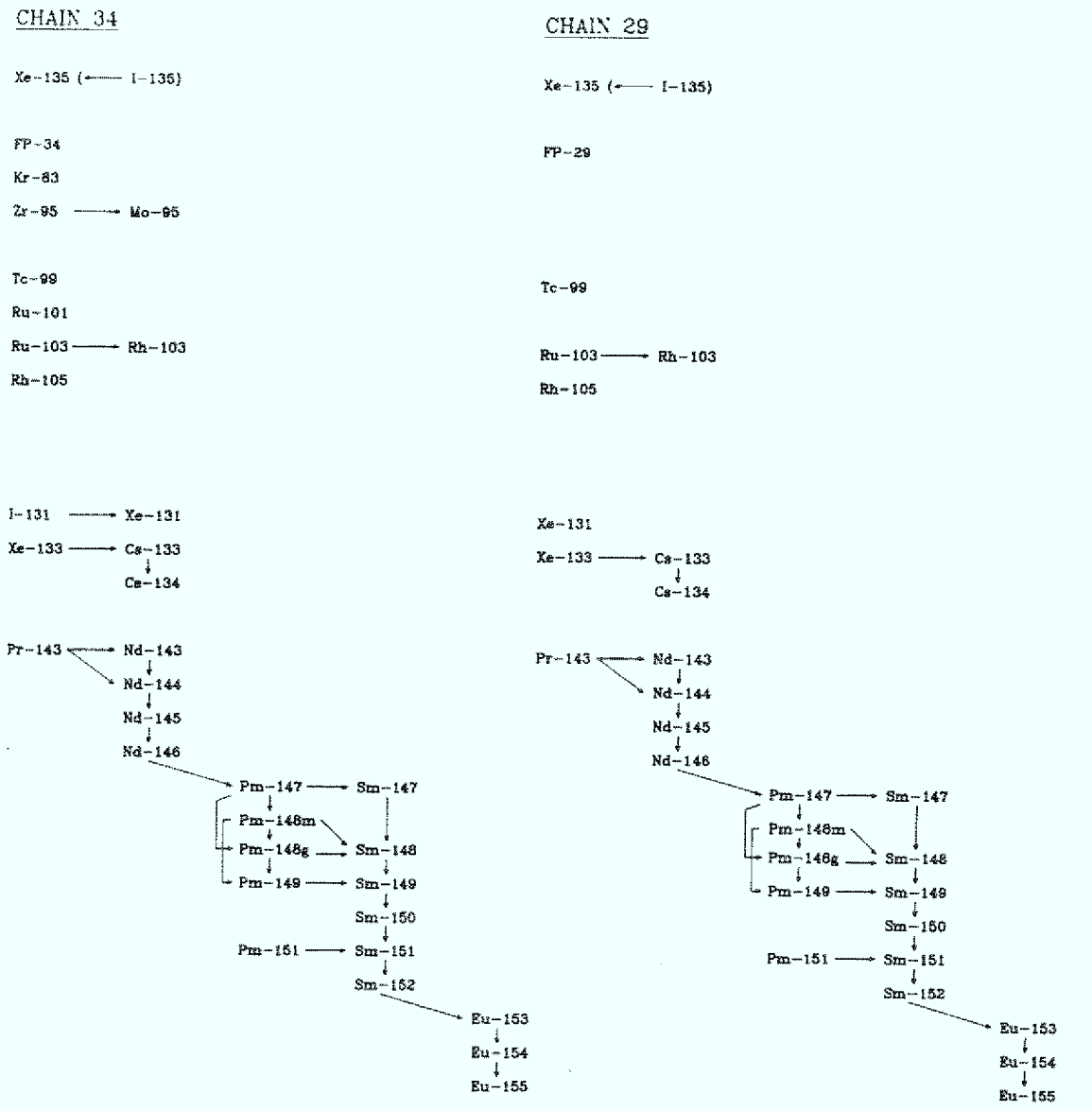

Fig. 4. Fission Product Chains 34 and 29

Table VI: Fission Product Chains

VSOP-Id.no.	Chain 44	GAM-Id.	Chain 39	GAM-Id.	Chain 34	GAM-Id.	Chain 29	GAM-Id.
14	^{135}Xe	87	^{135}Xe	87	^{135}Xe	87	^{135}Xe	87
15	FP-44	160	FP-39	161	FP-34	162	FP-29	163
16	^{136}Xe	88	^{83}Kr	35	^{83}Kr	35	^{99}Tc	57
17	^{83}Kr	35	^{95}Zr	149	^{95}Zr	149	^{103}Ru	151
18	^{95}Zr	149	^{95}Mo	52	^{95}Mo	52	^{103}Rh	62
19	^{95}Mo	52	^{99}Tc	57	^{99}Tc	57	^{105}Rh	143
20	^{97}Mo	54	^{101}Ru	59	^{101}Ru	59	^{131}Xe	84
21	^{99}Tc	57	^{103}Ru	151	^{103}Ru	151	^{133}Xe	152
22	^{101}Ru	59	^{103}Rh	62	^{103}Rh	62	^{133}Cs	89
23	^{103}Ru	151	^{105}Rh	143	^{105}Rh	143	^{134}Cs	144
24	^{103}Rh	62	^{105}Pd	64	^{131}I	156	^{143}Pr	154
25	^{105}Rh	143	^{108}Pd	67	^{131}Xe	84	^{143}Nd	101
26	^{105}Pd	64	^{109}Ag	69	^{133}Xe	152	^{144}Nd	102
27	^{108}Pd	67	^{131}I	156	^{133}Cs	89	^{145}Nd	103
28	^{109}Ag	69	^{131}Xe	84	^{134}Cs	144	^{146}Nd	104
29	^{113}Cd	75	^{133}Xe	152	^{143}Pr	154	^{147}Pm	107
30	^{131}I	156	^{133}Cs	89	^{143}Nd	101	^{148}Pm/m	148
31	^{131}Xe	84	^{134}Cs	144	^{144}Nd	102	^{148}Pm/g	147
32	^{133}Xe	152	^{141}Pr	99	^{145}Nd	103	^{147}Sm	108
33	^{133}Cs	89	^{143}Pr	154	^{146}Nd	104	^{148}Sm	109
34	^{134}Cs	144	^{143}Nd	101	^{147}Pm	107	^{149}Pm	155
35	^{141}Pr	99	^{144}Nd	102	^{148}Pm/m	148	^{149}Sm	110
36	^{143}Pr	154	^{145}Nd	103	^{148}Pm/g	147	^{150}Sm	111
37	^{143}Nd	101	^{146}Nd	104	^{147}Sm	108	^{151}Pm	175
38	^{144}Nd	102	^{147}Pm	107	^{148}Sm	109	^{151}Sm	112
39	^{145}Nd	103	^{148}Pm/m	148	^{149}Pm	155	^{152}Sm	113
40	^{146}Nd	104	^{148}Pm/g	147	^{149}Sm	110	^{153}Eu	116
41	^{147}Pm	107	^{147}Sm	108	^{150}Sm	111	^{154}Eu	117
42	^{148}Pm/m	148	^{148}Sm	109	^{151}Pm	175	^{155}Eu	118
43	^{148}Pm/g	147	^{149}Pm	155	^{151}Sm	112		
44	^{147}Sm	108	^{149}Sm	110	^{152}Sm	113		
45	^{148}Sm	109	^{150}Sm	111	^{153}Eu	116		
46	^{149}Pm	155	^{151}Pm	175	^{154}Eu	117		
47	^{149}Sm	110	^{151}Sm	112	^{155}Eu	118		
48	^{150}Sm	111	^{152}Sm	113				
49	^{151}Pm	175	^{153}Eu	116				
50	^{151}Sm	112	^{154}Eu	117				
51	^{152}Sm	113	^{155}Eu	118				
52	^{153}Eu	116	^{155}Gd	120				
53	^{154}Eu	117						
54	^{155}Eu	118						
55	^{155}Gd	120						
56	^{156}Gd	121						
57	^{157}Gd	122						

The scatterer nuclides must be given at the end. Here, they are also identified by their GAM-Id.numbers. Note, the code accepts several scattering matrices from the THERMOS-library for one and the same scattering nuclide, being due to different temperatures. That information is given at the cards T2 and T3 of the THERMOS input.

3.1.3 Fission Products

The library contains cross sections of 116 fission products (Tab. III,IV). Yields are included in the code for 87 fission products (Tab. VII). They have been taken partly from ENDF/B-IV, partly from ENDF/B-V. Four different fission product chains are also included which are given in Fig. 3 and 4. The sequence of identification numbers is given in Tab. VI.

The first member of every chain is ^{135}Xe. Normally the code calculates equilibrium concentration of the ^{135}Xe for every batch. By an option (card V10 or card R14) the time dependent history of ^{135}I and ^{135}Xe is explicitely followed. This option is needed for a short term follow of the burnup. This option is also useful when just an iteration is desired between spectrum and diffusion calculation without changes of nuclide concentrations. In that case the burnup time step DELDAY (card V15 or card R14) must be given so short (e.g. 10^{-4} days) that the concentrations of ^{135}I and ^{135}Xe remain unchanged.

The second member of each fission product chain is a "non saturating" fission product. It stands for the sum of many low absorbing fission products which are not included in the chain. The yields of the non saturating fission products of the chains 44 and 29 have recently been re-adjusted by comparison with the ORIGEN-JÜL-II code /20/ which comprises 821 fission products explicitely. In a follow of the HTR-MODUL (with burnup of 80 MWd/kg$_{HM}$) the 43 explicite fission products of the VSOP have been found to cover 98.02% of the total fission product absorption found with ORIGEN. The yields of the non saturating FP-44 have been adapted to cover the remaining 1.98% of the absorption.

It is possible to extend the fission product chains by defining new isotopes, new yields, and new chain informations at the cards V8,V9. Similarily the chains can be shortened, modified, or even fully replaced by the user of the code.

Table VII: Fission Product Yields (Values given in percentages)

Isotope	Type	^{233}U	^{235}U	^{239}Pu	^{241}Pu
^{82}Se	t	0.56262	0.33405	0.21092	0.11602
^{81}Br	t	0.31171	0.21005	0.1768	0.06469
^{83}Kr	t	1.0178	0.53076	0.29608	0.20498
^{84}Kr	t	1.7034	0.98786	0.48029	0.35393
^{85}Kr	c	2.1946	1.314	0.56834	0.39618
^{86}Kr	c	2.8581	1.9528	0.75863	0.61392
^{85}Rb	i	6.5296-5	8.23-5	5.85-5	5.3024-7
^{87}Rb	t	4.0088	2.551	0.94936	0.75709
^{88}Sr	t	5.4953	3.6228	1.3703	0.97473
^{90}Sr	c	6.7952	5.9137	2.1134	1.5363
^{89}Y	t	6.2568	4.8469	1.7075	1.2146
^{nat}Zr		6.4467	5.803	2.6405	2.645
^{90}Zr	i	0.05	0.047	0.0164	0.0164
^{91}Zr	t	6.5194	5.926	2.4941	1.8315
^{92}Zr	t	6.5949	5.966	3.018	2.2781
^{93}Zr	c	7.011	6.3703	3.9031	2.9643
^{94}Zr	c	6.8076	6.4228	4.4431	3.4018
^{95}Zr	c	6.2478	6.4678	4.9212	4.0456
^{96}Zr	t	5.6694	6.2506	5.0958	4.4232
^{95}Mo	c	9.5909-4	1.641-4	1.492-3	1.2927-5
^{96}Mo	i	6.5-3	5.85-4	7.7-4	7.7-4
^{97}Mo	t	5.4533	5.96	5.608	4.8208
^{98}Mo	t	5.1587	5.7787	5.8542	5.2217
^{100}Mo	t	4.4094	6.3096	6.977	6.2311
^{99}Tc	c	4.9573	6.1284	6.1405	6.2085
^{101}Ru	t	3.2258	5.0501	5.9135	6.0948
^{102}Ru	t	2.4492	4.2032	6.0201	6.4843
^{103}Ru	c	1.7066	3.1411	6.9845	6.2611
^{104}Ru	t	1.0276	1.8239	5.9539	6.9764
^{105}Ru		0.48	0.9	5.47	5.47
^{103}Rh	i	1.4219-9	1.858-9	1.358-7	5.6028-5
^{105}Rh	c	0.47126	1.0199	5.4261	6.2183
^{105}Pd	i	3.4998-11	9.83-11	2.03-8	1.6908-6
^{106}Pd		0.24063	0.37759	4.6234	4.6314
^{107}Pd	c	0.11417	0.16317	3.2361	5.3339
^{108}Pd	t	0.061481	0.071032	2.2319	4.0191
^{110}Pd	t	0.025376	0.022338	0.62204	1.2091
^{109}Ag	t	0.043363	0.029903	1.4115	2.2836
^{111}Cd	t	0.020268	0.019714	0.27428	0.57261
^{112}Cd	t	0.014602	0.012802	0.10707	0.23001
^{113}Cd	c	0.013152	0.012425	0.078216	0.15494
^{114}Cd	t	0.012268	0.011256	0.046789	0.075514

^{115}In		0.020052	9.9367-3	0.040467	0.040537
^{126}Te	t	0.24081	0.057818	0.19996	0.077127
^{128}Te	c	0.94592	0.35046	0.85079	0.35555
^{130}Te	c	2.3671	1.4466	2.4971	1.6617
^{127}I	t	0.67853	0.13037	0.49173	0.23046
^{129}I	c	1.616	0.65911	1.5039	0.77864
^{131}I	c	3.7089	2.8325	3.738	3.1411
^{135}I	c	4.8597	6.3482	6.3007	6.95
^{131}Xe	i	8.4795-5	1.54-6	1.652-5	1.3066-6
^{132}Xe	t	4.8038	4.2498	5.2688	4.6411
^{133}Xe	c	6.0307	6.7859	6.9758	6.741
^{134}Xe	c	5.7588	7.6825	7.389	8.1081
^{135}Xe	i	1.3374	0.2541	1.1517	0.22923
^{135}Xe	c	6.1971	6.6023	7.4524	7.1792
^{136}Xe	c	6.7934	6.2701	6.6153	7.2871
^{133}Cs	i	3.6998-5	5.08-5	1.61-5	4.302-7
^{134}Cs	i	1.1969-3	3.57-5	4.61-4	3.5416-5
^{135}Cs	c	6.1	6.45	7.22	7.8
^{137}Cs	c	6.7889	6.269	6.6834	6.698
^{138}Ba	t	5.8863	6.8272	5.7173	6.4446
^{139}La	t	5.885	6.4933	5.6456	6.2283
^{140}Ce	t	6.4334	6.3229	5.5751	5.894
^{141}Ce		6.24	5.73	6.11	6.11
^{142}Ce	t	6.6304	5.9247	5.0173	4.815
^{144}Ce		4.5117	5.962	4.4514	4.8644
^{141}Pr	t	6.6224	5.8929	5.3634	4.8534
^{143}Pr	c	5.8513	5.971	4.5613	4.5017
^{142}Nd		0.	0.009	0.0009	0.0009
^{143}Nd	i	2.4799-8	9.5-11	4.9-10	1.2106-10
^{144}Nd	t	4.6495	5.4523	3.834	4.1564
^{145}Nd	t	3.4248	3.9339	3.0833	3.2046
^{146}Nd	t	2.5973	2.9912	2.5333	2.7401
^{148}Nd	t	1.2867	1.69	1.6982	1.9257
^{150}Nd	c	0.49846	0.64593	0.99451	1.196
^{147}Pm	c	1.7753	2.2701	2.0769	2.2601
^{148}Pm/m	i	2.7899-5	7.49-7	2.09-6	5.4125-7
^{148}Pm/g	i	9.4395-7	5.73-6	2.09-6	5.4125-7
^{149}Pm		0.76953	1.0888	1.2617	1.4635
^{151}Pm		0.32293	0.42044	0.7772	0.90238
^{147}Sm	i	2.0099-10	0.	2.43-12	0.
^{148}Sm	i	1.7999-8	6.95-11	2.8-10	4.272-11
^{149}Sm		0.	0.	0.	0.
^{150}Sm	c	2.5782-3	5.413-4	1.7009-3	3.9438-4
^{151}Sm		0.	0.	0.	0.
^{152}Sm	t	0.20784	0.27057	0.59618	0.71704
^{154}Sm	t	0.04558	0.074689	0.27682	0.37979
^{153}Eu	t	0.10686	0.16264	0.37224	0.52815

^{154}Eu	i	3.7198-5	1.63-6	3.54-5	5.5626-6
^{155}Eu	c	0.021252	0.033025	0.17082	0.23181
^{154}Gd		0.	0.	0.	0.
^{155}Gd	i	3.6198-7	4.41-9	2.83-7	1.9109-8
^{156}Gd	t	0.011737	0.013517	0.11989	0.16955
^{157}Gd	t	6.7747-3	6.4651-3	0.076297	0.13153
^{158}Gd	t	2.2298-3	3.2163-3	0.040955	0.086707
^{159}Tb	t	9.2311-4	1.0394-3	0.021205	0.046741

i Independent fission yield
c Cumulative fission yield
t Total chain yield

Yields for Accumulated Fission Products

	^{233}U	^{235}U	^{239}Pu	^{241}Pu
Fiss.Prod. 44	112.3	94.76	115.6	110.4
" 39	154.1	132.4	159.0	150.9
" 34	205.2	183.9	276.2	266.0
" 29	299.57	268.42	398.82	388.17
^{131}Xe (Chain 29)	3.7089	2.8325	3.738	3.1411

3.1.4 Preparing a THERMOS-Library by Means of TTTT

The basic thermal library of VSOP is given in 96 thermal energy groups ranging between 0 and 2.05 eV. It is made in the structure of the zero-dimensional thermal spectrum code THERMALIZATION which was a precursor of the GATHER code. In VSOP that part of spectrum calculation has been replaced by the THERMOS code performing thermal cell calculation in one dimension and in 30 energy groups.

THERMOS requires a specific 30 groups library. This can be generated by condensing the 96 groups THERMALIZATION-library with the neutron flux belonging to the considered problem. For that purpose the VSOP input must be prepared for the respective reactor design case with one representative spectrum zone. On the card G1 the word IDTHER = 0 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 section 2.4.10).

The group structure of THERMALIZATION is given by the representative energy points E(I) of the groups I. They are given in units "eV". The group boundaries are in the middle between the representative energy points. At the THERMOS-library the

group structure is given by the group boundaries V(J) of velocity groups J in units "V_o(2200 m/sec)". The representative points YV(J) are the midpoints of the groups J.

3.2 Neutron Spectrum Calculation

Spectrum calculations are made by the codes GAM-I /12/ and THERMOS /13,14/. They are allowed for an unlimited number of spectrum zones.

GAM-I performs neutron flux evaluation in 68 energy groups ranging from 10 MeV to 0.414 eV. It uses the materials homogeneously distributed and applies the P1-approxi - mation. Heterogeneity effects can be included by defining selfshielding factors as derived from other codes. Cross sections of the resolved and unresolved resonances can be generated for ^{232}Th and ^{238}U by the ZUT-DGL code /4,5/. Leakage of neutrons from/to the adjacent spectrum zones is included by buckling terms which are generated from the diffusion calculation over the whole reactor.

The THERMOS code performs 1-dimensional cell calculation in 30 energy groups ranging from 0 to 2.05 eV. Again input of selfshielding factors allows to account for additional heterogeneity. The effect of coated particle grain structure can be included by evaluation of the collision probability for a neutron which travels through a coated particle. And neutron exchange with the other spectrum zones is accounted for by defining albedos out of the leakage terms /21/.

The resulting neutron fluxes are applied to form broad group cross sections for the subsequent diffusion calculation. The number of broad groups should be selected between 2 and 8, which is adequate for the output format of the code. In the thermal energy range only one broad group is possible to choose because upscattering is not included in the cross section transfer.

3.2.1 Resonance Integrals

For the isotopes ^{232}Th and ^{238}U resonance integrals are evaluated by the ZUT-DGL code. The corresponding absorption cross sections can be turned to the GAM. They are added to the background absorption cross sections of the GAM-library. That background is independent of lumping effects and temperature. (Note, for the unresolved resonances of ^{238}U (4.4 KeV to 0.1 MeV) the present GAM-library (ID = 5015) contains the full infinitely diluted resonance integral as a background. In case of high lumping of the fuel this background needs to be corrected by adequate cross section-selfshielding factors.)

Prior to running a VSOP problem, the resonance absorption cross sections must be prepared for the considered fuel assemblies and for different temperatures. They are stored at a permanent unit 30. The VSOP applies these sets for the different spectrum calculations during the follow of the reactor at its normal operation or accident simulation. The dependence of cross sections on the temperature is achieved by linear interpolation between the respective cross section sets.

3.2.2 Coated Particle Grain Structure

At energy ranges with $1/\Sigma_a(E)$ smaller than the mean cord length $\bar{l}$ of a coated particle, the grain structure is of importance in spectrum evaluation. This is due in the resonances and at the lower end of the thermal spectrum. Therefore, the capability of grain structure effect has been included in the ZUT and THERMOS codes.

The resonance integral calculation of the standard ZUT code is made for a homogeneous distribution of the resonance absorber in the finite volume of a lump. The transport equation is solved in very fine groups over the energy range of each resonance. The calculation also includes the neutrons which are born in the lump, leave it, and are absorbed or scattered down in any other lump of the same configuration. Excluded are those neutrons which leave the lump and undergo scattering reactions outside. Nordheim excludes these neutrons by the geometric escape probability

$$P(E) = \frac{P_o(E) \cdot (1 - C)}{1 - (1 - \bar{l}\,\Sigma_a(E)\,P_o(E)) \cdot C}$$

in which C is the Dancoff factor and $P_o(E)$ is the probability for a neutron to escape the lump of its birth. This method has proven to be a good approximation for lumps of all degrees of grayness.

In case of coated particles inside a fuel element the absorber lump is the inner kernel of a representative coated particle. Because of the smallness of a particle, the escape probability $P_o(E)$ is close to 1, even for neutrons with energy close to the peak of strong resonances. The neutron can travel through many coated particles without collision, whether through the coatings or stripping through the kernels. It can meet the boundary of the fuel matrix, pass through the outer shell of the fuel element, enter another matrix, and undergo collision in any of its coated particles or somewhere between them. Figure 5 gives the different possibilities of escaping from a coated particle.

For such "double heterogeneous" composition of the absorber lumps a Dancoff factor is hard to define, therefore in ZUT-DGL the escape probability $P(E)$ is directly evaluated by a numerical method.

The possible path of a neutron is subdivided into parts for which the probability of traversing or not traversing can rigorously be evaluated by a numerical treatment. This requires the evaluation of 8 different probabilities $W_1 - W_8$ as indicated in Fig. 5. For instance, W_1 is the probability for a neutron to undergo a collision in the coating of the coated particle in which it was borne. Finally, the geometric escape probability is

$$P(E) = W_1 + W_2(W_3 + W_4) + W_2 W_5 \frac{W_6 + W_7}{1 - W_8}$$

This formula can replace the $P(E)$ of Nordheim in the version ZUT-DGL. It has been derived for spherical and for cylindrical elements. The outline of the numerical treatment is given in Ref. /5/.

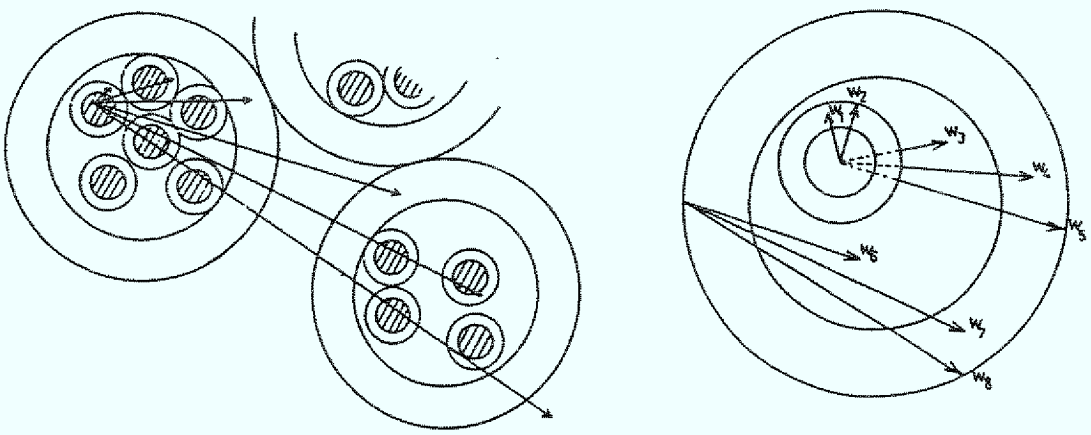

Fig. 5. Break Down of the Neutron Escape Probality

In thermal energy range - i.e. in the THERMOS code - the grain structure is treated analogeously: In the fuel matrix the mean path of a neutron from one coated particle to the next one be L. Its magnitude results from the diameter and from the volumetric filling of the particles in the matrix. For a neutron at the energy E the probability $W(E)$ of traversing one coated particle and the corresponding amount of matrix material is calculated by a direct numerical integration as outlined in Ref. /14/. Thereupon, $W(E)$ is used to define an effective macroscopic total cross section $\Sigma'(E)$ by the equation

$$W(E) = e^{-\Sigma^*(E) \cdot L}$$

$\Sigma^*(E)$ is used to replace the homogenized $\Sigma(E)$ of the mixture of matrix and coated particles in the THERMOS run. The individual reaction rates of the different materials are defined correspondingly. The computer time of the THERMOS run is increased by a fraction of a second.

3.2.3 Selfshielding Factors in Epithermal Energy Range

The GAM code performs epithermal spectrum calculations for the nuclide compositions homogenized over the respective spectrum zones. Selfshielding factors can be applied for the many nuclides. They can be given in coarse energy groups or in the 68 group structure of the GAM library.

Two types of selfshielding factors can be submitted:

SC: Cross section-selfshielding factors allow modification of the microscopic cross sections of the library. This might be desired to account for resonance shielding effects, for changes of the neutron energy spectrum within any fine energy group g, or for improved measurements of cross sections, respectively. The code allows input of LSUB different subsets of cross section-selfshielding factors SC_g. They can be applied for any nuclide in any spectrum zone. The SC_g are multiplied to the respective cross sections σ_g of the energy group g.

SF: Neutron flux-selfshielding factors allow to bring the cell structure local neutron flux in relation to the average cell flux.

When assuming a space and energy dependent cell calculation, the reaction rate per volume V_c of the cell is given by

$$RR = \sum_{g=1}^{NG} \sigma_g \cdot SC_g \cdot \sum_{k=1}^{NK} N_k V_k \phi_{kg}$$

with

g, NG energy groups of the GAM library
k, NK cell zones
σ_g, SC_g cross section and corresponding selfshielding factor
N_k atom density of considered nuclide in cell zone k
V_k volume of cell zone k

ϕ_{kg} neutron flux

(Note: RR is due for any nuclide in any spectrum zone. Respective subscripts have been dropped.)

In view of the homogeneous treatment of the cell in the GAM code, the reaction rate per cell volume can be formed in terms of the average cell flux ϕ_{og} :

$$RR = \sum_{g=1}^{NG} \sigma_g \cdot SC_g \cdot N_o V_o \phi_{og} \cdot \sum_{k=1}^{NK} \frac{N_k V_k \phi_{kg}}{N_o V_o \phi_{og}}$$

with the following cell zone averagings applied

$$V_o = \sum_{k=1}^{NK} V_k \qquad N_o = \sum_{k=1}^{NK} N_k \cdot \frac{V_k}{V_o} \qquad \phi_{og} = \sum_{k=1}^{NK} \phi_{kg} \cdot \frac{V_k}{V_o}$$

In the form of RR the last term can be written as

$$\sum_{k=1}^{NK} ANT_k \cdot SF_{kg}$$

which contains the neutron flux-selfshielding factors of the different cell zones

$$SF_{kg} = \frac{\phi_{kg}}{\phi_{og}}$$

and the fractions of the atom density N_o which are located in the respective cell zones

$$ANT_k = \frac{N_k V_k}{N_o V_o} \quad .$$

Applying said forms the reaction rate can be written in the homogeneous form

$$RR = \sum_{g=1}^{NG} \sigma_g^* \cdot N_o V_o \phi_{og}$$

with the cross section being modified by the selfshielding factors SC and SF:

$$\sigma_g^* = \sigma_g \cdot SC_g \cdot \sum_{k=1}^{NK} ANT_k \cdot SF_{kg} \quad .$$

These modified cross sections σ_g^* are applied in the GAM spectrum calculation. They are further applied to form the broad group cross sections which are turned to the diffusion and burnup calculations.

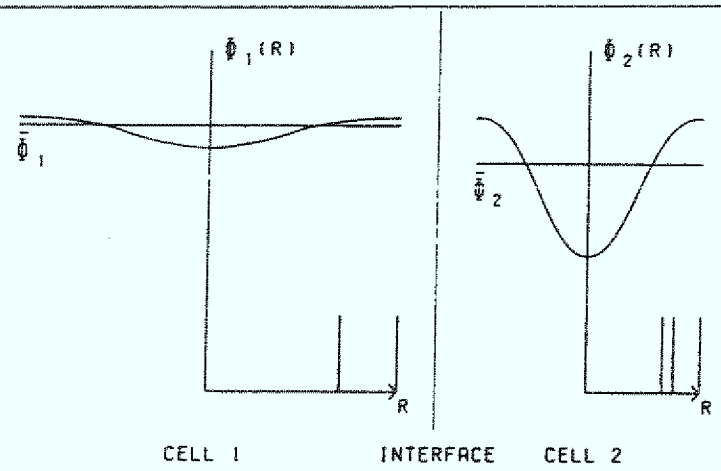

Fig. 6. Space Dependent Neutron Flux of two Adjacent Fuel Elements

Under given definition of the $SF_{kg} = \dfrac{\phi_{kg}}{\phi_{okg}}$, the neutron flux in the reaction rate has the meaning of the average cell flux ϕ_{okg}. Consequently, the neutron flux of the subsequent diffusion calculation has also the meaning of the average cell flux. In multi-region diffusion calculation, however, the meaning of the neutron flux must be the flux at the outer edge of the cell. This is because solution of the diffusion equation is based upon steady coupling of the neutron flux at the interface between neighbouring spectrum zones. And steadiness is given for the flux at the outer edge of the cell, but not for the average cell fluxes, as indicated in Fig. 6. The neutron flux at the outer edge of the cell is approximately equal to the flux of the outer cell zone $\phi_{NK,g}$. We can account for this by rewriting the reaction rate into

$$RR = \sum_{g=1}^{NG} \sigma_g^{**} \cdot N_o V_o \phi_{NKg}$$

with

$$\sigma_g^{**} = \sigma_g^{*} \cdot \frac{\phi_{og}}{\phi_{NKg}} = \sigma_g \cdot SC_g \cdot \sum_{k=1}^{NK} ANT_k \cdot SF_{kg}^{*} \quad .$$

Here, the neutron flux-selfshielding factor is modified into

$$SF_{kg}^{*} = SF_{kg} \cdot \frac{\phi_{og}}{\phi_{NK,g}} = \frac{\phi_{kg}}{\phi_{NK,g}} \quad .$$

When defining selfshielding factors in this way, the code applies the modified cross sections σ_g^{**}, and the neutron flux has the meaning of the flux in the outer cell zone. This is more adequate for the diffusion calculations.

The selfshielding factors SC_g, SF_{kg} (or SF_{kg}^{*}), and the fractional density distribution ANT_k are given at the input cards G9 - G11. They can be given in few broad energy groups I. The code books them into the respective fine groups g.

Further, the NXS different spectrum zones can be supplied with different sets of self-shielding factors. Every set must be defined by the set of cards G7 - G11.

3.2.4 Leakage Feedback in the VSOP

The 2 dimensional diffusion run by the CITATION module provides leakage terms L_{SI} for the different spectrum zones S and coarse energy groups I (option IBUCK > 0 on card V2). They are available for the subsequent spectrum run. For the first spectrum run at the beginning of the reactor life all leakage terms are given as $L_{SI} = 0$. Startup leakage terms can be generated by running a dummy initial burnup cycle of a very short time interval, e.g. 1 minute.

For the epithermal coarse groups the leakage terms are transformed into bucklings

$$B_{SI}^2 = \frac{L_{SI}}{D_{SI} \cdot \Phi_{SI} \cdot V_S}$$

which are needed by the P1 approximation of the GAM code. Under the option IBUCK = 1 the bucklings are directly booked into the corresponding fine groups. Under the option IBUCK = 2 the code prepares one average epithermal buckling to be booked into all fine groups of the GAM. In some cases the use of 3 coarse group bucklings led to unreliable results, being strongly dependent on the coarse energy group structure. But stable results are obtained by application of one single averaged buckling.

For the thermal cell code THERMOS the thermal leakage is transferred into the albedo at the surface of the cell /21/.

$$\alpha = \frac{J_-}{J_+}$$

This is the ratio of the current J_- of neutrons entering the cell divided by J_+ leaving the cell. The partial currents are given by

$$J_- = \frac{\Phi_0}{4} - \frac{1}{2} J_0$$

$$J_+ = \frac{\Phi_0}{4} + \frac{1}{2} J_0$$

in which $J_0 = J_+ - J_-$ is the net current leaving the cell per cm² /22/.

The net current of the cell is equal to the ratio of the leakage L_C of the cell per surface S_C.

$$J_0 = \frac{L_C}{S_C}$$

The leakage of one cell is equal to the leakage L_S of the whole spectrum zone divided by the number of cells in the spectrum zone, as given by the ratio of the volumina V_S/V_C of spectrum zone and cell.

$$L_C = L_S \cdot \frac{V_C}{V_S}$$

Further the neutron flux Φ_0 at the surface of each cell is equivalent to the average neutron flux Φ_S of the whole spectrum zone. As a result the albedo is

$$A = \frac{1 - 2\dfrac{L_S}{\Phi_S \cdot V_S} \cdot \dfrac{V_C}{S_C}}{1 + 2\dfrac{L_S}{\Phi_S \cdot V_S} \cdot \dfrac{V_C}{S_C}}$$

In the case of a spherical cell of the pebble bed the V_C includes the volume of the void per cell, but S_C is just the surface of the cell.

3.3 Design Specifications

The aim of the VSOP is to allow simulation of all types of thermal reactors and of their fuel cycles. Therefore, high flexibility is required for the design of fuel elements, of the reactor lay-out and of the fuel management. This has been achieved in the past by the adaption of the code to various reactor systems with specific lay-out requirements. Especially, the studies of pebble bed reactors with many choices of operation caused us to introduce flexibilities in treating mixtures of fuel elements, onload fuel shuffling, and

simulation of closed cycles. The design features included are automatically turned to the different code members.

3.3.1 Fuel Element Design (by DATA-2)

Basically the VSOP requires atom densities homogeneously distributed for the many different batches in the reactor. For spectrum cell calculation the THERMOS code requires information how to form a cell configuration and how to distribute the different nuclides in the cell (cards T6 - T10). Further cell zone and fuel element instructions are needed for the epithermal selfshielding factors, for resonance integral calculation, for the thermal hydraulics part, and for the cost calculations.

For the High Temperature Reactors both with spherical and prismatic fuel elements the design of the elements is more complex than for the other reactors because the fuel is contained in coated particles which are embedded in a graphite matrix forming the fuel zone of the fuel elements. Here, the auxiliary program DATA-2 can be applied prior to a VSOP run. It is fed with basic design data and delivers all relevant fuel element information to a data set unit. Data can be prepared for different types and variants of fuel elements, and they are ready for use in different parts of VSOP instead of giving them in an explicite input.

3.3.2 Reactor Lay-out (by BIRGIT, TRIGIT)

Geometric design of the reactor is provided in an auxiliary code named BIRGIT (2-d) or TRIGIT (3-d). The input of VSOP only requires the material data to be loaded into that geometry. The BIRGIT code must be run prior to the VSOP. Geometric data can be stored at a permanent data set thus saving repeated running of the BIRGIT.

In the VSOP the basic unit of reactor material compositions is named a "batch". For the first core loading the reactor design must be subdivided into batches. They all must be loaded with fuel material or, at the outside, with the materials of the reflectors etc. The calculational follow is individually performed for every batch: That is the follow of the burnup, of fuel shuffling, cost evaluation, and of the afterheat production in accident simulations.

In many cases different types of fuel elements, or elements of different irradiation ages are mixedly inserted in the reactor. They are exposed to the same local neutron flux. For that purpose a mix of the respective batches can be put together forming a "layer". These layers really present partial volumes $V(l)$ of the reactor, which provide the dis-

tribution of materials (and their cross sections) for the 2-dimensional calculation of the neutron flux (Fig. 7). Further, some larger number of batches are grouped together forming "spectrum zones". Spectrum calculations are based on the averaged atom densities of these zones. They provide the broad group cross sections for the respective batches.

In the pebble bed reactor the fuel elements move downward in a given flow pattern which is gained from the experimental research on test facilities. Here, the shape of the layers and their shuffling must fit into the flow pattern. On the other hand the calculation of the neutron flux is performed by the CITATION code /15/, and this is confined to a pattern of "CITATION-compositions" $W(J)$ with perpendicular boundaries in r-z coordinates. Similarly the thermal hydraulics code member THERMIX /17/ is subject to a mesh lattice of perpendicular r-z coordinates. Transfer of the relevant data from the VSOP-layers to CITATION and back is provided by a volume matrix being generated in the auxiliary code BIRGIT prior to the VSOP run.

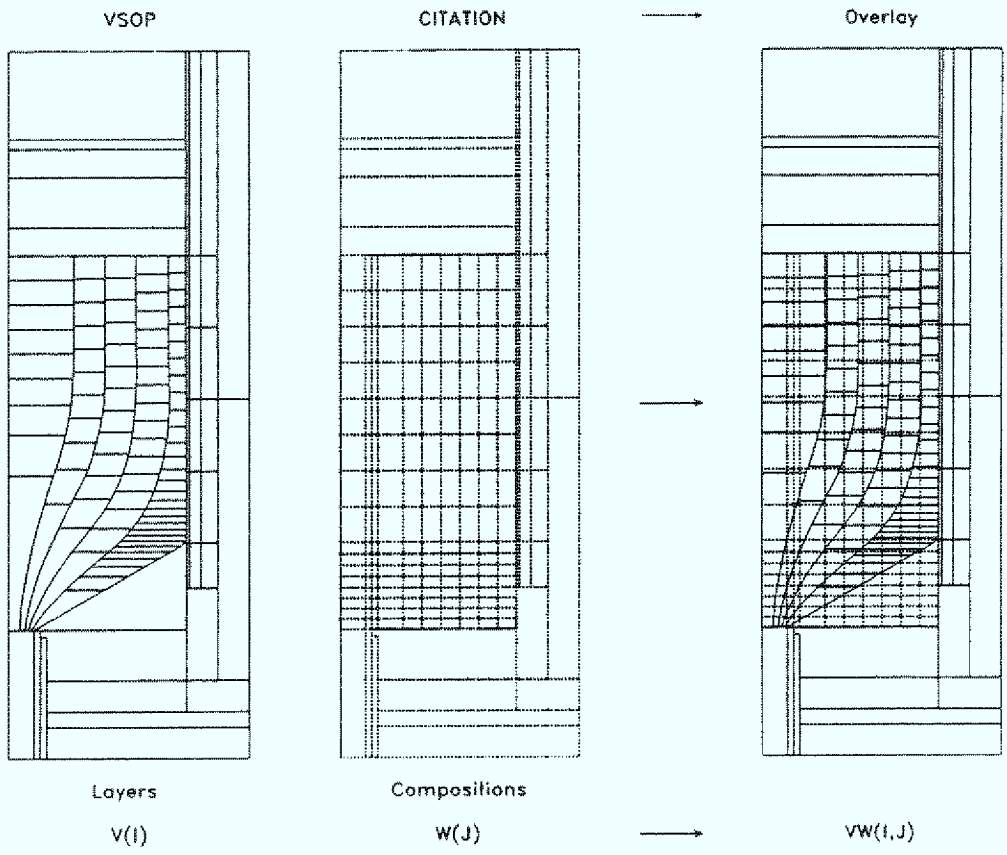

Fig. 7. Overlay of VSOP-Layers and CITATION-Compositions

The BIRGIT code generates both VSOP layers $V(I)$ and CITATION compositions $W(J)$. Herefrom it synthesises a matrix of volumes $VW(I,J)$, which is the overlapping set of the $V(I)$ and $W(J)$ as shown in Fig. 1.

The transfer of data between VSOP and CITATION proceeds as follows:

- Macroscopic cross sections Σ are made for the VSOP batches, and thereafter for the VSOP layers: $\Sigma(I)$.
- The $\Sigma(I)$ are converted into macroscopic cross sections $\Sigma(J)$ of the CITATION compositions by

$$\Sigma(J) = \frac{\sum_I \Sigma(I) \cdot VW(I,J)}{W(J)}$$

- CITATION provides criticality and neutron flux calculation.
- Neutron fluxes $\Phi(J)$ of the CITATION compositions are transformed to fluxes $\Phi(I)$ of the VSOP layers by

$$\Phi(I) = \frac{\sum_J \Phi(J) \cdot VW(I,J)}{V(I)}$$

and this is applied for the further burnup calculations of the VSOP batches.

Analogeously the BIRGIT provides a transfer matrix $VW(I,K)$ between the VSOP layers $V(I)$ and the fine mesh volumes $W(K)$ of the code member THERMIX (Fig. 8). Here, the power distribution, fast neutron dose, local decay heat function, and spectrum zones identification numbers are turned to the THERMIX. The temperatures of the fuel and moderator of the different spectrum zones are turned back.

As seen from Fig. 7, the two different mesh grids overlap in the area of the core. But they are congruent in the reflector.

An overall coarse mesh design of the reactor is defined by the cards BI6 - BI8. The compositions of the reflector are marked by preliminary identification numbers, whilst the core area is marked by zeros.

For the VSOP the cards BI3 - BI5 define the flow channels of the spheres in the core. The limiting curves of the channels are defined by few coarse points, and the curves are

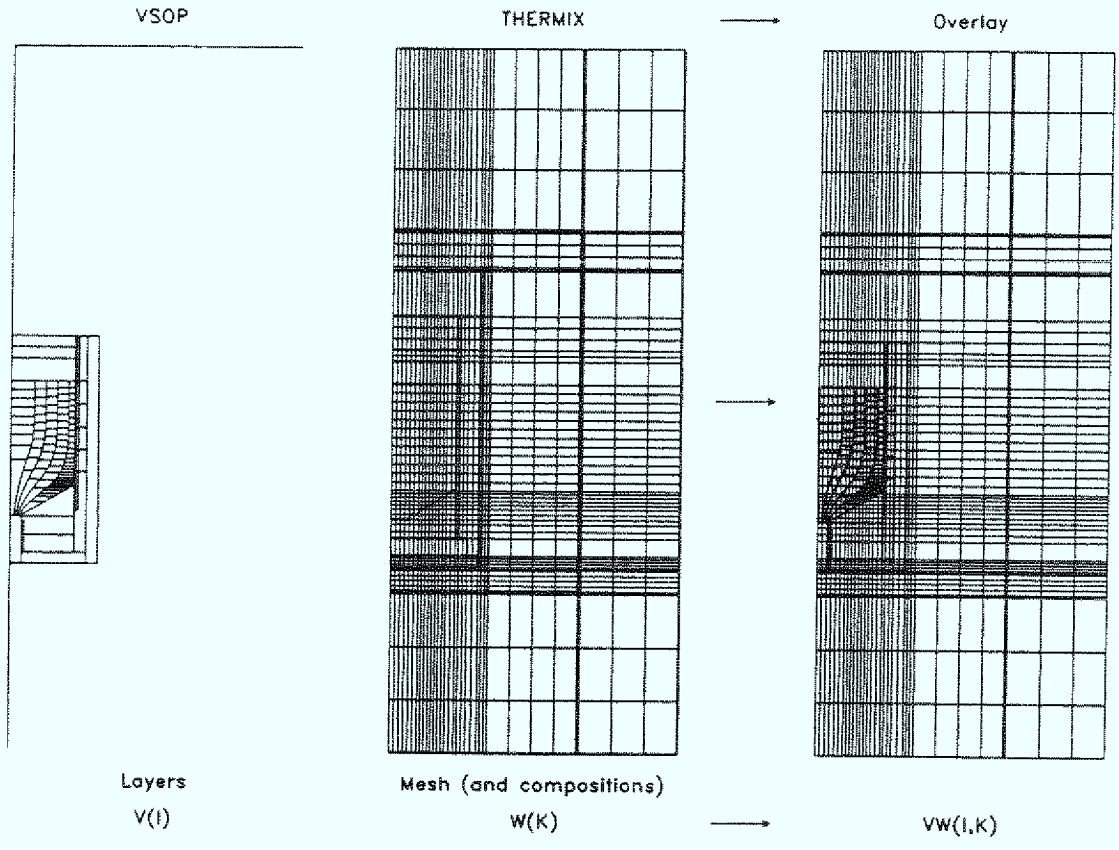

Fig. 8. Overlay of VSOP-Layers and THERMIX-Meshes

gained by interpolation. The radial position of the coarse points can internally be modified in order to adjust the channel volume to a given value. Each channel is subdivided into layers $V(I)$, which are numbered by the code from top to bottom starting with the first inner channel. Subsequent upon the highest layer number of the core the reflector layers are renumbered in the order as given on the card BI8.

For the CITATION layout of the core a finer mesh pattern is defined by the cards BI9, BI10. Every coarse mesh represents an individual CITATION composition $W(J)$. They are numbered by the code from top to bottom starting with the first inner column. Subsequent upon the highest number new numbers are assigned to the reflector compositions just in the order as given on the card BI8. It is important to note that the number of CITATION compositions is limited to 1515.

The matrix of volumes $VW(I,J)$ is derived in the following way: A very fine mesh grid of an elementary volume of few cm^3 is superposed over the given grids (card BI2). For

every little mesh the code identifies the respective $V(I)$ and $W(J)$ in which it is located. It adds the elementary volume to the corresponding element of the $VW(I,J)$ volume matrix. For a very small elementary volume of few cm^3 the computing time comes into the order of 1/2 hour. Therefore the matrix can be stored on a permanent data set for the use in later runs of the identic layout.

The automatic assignement of VSOP layers and CITATION compositions can also be applied for parts of the reflector. On card B18 these parts must be marked by "-1" instead of "0" in order to inform the program that the area is non power generating.

For the THERMIX code the overlay can be defined in the same way. But it is easier to define the overlay only for the area of the core, in which the power production takes place. The return of temperatures to the reflector spectrum zones is made by the code independently from the volume transformation of the BIRGIT.

Similarly TRIGIT prepares the geometric design in 3 dimensions (x-y-z). Here, of course, VSOP layers and CITATION compositions must be identic, and the volume matrix is $VW(I,J) = V(I)$ when $I = J$ or $= 0$ when $I \neq J$. For the 3-dim. version the possible number of CITATION compositions has been extended up to 9999!

3.3.3 Burnup Time Steps

The reactor life time simulation is an alternation between burnup calculation of the batches and their shuffling. One burnup cycle is the phase between two shuffling steps. It is subdivided into JNSTOP "large burnup time steps" at which the diffusion calculation can be repeated. Optionally spectrum calculations and/or control poison adjustments can also be repeated.

The large time steps are subdivided into JNUM "small time steps". At these steps the field of neutron flux is kept unchanged, but its absolute value is readjusted to the given power production of the core, thus compensating for the depletion of the fissile isotopes.

3.3.4 Out of Pile Fuel Positions

During the burnup cycle the many batches of the reactor (core, reflectors etc.) are stored in an array in the COMMON. The atom densities are subject to burnup.

Prior to shuffling the content of all batches is copied to the data set unit 11 being defined in direct access. The contained material is identified by its fuel type id.number, volume,

residence time etc. From here the batches are shuffled into their new batch positions in the array as specified on cards R24.

Beyond the batches of the reactor there are numerous further positions reserved, which represent Out of Pile Fuel Positions. They serve as storages for the fresh fuel, and for the unloaded fuel which can be reinserted into the reactor, or stored, or reprocessed, or removed and sold, respectively. Four different types of Out of Pile Fuel Positions can be defined (see Fig. 9):

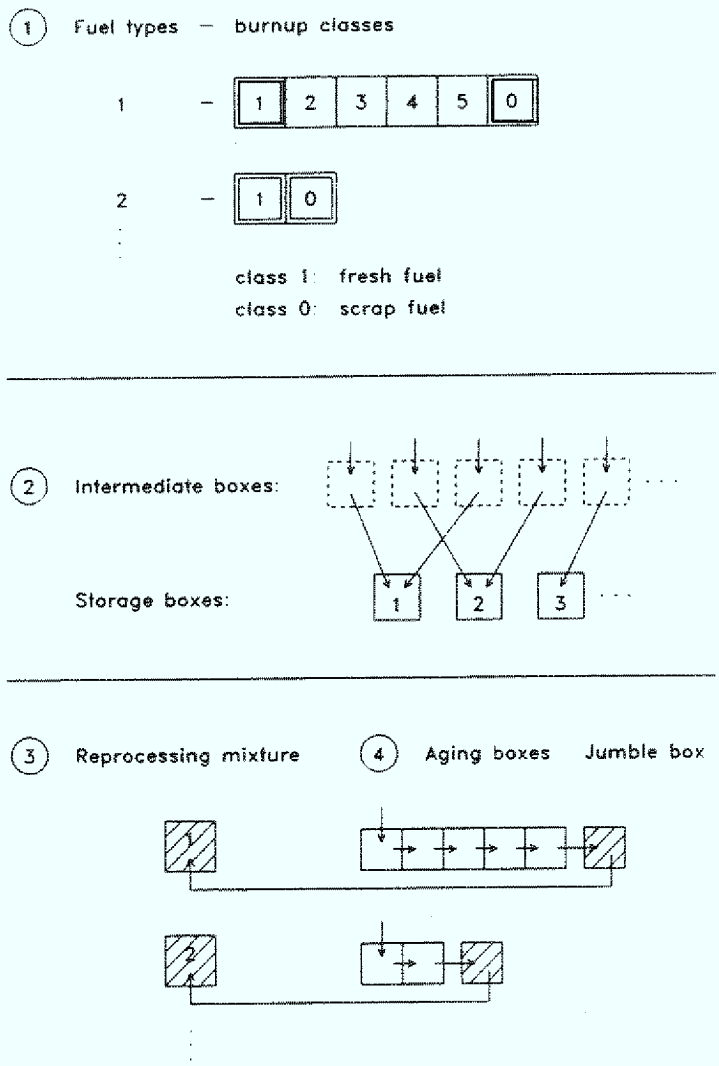

Fig. 9. Out of Pile Fuel Positions

1. "Fuel types and their burnup classes". In course of the shuffling the reactor batches can be loaded with fuel from these Fuel Positions. They can be defined for 1 to 10 different fuel types.

   The burnup class 1 represents the storage of the fresh fuel for every fuel type. The higher burnup classes contain the unloaded fuel of the preceding shuffling step. The burnup class 0 contains scrap fuel.

   After the shuffling of the batches of the reactor is finished, the remaining fuel of the burnup class 0 is removed. It can be sold or transmitted to a reprocessing mixture. After that, the remaining fuel of the higher burnup classes (≥ 2) is filled into this burnup class 0. Also crashed fuel elements are turned to the class 0. After that, all fuel of the reactor is considered which has not been used in the shuffling specifications of the reactor batches. It is loaded into the respective burnup classes, and here, it is ready for use in the next shuffling step.

2. "Storage boxes". Shuffling specification of the cards R24 can also direct fuel into storage boxes. Temporarily it is stored in intermediate boxes, because the content of the storage boxes stems from the preceding shuffling and is available for reinsertion at the present shuffling.

   After the shuffling is finished the remaining fuel of the storage boxes is turned to the scrap fuel (class 0) of the respective fuel types. Thereupon, the content of the intermediate boxes is directed into the storage boxes, being ready for use at the subsequent shuffling.

3. "Reprocessing mixtures". The scrap fuel (class 0) of one or more fuel types can be directed into a reprocessing mixture. Here, the amount of fuel adds up from cycle to cycle, and parts of it can be used for recycling. Re-use of the fuel can be defined with reprocessing and refabrication of new fuel elements.

4. "Aging boxes". This is an extension of the reprocessing mixture option, which simulates an intermediate storage for isotopic decay. This option allows real bookkeeping of the out of pile fuel inventories with given decay periods prior to reprocessing. It has been developed for simulation of closed fuel cycles.

   The scrap fuel is firstly turned to a sequence of aging boxes in which the decay proceeds over a given period of time. For that time the fuel is bound to the out of pile storage and not available for re-use. The last box (named jumble box) is reserved for accumulation of the fuel which has gone through the aging period. At every

shuffling step its content is turned to the respective reprocessing mixture for the purpose of re-use. After the shuffling is finished the amount of unused fuel is turned back to the jumble box.

3.4 Reactor Operation

As seen from the input manual, the design of reactor life time follow requires information of many different physical events which are mutually coupled with each other (cp. Fig. 1). The user should be familiar with the respective physical laws and with their calculational representation. For the design of a new case it is a great help to start from the input listing of a similar design case. Beyond the input description, however, the following comments might give a further help in setting up a reactor simulation.

3.4.1 First Steps of a Life Time Follow

Startup of reactor life simulation begins with spectrum calculation followed by a diffusion run and subsequent burnup cycle. Actually, the spectrum calculation requires information of the neutron exchange between the spectrum zones, which results from leakage evaluation of a forgoing diffusion run. Further, it requires the ^{135}Xe-concentration of a relevant burnup evaluation. The code does not contain an iteration on these features, but such iteration can be simulated by a short startup cycle of 2 or 3 time steps with repeated spectrum and diffusion calculation. The length can be selected few seconds (e.g. DELDAY = 0.0001 on card V15), which keeps the burnup neglegible. ^{135}Xe buildup must be defined by the equilibrium option (IXEN = 0 on card V10). That cycle can be followed by a first shuffling step which leaves all batches in their position (NKEEP = 2 on card R9). By this way startup conditions are readily prepared.

For the repeated calculation of the thermal neutron spectrum an efficient acceleration is included in the code: It just preserves the field of neutron flux and provides it as startup guess for the subsequent calculation. The same idea is followed for repeated diffusion calculations. If during the burnup periods in between the isotopic concentrations change only slightly, the number of iterations is reduced by that measure about 90% or more.

Another acceleration of the burnup calculation is left to the user. If for some period of reactor life the demands upon accuracy are less stringent, he can decide to drop spectrum and diffusion calculations for that period at all. Burnup calculation (of course with repeated renormalization of the flux level) and shuffling performance proceed very fast.

3.4.2 Restart

When the option of preparing restart data is defined (JTPE9 > 0 on card V2), the code prepares two different data sets for the use at restart:

- Unit 20 will be loaded with the basic informations of the spectrum calculation, i.e. libraries, group structure, cell structure etc. It will be written at the end of the first burnup cycle.

- Unit 15 will be loaded with the information of an individual status of reactor life, i.e. broad group cross sections, atom densities of the batches, shuffling scheme etc. It will be written at the end of the last burnup cycle of the run. The code still performs the specified shuffling and sets all definitions for the next cycle. Thereupon, instead of starting the next cycle, it writes the relevant information to the unit 15 and turns to the end of the run.

When performing the restart, the code reads the units 20 and 14. The unit 14 must contain the information formerly being written on unit 15. By this way writing of another set of restart data is possible on unit 15 at the end of this restart run.

After reading the two data sets the code follows the burnup cycle as defined before. Prior to the first diffusion calculation, however, the code again requires the full input of CITATION (cards C0-1 - CX-1), because the diffusion calculation starts from scratch. By this way it is possible to provide a modified mesh structure for the diffusion calculation, or a modified output option, or even a modified geometric design of the reactor layers if desired by the research plan, respectively.

As an option card R8 allows to change various informations for the first cycle of the restart. This can favorably be used to direct the reactor into a special status for detailed research.

For parametric research at restart, precursory steps are recommended as follows:

1. Directing the reactor into the status of consideration.
2. Performing a shuffling which keeps all batches in their positions (NKEEP = 2 on card R9).
3. Defining a short (dummy) burnup cycle (e.g. DELDAY = 0.0001) of 2 or 3 time steps with repeated spectrum and diffusion calculation, and with ^{135}Xe-equilibrium option IXEN = 0. By this way leakage feedback and Xenon distribution will be stabilized.

4. Performing of another shuffling with unchanged batch positions and defining explicite follow of the ^{135}I- ^{135}Xe concentrations by IXEN = 1. By this way Xenon concentration remains almost unchanged over following short time steps, even when neutron flux or power is considerably influenced by given operational changes. Additionally in this shuffling step the changes can be defined, which are the matter of research.

By this way parametric research can easily be made at different time steps of the reactor life history, i.e. at selected time steps of the running-in period or at different time steps of an annual loading cycle. Research can be applied for simulation of load follow, performance of the control system, reactor shut down, temperature coefficients, water ingress in HTR systems, thermal evaluation, for the follow thermal transients at accidents etc.

3.5 Fuel Cycle Costs

Evaluation of fuel cycle costs is based on the present worth method. It is performed by the cost calculational modul KPD /18/ which is also available in a stand-alone version.

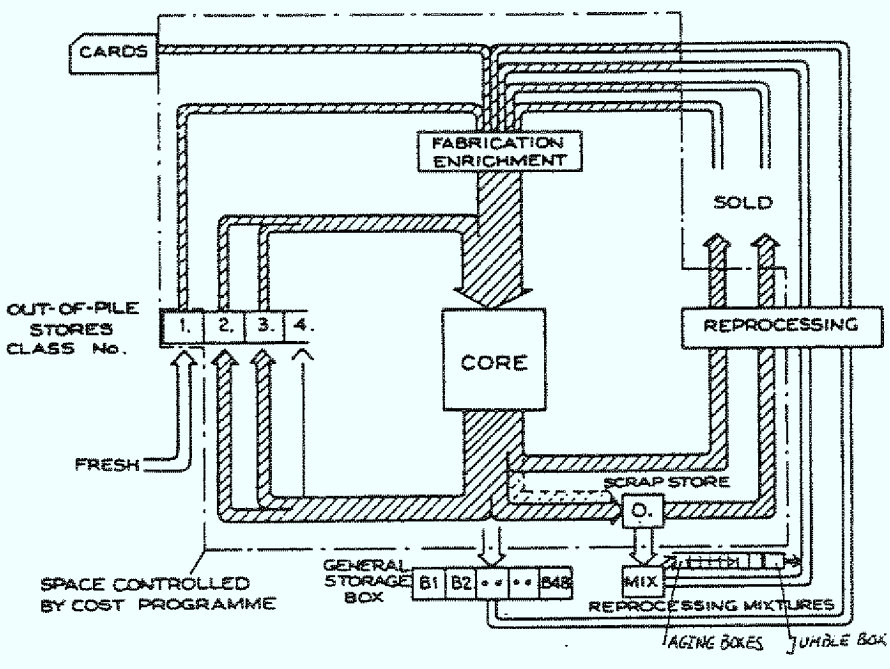

Fig. 10. Scheme of the Possible Variants of the Out-of-Pile Fuel Management

Before and after every step of fuel shuffling, the code accepts the inventories of the heavy metal isotopes of all in-core batches and of the out of pile fuel types. All fuel which en-

ters the system is regarded as bought, and the fuel leaving the system is regarded as sold (Fig.10). Basing on that knowledge the code evaluates expenditures and revenues individually for every burnup cycle. Herefrom it prints the fuel cycle costs of every cycle, being dated to the beginning of the cycle.

Life time - fuel cycle costs are derived from the individual cycle - fuel cycle costs being re-dated to the startup of the reactor operation. For that evaluation the last cycle of the run is considered as an equilibrium cycle. It is considered to be identically repeated up to the end of reactor life time.

An important role play the delay times of payments and revenues, especially for the costs of fabrication and spent fuel storage. The many choices of lead and lag times are shown in Fig. 11. They are grouped together as also shown in that figure.

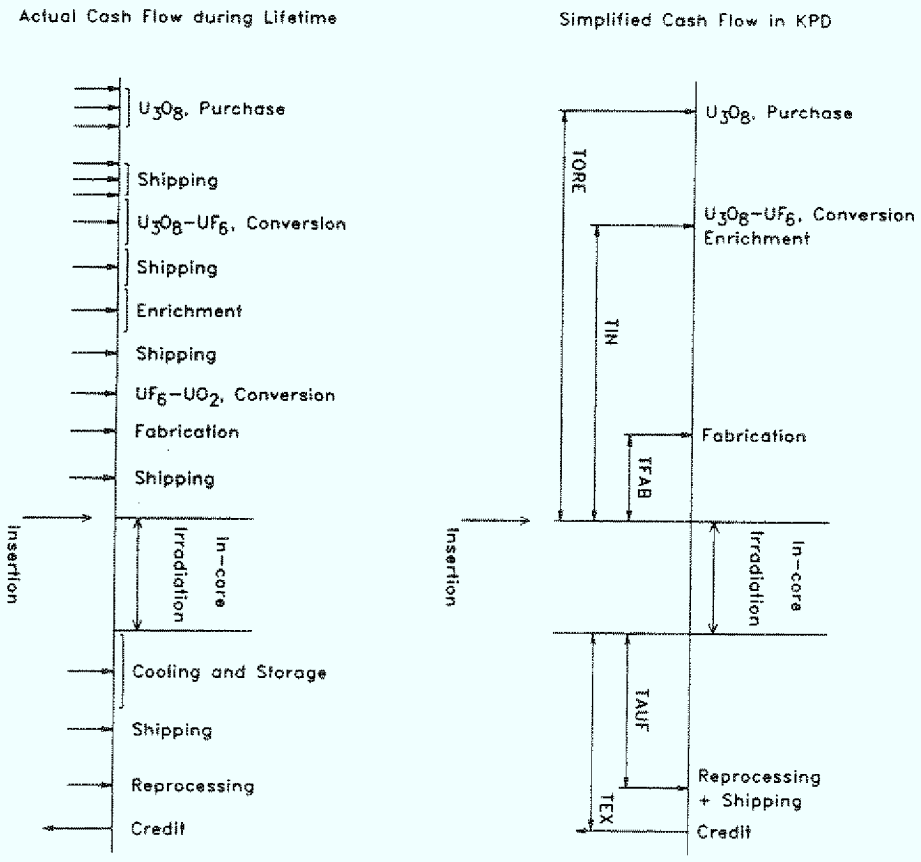

Fig. 11. Lead and Lag Times of Payments

Break down of the fuel cycle costs is given in four different terms:

1. Fuel costs include the expenditures for the fuel and working capital costs.
2. Revenue for the spent fuel assumes reprocessing. In case of final storage it can be nullified by depreciation factors on card K8.
3. Fabrication costs, which also include the refabrication in closed cycles.
4. Reprocessing costs, which more accurately should be named "spent fuel handling costs", because it could also be the costs of final storage if an adequate figure is given for the input of CAUF on card K7.

The whole history of the reactor life time can be given to a cost library (see Fig. 1). Here it is available for the stand-alone version of the KPD code. By this way parametric research is possible for the many cost input data. The running time of one case is in the order of few seconds.

3.6 Thermal Hydraulics by the THERMIX Code

The THERMIX-KONVEK code has been developed for thermal hydraulics evaluation of the pebble bed HTR in two dimensions, r-z geometry /17,23,24/. The code calculates

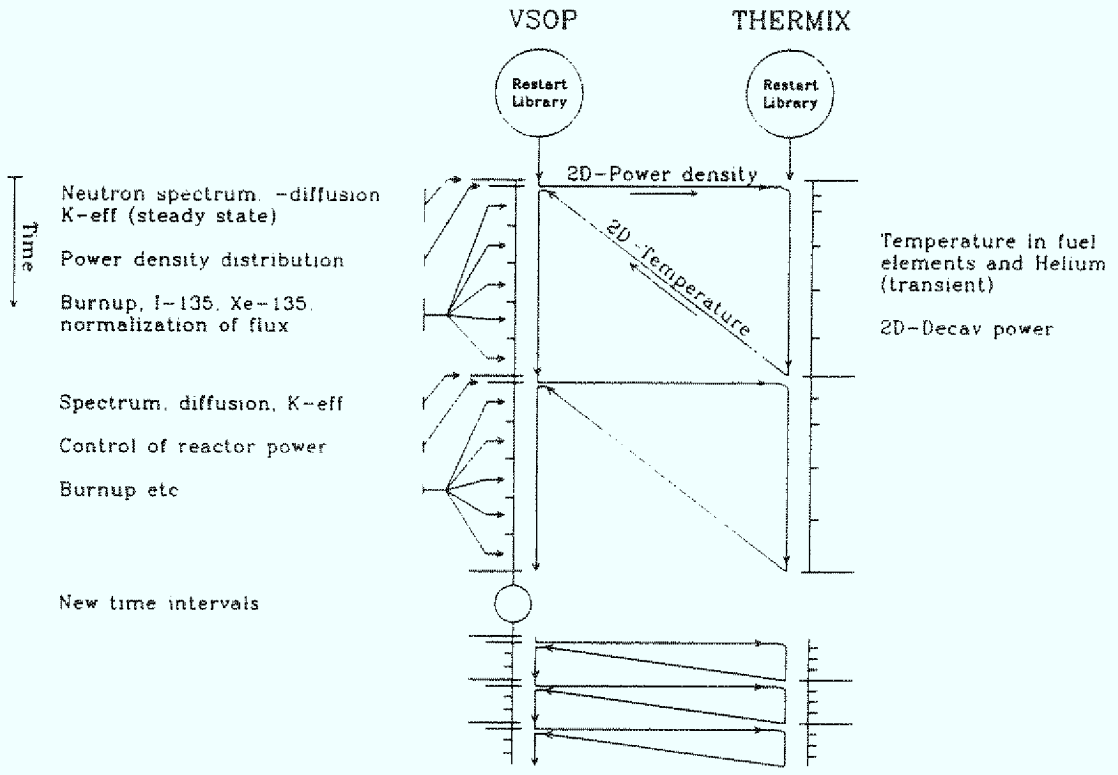

Fig. 12. Coupling between Neutronics and Thermal Hydraulics

the temperature and flow conditions for steady state conditions and for transient conditions which follow shutdown of the reactor.

The code is linked into the VSOP as to Fig.1. At given timestep it receives the power distribution of the reactor from the nuclear code modules. It returns the corresponding temperatures of the fuel and moderator averaged over the volumes of the reactor spectrum zones, being ready for further neutronics evaluation (Fig. 12).

3.6.1 Basic Equations

The calculation of the overall heat transmission is synthesized of the coupling of different physical equations which represent conservation laws. The equations are solved individually and the synthesis is made by a superposed iteration (Fig.13).

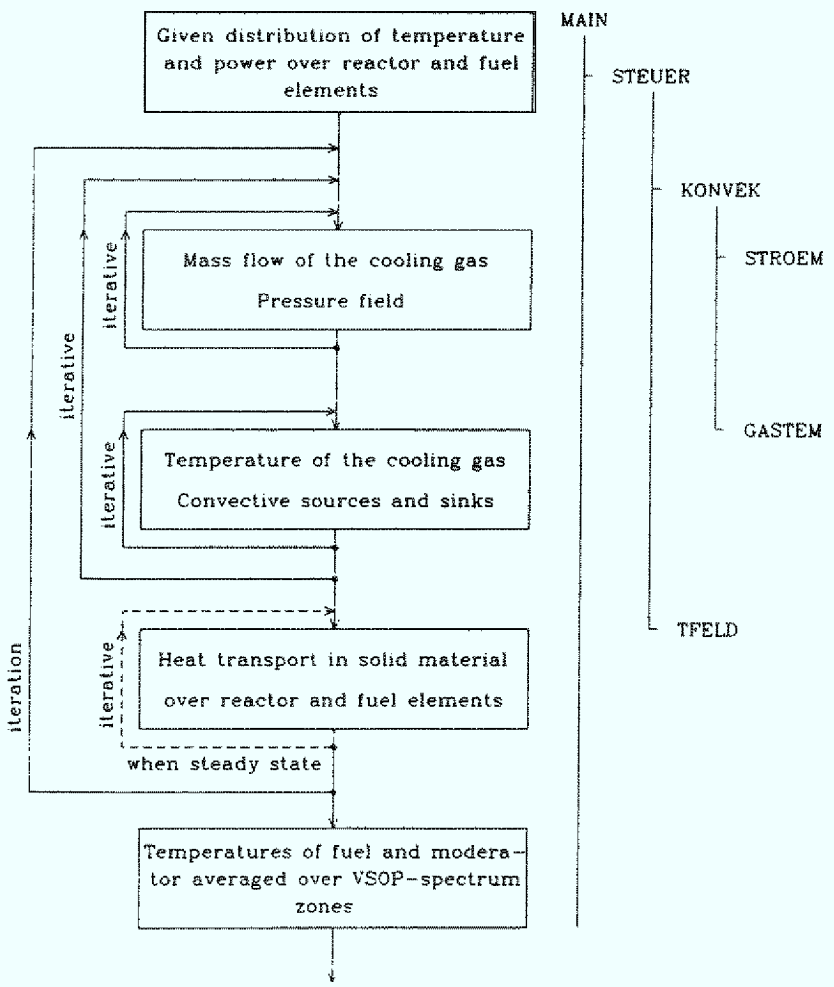

Fig. 13. Flow Scheme of the THERMIX

The conservation of mass of the cooling gas in quasi-static representation yields the mass flow vector $G = \rho_G \vec{v}$ over the circuit. It is given by

$$\nabla \rho_G \vec{v} = q \tag{1}$$

where

ρ_G = density of the cooling gas [kg/m^3]
$\vec{v}$ = velocity [m/s]
q = mass source rate density [kg/s/m^3]

The conservation of momentum quasi-static representation yields the pressure field p over the circuit. It is given by

$$\nabla p - \rho_G \vec{g} + \vec{R} = 0 \tag{2}$$

where

p = static pressure
$\vec{g}$ = gravity
$\vec{R}$ = frictional force

Eq. (2) gives the balance of the gradient of the pressure, the hydrostatic force of the gravity, and the frictional force per unit volume. The spatial acceleration and inertia are neglected. According to Ref./25/ the frictional force is given by

$$\vec{R} = \frac{\psi}{d} \frac{1-\varepsilon}{\varepsilon^3} \frac{|G|}{2\rho_G} \vec{G}$$

where

ψ = pressure loss coefficient for flow through pebble bed
(given in Ref./25/ as a function of the Reynold number)
d = pebble diameter

Evaluation of the equations (1) and (2) is done in the subroutine STROEM.

The conservation law of the energy in quasi-static representation yields the gas temperature field T_G :

$$\nabla \lambda_G \nabla T_G - \nabla(\rho_G \vec{v}\, c_p\, T_G) + \alpha \frac{F}{V}(T - T_G) = 0 \qquad (3)$$

where

c_p = gas specific heat capacity
λ_G = effective thermal conductivity of the gas due to dispersion
T = temperature of the solid, e.g. at surface of the fuel elements
$\alpha \frac{F}{V}$ = coefficient of heat transition between the solid and gas

In eq.(3) the first term gives the heat transport in the gas by thermal conduction. The second term is the heat transport according to the mass flow of the gas. The third term is the heat source or sink due to heat transition between the gas and the fuel elements. The compressive work term and time dependent energy storage are neglected. Eq.(3) is evaluated in the subroutine GASTEM.

For given temperature field T of the solid material, the quasi-static status of the gas is derived by the code member KONVEK. It contains an iterative procedure between the subroutines STROEM and GASTEM.

The conservation law of energy in the solid material is evaluated in the dynamic representation. It yields the temperature field T:

$$\frac{\partial(\rho\, c\, T)}{\partial t} = \nabla \lambda_{eff} \nabla T + \alpha(T_G - T) + Q \qquad (4)$$

where

T = $T(\vec{r}, t)$ temperature of the solid, i.e. at the surface of the fuel elements, in reflectors, etc.
ρ = density of the solid
c = heat capacity
λ_{eff} = effective thermal conductivity, which includes thermal conduction and radiation
α = coefficient of heat transition between gas and solid
Q = $Q(\vec{r}, t)$ nuclear heat source

In eq.(4) the time dependent change of the energy per volume results from the balance of heat transport by thermal conduction (first term), from the heat sink due to the heat transition to the gas (second term), and from the heat source due to the nuclear power production and decay heat (third term).

In the inner of the fuel elements the temperature distribution T_F is also given by the conservation law of energy in time dependent representation:

$$\frac{\partial(\rho\, c\, T_F)}{\partial t} = \nabla\lambda\, \nabla T_F + Q \tag{5}$$

where c and λ are dependent on the local temperature T_F. At the surface of the fuel element the temperature T_F is equal to T of the eq.(4) at the respective position in the reactor.

Both eq.(4) and (5) are solved in the subroutine TFELD. Under steady state condition an iterative procedure is between the TFELD and KONVEK routines, which yields a consistent solution for the temperatures of the solid and gas. Under dynamic condition the time dependent changes of T and T_F are explicitely followed. Here, the time dependent changes of the heat source Q are also included which are due to given changes of the power or of the isotopic decay heat. At any time step the status of the gas is solved in the static representation.

3.6.2 Coupling with Nuclear Routines

In VSOP the included THERMIX is operated by its own input section. By far, the input is that of the stand-alone version. Major changes have been made for the geometric design and for the data to be transmitted between the code members. The transfer is made via the matrix of partial volumes $VW(I,K)$ as explained in section 3.3.2 (see Fig. 8).

The transmission from VSOP to THERMIX is made for the following data fields:

- Power density of VSOP batches is transformed to power density of layers. Applying the matrix $VW(I,K)$ it is converted into power density of the THERMIX mesh grid. Here it is normalized to given integral power or, by option, to any other integral value.

- Fast neutron dose is transformed analogeously. It is applied in calculation of thermal conductivity in the fuel elements, which can be given as a function of temperature and fast dose.

- Decay power can be individually evaluated for every VSOP-batch during a thermal transient follow (section 3.7). The transformation is made analogeous to the power density.

– Assignement of spectrum zones of VSOP batches is also transmitted in that way.

Out of the local heterogeneous temperature calculation the THERMIX prepares the temperature of the fuel and moderator for each mesh. Average values are prepared over the areas of the spectrum zone assignments. They are returned to VSOP for subsequent neutron spectrum calculations (see Fig. 12).

3.6.3 Thermal Conductivity of Graphit and Pebble Bed

Thermal conductivity λ of graphite is a function of four parameters:

1. Type of graphite material due to its fabrication techniques,
2. Temperature T,
3. Fast neutron exposure D,
4. Temperature at which the fast neutron exposure occurred.

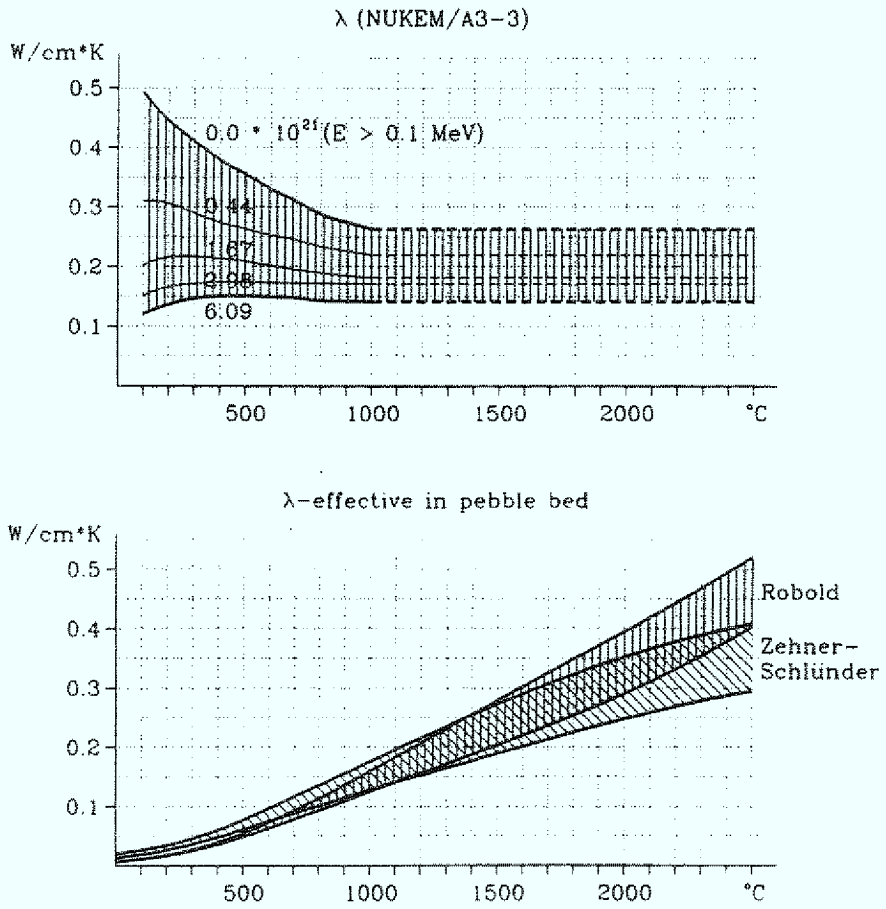

Fig. 14. Thermal Conductivity

Broad experimental research on that has been performed by L.Binkele /26/.

As an example Fig. 14 gives $\lambda(T, D)$ for the NUKEM/A3-3 graphite being exposed to fast flux under the temperature of 950°C. Measurements have been made at 10 different temperatures (100 ... 1000°C) and for 5 different status of fast neutron exposure (0 ... 6.09 * 10^{21} [cm^{-2}] [E > 0.1 MeV]). For T > 1000°C experimental values are missing, therefore λ is assumed to be constant. That function $\lambda(T, D)$ is included in the code, but it can be replaced by any other field to be given as input.

For many other materials the functions $\lambda(T)$ are contained in the code. An overview of the contained functions is given in Tab. VIII. For more detailed information we would like to refer to the subroutine XLAMT. Similarily, the contained functions of the heat capacity (Tab. IX) are given in the subroutine WKPT.

Tab.VIII: Possible Formula of Thermal Conductivity

Id.no.	Material function of temperature and dose dependent λ	
1	Natrium (flüssig)	
2	Matrix-Graphit,	T = Bestr.Temp.
3	Reflektor-Graphit,	Interpolation aus Wertetabellen (siehe Subroutine GFIT)
4	EPS > 0.: Helium EPS = 0.: Stagnierendes Helium	LAM0 = Druck (bar) 1 bar
5	Kugelschüttung	Extrapolation aus neuen Barthels-Exp. mit korr. L-Matrix
6	Zehner-Schlünder für Steatit	Experiment (K. Verfondern)
7	Reaktor-Graphit	LAMBDA(0) = LAM(Komp.)
8	Kohlestein	nach Lukascewicz
9	Stagnierende Luft	1 bar
10	Thermischer Schild (HRB)	
11	V2A - Stahl (THYSSEN)	DIN 4541
12	Kugelschüttung	Breitbach / Barthels
13	Steatit	für heterogene Berechnung
14	Graphitkugeln (Abb. 6.2 b)	Experiment (Robold)
15	Stahlbeton	
16	Prismatisches Core	axial
17	Kohle- und Graphitfilz	in Vakuum
18	Kohle- und Graphitfilz	in Ar- oder N_2-Atmosphäre
19	Wälzlagerstahl	100CR6
20	Stagnierender Stickstoff	

21	Kaowool-Matten	in Luft (JÜL-992RB)
22	H A W - Glas	
23	Kugelschüttung	Schürenkrämer (II.84)
24	Kugelgraphit, Binkele/A3-Graphit	Temp.-Dosis-Abhängigkeit explizit
25	LAMBDA-eff. Kugelschüttung	Temp.-Dosis-Abhängigkeit (Robold)
26	LAMBDA-eff. Kugelschüttung	Temp.-Dosis-Abhängigkeit (Zehner-Schlünder)
27	LAMBDA-eff. Kugelschüttung	Temp.-Dosis-Abhängigkeit (Robold u. Zehner-Schlünder)
28	Al_2O_3	linear (Salmang/Scholz "Keramik")
29	Gilsonitkoks (AGL-IE 1-24)	bestrahlt bei 760°C (Binkele)

Tab.IX: Possible Formula of Heat Capacity

Id.no.	Material function of temperature dependent heat capacity	
6	Steatit (Magnesium-Silikat)	
7	Reaktorgraphit (HRB),	Dichte = 1.75 gr/cm^3
8	Kohlestein (wie Reaktorgraphit),	Dichte = 1.55 gr/cm^3
11	V2A - Stahl (HOESCH)	DIN 4541
12	Thermischer Schild (HRB)	
13	Reaktorgraphit (HRB),	Dichte = 1.70 gr/cm^3
14	Reaktorgraphit (HRB),	Dichte = 1.60 gr/cm^3
15	Reaktorgraphit (HRB),	Dichte = 1.80 gr/cm^3
16	Aluminium-Oxyd (Al_2O_3),	temperaturunabhängig

The heat transport through the bed of pebbles takes place partly by thermal conduction through the pebbles partly by thermal radiation from one pebble to the other. Theoretical models have been developed for describing the mechanism of heat transport. At the end an effective thermal conductivity $\lambda_{eff}(T, D)$ is defined which can be applied in the normal equation (4) of thermal conduction.

The model of Zehner-Schlünder accounts for the heat transport from one pebble to the next one according to figure 14. His finding is represented in the heat atlas /27/. It has been verified in experiments, and it is recommended for the pebble bed at low and medium temperatures.

The model of Robold /28/ takes special care of the radiational heat transport through the openings between the pebbles of the bed. Again it derives an $\lambda_{eff}(T, D)$ which is preferred at higher temperatures, i.e. for $T > 1400$°C.

Effective thermal conductivity of both models is given in Fig. 14. It is drawn both for the highest neutron dose and for the lowest one, and the hatched area between corresponds to the hatched area of the function $\lambda(T, D)$ of the graphite. In current calculation the code evaluates both models of Zehner-Schlünder and Robold, and it applies the respective maximum of the two models.

3.6.4 Local Decay Power for Transiental Accident Follow

The reactor power density is turned to the THERMIX in a 2-dimensional distribution, i.e. in r-z geometry. Calculation of the time dependent follow of the temperature distribution must be fed with the 2-d power density field in its dependency on time, which can be generated by the VSOP.

In case of shutdown under accidental condition the power density reduces to the decay power, which is also a 2-dimensional function. The THERMIX code has been made to understand the LIFE library (see Section 3.7.1). Herefrom it evaluates the decay power for every batch and forms it into the local decay power distribution at any time step after shutdown.

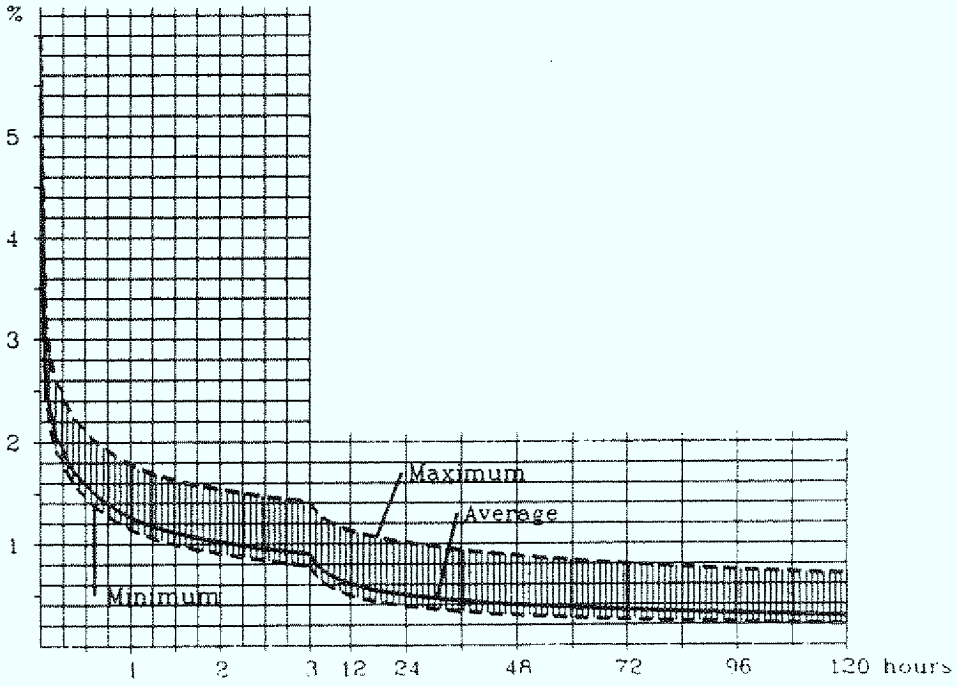

Fig. 15. Decay Power

The ratio of the local decay power at given time step divided by the local nuclear power at time t_0 of shutdown is the relative decay power. The variance of this function over the core is outlined in Fig. 15. It appears that the span between maximum and minimum (the hatched area) is considerably large. After 12 hours it becomes larger than the average over the core. Therefore, considerable effect on the heating of the fuel elements must be expected from an application of the correct 2-d-distribution of the decay power function.

3.7 Fuel Life History and Local Decay Power Evaluation

The core of a reactor is subdivided into layers being composed out of a mix of one or more batches (Section 3.3.2). These batches go through burnup and fuel shuffling. For the accident analysis the decay power of every batch is required as a function of its preceding life history.

In a VSOP run the data of the life history can optionally be preserved on data set unit 60 (NKEEP on card R9). From these data the auxiliary program LIFE prepares a LIFE library which is basic for the local decay power evaluation of the THERMIX. The LIFE library contains the relevant data of the prehistory of every batch in coarser time intervals, i.e. the power, burnup, fraction of fissions of ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu, ^{238}U, and capture of ^{232}Th, ^{238}U.

3.7.1 LIFE-Library

Most complex is the compiling of the life history for the multiple passes of the elements through the reactor. It is made by analogy with the fuel shuffling.

As an example a coarse shuffling scheme has been designed of only 2 flow channels and 3 passes through the reactor (Fig. 16). Every layer is filled with the mix of three batches, which is indicated by the dotted partition curves. In the second layer of the first flow channel the mixed batches are named A, B, C. Their power production Q during their pre-history is given in Fig. 17.

Batch A stayed in the present position for a half burnup cycle, and it was in the previous position for one full cycle. Before that it was loaded as fresh fuel.

For the batch B, the loading came from the storage box 1 containing the elements which have made before one pass through the core. Their pre-history is an average of the his-

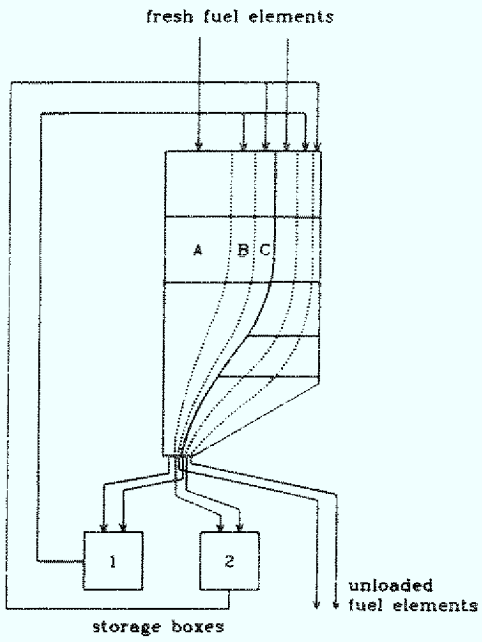

Fig. 16. Coarse Shuffling and Flow Scheme

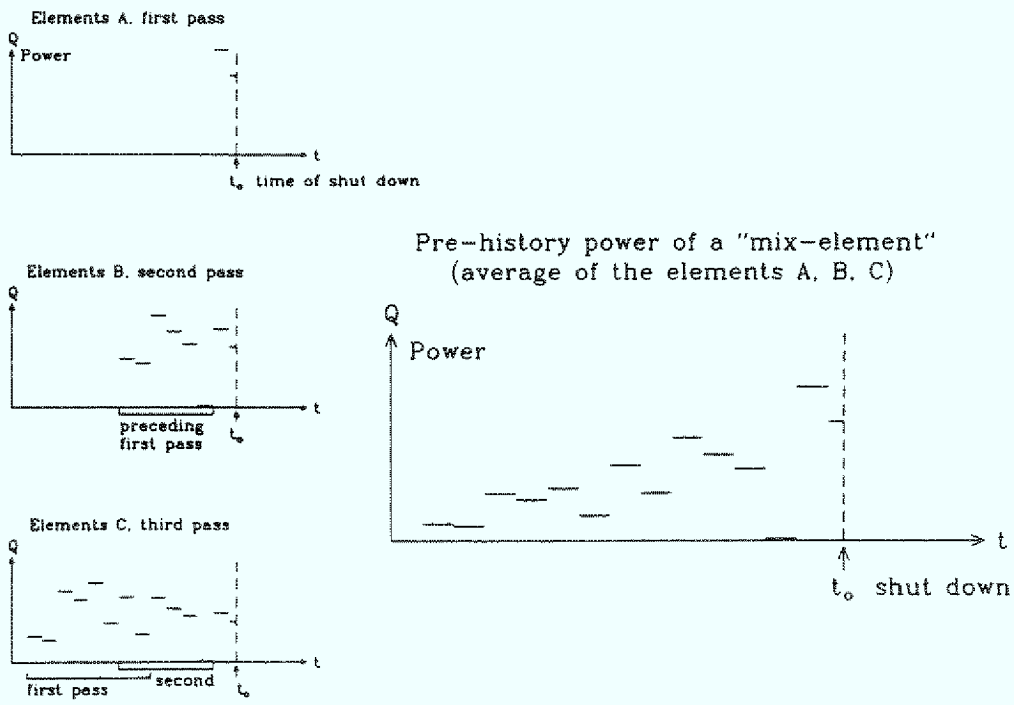

Fig. 17. Power Production Q during Prehistory

tories of the elements which already made one pass through the core in the inner or outer flow channel, respectively.

Similarly, the batch C contains the elements with two previous passes. Their synthesized power history is outlined in the third diagram of the Fig. 17.

The last diagram presents the average of these pre-histories. It represents the pre-history of the whole layer which is formed out of the mix of the batches A, B, C.

In calculational cases the cycle length can be different from cycle to cycle, shutdown periods can be included, and the residence time in the out of pile boxes normally is different from the cycle length. For forming averages of different pre-histories a standardized set of time intervals must be defined. The code transforms the life time data from the given pattern of time steps into the standardized time intervals. This transformation is made for the pre-history of every storage box, and at the end it is also applied to the life history of every batch.

The present version of the code allows to subdivide the whole burnup period into 49 intervals of graded length. The first interval DT should be selected as short as the last cycle was prior to the shut down at the time t_o. The time steps are made from a geometrical progression for the intervals I:

$$TG(I) = TG(I-1) + DT \cdot (1 + E1)^{I-1}$$

$E1$ is an incremental parameter being derived iteratively by the condition

$$\frac{TG(MTMAX) - TN}{DT} < TEPS$$

with

$MTMAX$	Given number of graded time steps (≤ 49).
TN	Span of time to be covered by the graded time steps ($\geq$ maximum fuel element residence time).
$TEPS$	Criterion of convergency (e.g. = 0.1).

By this way the last intervals are fine, and the very early intervals with low importance to the decay power are broad.

The LIFE code prepares the life history library of any fuel management scheme being followed in the VSOP. It can evaluate the running-in periods and any load follow prior to the shut down time t_e.

By option it is also able to evaluate an equilibrium cycle. In that case it prepares an equilibrium life just by copying one designated cycle many times, and then it proceeds as described above.

3.7.2 Decay Power Evaluation

The values of the afterheat production of the nuclear fuel for use in THERMIX are calculated by means of the subroutine NACHW, which also exists as stand-alone version NAKURE /29/. It employs the calculational methods of the German Standard DIN 25485 /30/, which was established for the evaluation of the afterheat production of High-Temperature-Reactor fuel.

The main part of the data input necessary for this procedure is the power history of the fuel as it is described above and as illustrated in Fig. 17.

3.7.2.1 Decay Power of the Fission Products

The contribution P_s of the fission products to the decay power calculated as the sum of the seperate contributions of the considered fissile isotopes i is given as:

$$P_s(t,T) = \sum_i P_{si}(t,T)$$

T being a time period of reactor operation and t being the cooling down time.

In /30/ the decay power P_{si} of the fission products resulting from fissions of each fissile isotope i is approximated by the sum of 24 exponential functions.
The energy release rating $f_i(\tau)$ of the fission products of one single fission of isotope i is calculated as:

$$f_i(\tau) = \sum_{j=1}^{24} \alpha_{ij} \cdot e^{-\lambda_{ij} \cdot \tau} \qquad (1)$$

where τ is the time elapsed since the fission occured. The coefficients α_{ij} and λ_{ij} for fissions of ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu are listed in /30/. In case of fuel containing

thorium, the coefficients of the ^{235}U are also applied for the bred ^{233}U in subroutine NACHW.

Subdividing the power history of the fuel into a series of small time periods K with the length T_k, the afterheat rating of the fission products related to one fission per second is calculated as:

$$F_i(t_k,T_k) = \int_0^{T_k} f_i(T_k - T' + t_k)dT' \qquad (2)$$

with t_k being the cooling down time, i.e. the elapsed time since the end of time interval T_k.

Integrating equation (2) using equation (1) for f_i results in

$$F_i(t_k,T_k) = \sum_{j=1}^{24} \frac{\alpha_{ij}}{\lambda_{ij}} (1 - e^{-\lambda_{ij} \cdot T_k}) \cdot e^{-\lambda_{ij} \cdot t_k}$$

and the contribution of the fission products to the decay power at time t after reactor shut down amounts to

$$P_s(t,T) = \sum_i \sum_k \frac{P_{ik}}{Q_i} \cdot F_i(t_k,T_k)$$

with

P_{ik} Thermal power of the fissile isotop i during the time interval T_k.

Q_i Total thermal energy release of one fission of the fissile isotope i.

T Total time of fuel operation in the reactor from the initial loading until the last considered shut down.

3.7.2.2 Decay Power of Th-233, Pa-233, U-239 and Np-239

The decay power P_h of these isotopes as precursors of the bred fissile materials ^{233}U and ^{239}Pu, respectively, is shown to be /30/

$$P_b(t,T) = \sum_k \left[\frac{P_k}{Q} \sum_I F_I(t_k, T_k) \right]$$

being

$$\frac{P_k}{Q} = \sum_i \frac{P_{ik}}{Q_i}$$

and I = ^{233}Th, ^{233}Pa, ^{239}U and ^{239}Np, respectively.

Where is:

$$F_U(t_k, T_k) = E_U \cdot R_{Uk} \cdot (1 - e^{-\lambda_U \cdot T_k}) \cdot e^{-\lambda_U \cdot t_k}$$

$$F_{Np}(t_k, T_k) = E_{Np} \cdot R_{Uk} \left[\frac{\lambda_U}{\lambda_U - \lambda_{Np}} (1 - e^{-\lambda_{Np} \cdot T_k}) \cdot e^{-\lambda_{Np} \cdot t_k} - \frac{\lambda_{Np}}{\lambda_U - \lambda_{Np}} (1 - e^{-\lambda_U \cdot T_k}) \cdot e^{-\lambda_U \cdot t_k} \right]$$

The same equations hold for the decay power of Th and Pa when using the indices *Th* and *Pa* instead of *U* and *Np*.

The meanings of the variables are:

E_U mean decay energy of ^{239}U (0.474 MeV)
E_{Np} mean decay energy of ^{239}Np (0.419 MeV)
E_{Th} mean decay energy of ^{233}Th (0.442 MeV)
E_{Pa} mean decay energy of ^{233}Pa (0.408 MeV)
λ_U decay constant of ^{239}U (4.91 E-4/s)
λ_{Np} decay constant of ^{239}Np (3.41 E-6/s)
λ_{Th} decay constant of ^{233}Th (5.18 E-4/s)
λ_{Pa} decay constant of ^{233}Pa (2.97 E-7/s).

R_{Uk} and R_{Thk} are the capture rates of ^{238}U and ^{232}Th, respectively, divided by the total fission rate during time interval K.

3.7.2.3 Contribution of Neutron Capture in Fission Products and in Actinides

An example for neutron capture in fission products and in the actinides is given in Fig. 18. Of course, the P_b actinides are treated according to Section 3.7.2.2 .

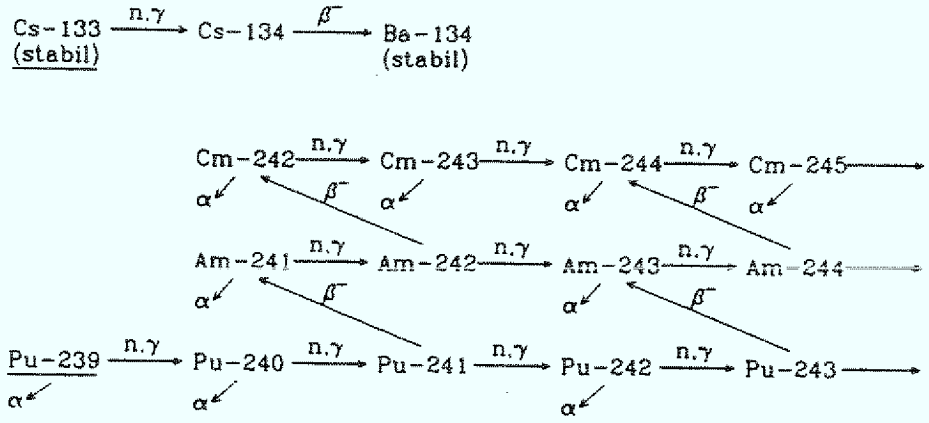

Fig. 18. Neutron Capture in Fission Products and in Actinides

The contribution of the decay power due to neutron capture in fission products (P_e) is calculated as a function of the decay time:

$$P_e(t,T) = P_s(t,T) \cdot H(t)$$

using table 4 of /30/ for $H(t)$.
Excluded hereby is the contribution of the long-lived ^{134}Cs. This is calculated as P_{cs} according to equations 32 - 38 of /30/.

The contribution to the decay power due to neutron capture in heavy metal nuclides, P_a, is calculated using equation 19 and table 3 of /30/:

$$P_a(t,T) = P_s(t,T) \cdot f(\text{heavy metal density, heavy metal burnup, power density, t})$$

The total decay heat is finally summed up to be

$$P_n = P_s + P_b + P_e + P_{cs} + P_a$$

4.0 References

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