HTR-N

HTR-N & N1
High-Temperature Reactor Physics and Fuel Cycle Studies
(EC-funded Projects: FIKI-CT-2000-00020 & FIKI-CT-2001-00169)))

Work Package: 3	HTR-N project document No.: **HTR-N-01/02-D-3.1.5**			Q.A. level: 1
Task: 3.1	Document type: Report/Contribution to deliverable 3.1.1			Document status: final
Issued by: NRG	original document No.: 20570/02.47594 FAI/JCK/MB	Rev. 2	Q.A. level A	Dissemination level: CO

Document Title

Definition of common output parameters

Author(s)

J.C. Kuijper and J.B.M. de Haas

Organisation, Country

NRG, the Netherlands

Notes

Electronic filing ……………….. Electronic file format Microsoft Word 97

1	**20 06 2002**	Final (agreed on WP3 meeting of 28-05-2002)	NRG	CEA FZJ IRI	ANS	FZJ
0	31 05 2001	First issue	NRG	N/A	N/A	N/A
Rev.	**Date**	**Description**	**Prepared by**	**Partners' comments / amendments**	**Review**	**Issue approval**

1. INTRODUCTION

Work Package 3 is concerned with the performance of the fuel types (in different HTR systems) to be investigated with respect to Pu-incneration capabilities, economics and safety. In order to be able to intercompare the results for different fuels in different reactor systems, obtained by different partners, a common set of economics and safety related output parameters is presented here, which are to be calculated for the fuel type/reactor system combinations under investigation. The parameters can be calculated on coated particle-, compact-/pebble-, block- and reactor level, depending on the fraction of the entire system taken into account in the calculation. For a real intercomparison a full 3-D calculation on the entire reactor level is desirable. However, calculations on a fraction of the reactor system (coated particle, compact/pebble, block) may also yield useful information, e.g. on the influence of burnable poison on certain parameters. The parameter set listed below is intended as code-independent, data library-independent and system-independent as possible. However, some parameters may seem -and actually are- redundant or superfluous for the specific system (part) under consideration, while it may not always be possible to calculate all requested parameters for the specific system (part) under consideration with the available code system and/or nuclear data libraries. Also parameters have been included which are not directly economics and safety related, but which are intended to support interpretation of calculation results.

2. REQUESTED PARAMETERS FOR INTERCOMPARISON

In the following it is assumed that the reactor system is at 100% of its nominal thermal power for a fraction of its operating cycle length, equal to the **capacity factor**. For a system with continuous reload, like the HTR-MODUL pebble-bed reactor, the operating cycle length is -somewhat arbitrarily- defined as **1 year = 365 days**. For other systems, the **operating cycle length** is defined as the number of days between sucessive starts of operating cycles (so **operation time + reload stop**). The Beginning of Life ("BOL") is the point in time of the start of the operating cycle (reactor at nominal thermal power), the End of Life ("EOL") is the end of the full power operation time (beginning of possible reload stop). The Mid of Life ("MOL") is the point in time exactly between BOL and EOL. For a continuous reload system (in the equilibrium state) the values of parameters at BOL, MOL and EOL will be identical.

The following information/parameters should be supplied/calculated. It should be noted that the parameter sets considered the most important for the assessment and intercomparison of transmutation capabilities and safety are 2, 3, 4, 7 and 8.

0. Case identification and description.
   - 0.1. Origin
   - 0.2. Organisation
   - 0.3. Case number
   - 0.4. Date
   - 0.5. Applied code system
   - 0.6. References

1. General fuel/reactor/system specifications. This section is intended as a complete description of the fuel, the reactor (system) and the applied fuel loading and discharge scheme.
   - 1.1. System (part) under consideration (reactor, supercell, etc.)
   - 1.2. Main system dimensions
   - 1.3. Coated particle dimensions (kernel and coatings) (per coated particle type)
   - 1.4. Initial coated particle composition per nuclide per material zone (units: $(\text{barn cm})^{-1}$) (per coated particle type; including impurities)
   - 1.5. Compact/pebble dimensions

- 1.6. Compact/pebble composition per nuclide (outside coated particles; including impurities) (units: $(\text{barn cm})^{-1}$)
- 1.7. Block composition per nuclide (outside coated particles; including impurities) (units: $(\text{barn cm})^{-1}$)
- 1.8. Number of coated particles per pebble compact (of each coated particle type)
- 1.9. Operating cycle length (units: full power days)
- 1.10. Reload stop duration (units: days) (may be 0 in case of continuous reload, in which case EOL coincides with the end of the operating cycle)
- 1.11. Nominal reactor power (units: MW)
- 1.12. Capacity factor (units: -)
- 1.13. Number of fuel batches (batch wise reload only) (units: -)
- 1.14. Nominal coolant inlet temperature (units: K)
- 1.15. Nominal coolant inlet pressure (units: Pa)
- 1.16. Nominal coolant outlet temperature at nominal (Hot Full Power, HFP) conditions (units: K)
- 1.17. Nominal coolant outlet pressure at nominal (Hot Full Power, HFP) conditions (units: Pa)
- 1.18. Nominal coolant mass flow (unit: kg/s)
- 1.19. Description of fuel cycle strategy and other relevant information on the specific case.

2. Rating and power density
   - 2.1. Power produced per coated particle (per coated partcile type) (units: W):
     - 2.1.1. Maximum value occurring anywhere in the core at any time during the operating cycle
     - 2.1.2. Maximum value anywhere in the core as function of time over the operating cycle
   - 2.2. Power produced per compact/pebble (units: W)
     - 2.2.1. Maximum value occurring anywhere in the core at any time during the operating cycle
     - 2.2.2. Maximum value anywhere in the core as function of time over the operating cycle
   - 2.3. Power produced per unit heavy metal mass (units: W/kg)
     - 2.3.1. Maximum value occurring anywhere in the core at any time during the operating cycle
     - 2.3.2. Maximum value anywhere in the core as function of time over the operating cycle
   - 2.4. Power density in the core (units: W/m^3)
     - 2.4.1. Maximum value occurring anywhere in the core at any time during the operating cycle
     - 2.4.2. Maximum value anywhere in the core as function of time over the operating cycle

3. Core inventory
   - 3.1. Amount of each of the heavy metal isotopes present in the core (units: kg)
     - 3.1.1. At BOL
     - 3.1.2. At MOL
     - 3.1.3. At EOL
   - 3.2. Fissile Pu fraction, i.e. amount of (^{239}Pu and ^{241}Pu) divided by the total amount of Pu (units: -) (this can be derived from 3.1)
     - 3.2.1. At BOL
     - 3.2.2. At MOL
     - 3.2.3. At EOL

4. Fuel (actinide) consumption, actinide and fission product production and discharge burnup at nominal conditions. A list of nuclides under consideration is presented in section 4.
   - 4.1. Amount and composition of fresh fuel loaded into the system for one operating cycle (per heavy metal nuclide) divided by the operating cycle length (units:kg/year)
   - 4.2. Amount and composition of fuel discharged from (and not reloaded into) the system for one operating cycle (per heavy metal and fission product nuclide) divided by the operating cycle length (units: kg/year)
   - 4.3. Balance of heavy metal and fission products, i.e. the difference between corresponding items 4.1 and 4.2, divided by nominal thermal power times capacity factor (units: kg/MWd)
   - 4.4. Attained discharge burnup of the fuel (units: MWd/kg)

4.4.1. Minimum value
4.4.2. Average value
4.4.3. Maximum value

5. Reaction rates at nominal conditions
5.1. Neutron induced fission rate per heavy metal nuclide in the entire system (units: s^{-1})
5.1.1. At BOL
5.1.2. At MOL
5.1.3. At EOL
5.2. Neutron absorption rate for all (heavy metal, fission product and possibly burnable poison) nuclides present in the kernels of all coated particles (units: s^{-1}) (per nuclide)
5.2.1. At BOL
5.2.2. At MOL
5.2.3. At EOL
5.3. Neutron absorption rate in all other material in the core cavity (units: s^{-1}) (per nuclide, including burnable poison if present)
5.3.1. At BOL
5.3.2. At MOL
5.3.3. At EOL
5.4. Net neutron leakage rate from the core cavity (units: s^{-1})
5.4.1. At BOL
5.4.2. At MOL
5.4.3. At EOL

6. Fast and thermal neutron flux (fluence rate) and fluence measures at nominal conditions
6.1. Thermal flux below 1.86 eV (units: $m^{-2}s^{-1}$). The items listed below should be calculated at BOL, MOL and EOL.
6.1.1. Average value in the core
6.1.2. Peak value in the core
6.1.3. Average value in the reflector
6.1.4. Peak value in the reflector
6.1.5. Axial distribution of the thermal flux along the centre axis
6.1.6. Radial distribution of the thermal flux at half core height
6.2. $^{59}Co(n,\gamma)$ reaction rate of a 10^{-10} (barn cm)$^{-1}$ trace of ^{59}Co in all materials in the core and reflector. This is a measure of the thermal flux below ~1 eV, which is independent of the energy group structure employed in the calculations. The items listed below should be calculated at BOL, MOL and EOL.
6.2.1. Total reaction rate in the core (units: s^{-1})
6.2.2. Total reaction rate in the reflector (units: s^{-1})
6.2.3. Peak value of the reaction rate density in the core (units: $s^{-1}m^{-3}$)
6.2.4. Peak value of the reaction rate density in the reflector (units: $s^{-1}m^{-3}$)
6.2.5. Axial distribution of the reaction rate density along the centre axis (units: $s^{-1}m^{-3}$)
6.2.6. Radial distribution of the reaction rate density at half core height (units: $s^{-1}m^{-3}$)
6.3. Fast flux (fluence rate) above 0.1 MeV (units: $m^{-2}s^{-1}$). The items listed below should be calculated at BOL, MOL and EOL.
6.3.1. Average value in the core
6.3.2. Peak value in the core
6.3.3. Average value in the reflector
6.3.4. Peak value in the reflector
6.3.5. Axial distribution of the fast flux along the centre axis
6.3.6. Radial distribution of the fast flux at half core height
6.4. $^{58}Ni(n,p)$ reaction rate of a 10^{-10} (barn cm)$^{-1}$ trace of ^{58}Ni in all materials in the core and reflector. This is a measure of the fast flux above ~2 MeV, which is independent of the energy

group structure employed in the calculations. The items listed below should be calculated at BOL, MOL and EOL.

6.4.1. Total reaction rate in the core (units: s^{-1})
6.4.2. Total reaction rate in the reflector (units: s^{-1})
6.4.3. Peak value of the reaction rate density in the core (units: $s^{-1}m^{-3}$)
6.4.4. Peak value of the reaction rate density in the reflector (units: $s^{-1}m^{-3}$)
6.4.5. Axial distribution of the reaction rate density along the centre axis (units: $s^{-1}m^{-3}$)
6.4.6. Radial distribution of the reaction rate density at half core height (units: $s^{-1}m^{-3}$)

6.5. Fast fluence above 0.1 MeV of discharged fuel (kernel, coatings, matrix) (units: m^{-2})

6.5.1. Minimum value
6.5.2. Average value
6.5.3. Maximum value

7. Temperatures at nominal conditions

7.1. Coated particle temperature (units: K)

7.1.1. Maximum value occurring anywhere in the core at BOL
7.1.2. Maximum value occurring anywhere in the core at EOL
7.1.3. Maximum value occurring anywhere in the core at any time during the operating cycle

7.2. Pebble surface temperature

7.2.1. Maximum value occurring anywhere in the core at BOL
7.2.2. Maximum value occurring anywhere in the core at EOL
7.2.3. Maximum value occurring anywhere in the core at any time during the operating cycle

8. Temperature reactivity coefficients. The perturbed state has “frozen” thermal hydraulics and the same nuclide concentrations as the reference state anywhere in the system. The local temperature of the system part (fuel, moderator, reflector) for which the temperature reactivity coefficient is to be calculated is increased by $\Delta T = 50$ K (k_{delta}), while the temperature of the remainder of the system is at the same temperature as in the reference state. The temperature reactivity coefficient (α) is subsequently calculated as:

$$\alpha = (1/\,k_{ref} - 1/\,k_{delta}\,)\,10^5\,/\,\Delta T \quad \text{(units: pcm/K)}$$

The following items should be calculated as function of time over the operating cycle, at least at BOL, MOL and EOL. The exact part of the system for which the coefficient is calculated should be indicated.

8.1. Temperature reactivity coefficients at Cold Zero Power (CZP, zero xenon) conditions (units: pcm/K). The reference state for this calculation is an isothermal reactor at 300 K (k_{ref}). The temperature reactivity coefficients should be calculated for:

8.1.1. Fuel compacts/pebbles
8.1.2. Moderator in the core cavity
8.1.3. Reflectors

8.2. Temperature reactivity coefficients at Hot Zero Power (HZP, zero xenon) conditions (unit: pcm/K). The reference state for this calculation is an isothermal reactor at nominal coolant inlet temperature (k_{ref}) (see item 1.14). The temperature reactivity coefficients should be calculated for:

8.2.1. Fuel compacts/pebbles
8.2.2. Moderator in the core cavity
8.2.3. Reflectors

8.3. Temperature reactivity coefficients at Hot Full Power (HFP or nominal, equilibrium xenon) conditions (units: pcm/K). The reference state for this calculation is the temperature distribution at nominal conditions (k_{ref}). The temperature reactivity coefficients should be calculated for:

8.3.1. Coated particles (per coated particle type)
8.3.2. Fuel compacts/pebbles

8.3.3. Moderator in the core cavity
8.3.4. Reflectors

8.4. Differences in reactivity (units: pcm) between:
8.4.1. CZP (zero xenon) state and HZP (zero xenon) state
8.4.2. CZP (zero xenon) state and HFP (equilibrium xenon) state

3. FILE FORMAT

The items mentioned above for a specific case should be send to the Work Package 3 manager in the form of an ASCII text file (one file per case) in which each of the items mentioned above is indicated, in the leftmost columns, by an identifier derived from the item number (format: "#<item number>#). Multiple values for the same item are put in consecutive lines, each preceeded by the item indicator. E.g. the lines containing values for item 4.1 ("Amount and composition of fresh fuel loaded into the system for one operating cycle (per heavy metal nuclide) divided by the operating cycle length (units:kg/year)") look like:

```
#4.1#      U235      <value>
#4.1#      U238      <value>
.
.
.
#4.1#      Pu239     <value>
```

This also holds for textual information (e.g. item 1.19). So effectively everly line must be preceeded with the appropriate item indicator. Any other comment should be preceeded by "##" in the two leftmost columns. A full example of an output file, together with some further intructions, is given in [3]. The Unix 'grep' and 'awk' commands will be used to extract data from this file (item sets 2 to 8) for further postprocessing and intercomparison.

4. ACTINIDES AND FISSION PRODUCTS UNDER CONSIDERATION

For items 3, 4 and 5 of section 2, values have to be calulated per nuclide: actinides (heavy metal) and fission products. The lists of nuclides to be taken into account are given in table 1 and 2. The fission products are selected on their relevance with respect to final disposal [1]. The selection of the actinides is identical to the one employed in the EU 5FP project THORIUM [2], also to facilitate intercomparson with other reactor types, such as LWRs.

Table 1 List of selected fission products for intercomparison

Se-79	Sn-126
Rb-87	I-129
Sr-90	Cs-135
Zr-93	Cs-137
Mo-93	Sm-147
Nb-94	Sm-151
Tc-99	Eu-154
Pd-107	

Table 2 List of selected actinides for intercomparison

Th-230	Pa-231	U-232	Np-237	Pu-238	Am-241	Cm-242
Th-232	Pa-233	U-233	Np-238	Pu-239	Am-242m	Cm-243
		U-234	Np-239	Pu-240	Am-243	Cm-244
		U-235		Pu-241		Cm-245
		U-236		Pu-242		
		U-238		Pu-243		
		U-239		Pu-244		

5. REFERENCES

[1] Commissie Opberging te Land (OPLA), “Eindrapport Fase 1, Bijlage 1, Samenvatting van de Veiligheidsstudie”, Ministry of Economic Affairs, the Netherlands, May 1989.

[2] T. Bodewig *et al.*, “Report on the basic data for the reference core”, Report Th5-DOC-005, EU 5FP project THORIUM, contract no. FIKI-CT-2000-00042, March 2002.

[3] Sample output file “SAMPLE_FORMAT.20020620.txt”, SINTER document HTR-N-02/06-S-3.1.1, June 2002.