KAPROS-E: A Modular Program System for Nuclear Reactor Analysis, Status and Results of Selected Applications.

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Outline of presentation

- **Introduction**
- **Main features of original KAPROS version:**
  - **Basic principles**
  - **Cross section generation and collapsing**
  - **Criticality, flux- and power-distribution calculations**
  - **Burn-up calculations**
- **KAPROS-E : coupling of KAPROS with stand-alone codes. Examples of recent applications**
- **Summary and outlook**

Characteristics of KAPROS (I)

- **Fully modular code system for the calculation of nuclear reactor systems**
- **Development since about 30 years with more than 100 man-years efforts by many contributors**
- **Since KAPROS77 kernel FORTRAN77 with only few exceptions (now C-routines)**
- **Calculation modules mostly FORTRAN77**
- **Common data bases on different levels:**
  - **Fast memory storage as much as available**
  - **Temporary disk storage as much as required**
  - **Disk/tape storage of data archive**

Characteristics of KAPROS (II)

Standard KAPROS interfaces available for cross sections, spectra, fluxes, etc

- **Use of international standard interfaces convenient for new developments**
- **Powerful archiving and restart features**
- **On-line documentation available**
- **Exhaustive applications for FBR and TLLWR investigations, subsystem KARBUS for depletion calculations, several procedures for specific calculation tasks**
- **Portable version for UNIX workstations, including LINUX PC**

KAPROS / KARBUS cross section processing

FZK-own development GRUBA library / GRUCAL processing code

- Multi-group library GRUBA with very flexible data storage on direct access files
- Data structures are combination of features of fast and thermal reactor codes (up-scattering, separate treatment of elastic, inelastic, (n-2n), .. processes, improved fission spectrum, etc)
- Directives for cross section calculations not hard-coded in GRUCAL program, but defined on “Steuerfile” with calculation rules; unique solution for cross section calculations.
- Easy to use features for the application of special data testing (secondary input)
- Refined resonance treatment based on self-shielding tabulations (improved Bell-factor formalism), fine flux cross section calculations optional
- Well validated for various applications (LWR, TLLWR, FBR, ADS, HPLWR,…)

Characteristics of 69 group master library

- FZK own library structure on direct access files, including retrieval and management software, is standard library structure for microscopic cross section storage in KAPROS
- Contains all data needed for multi-group diffusion and transport calculations, including data for delayed neutrons, for ≈160 isotopes.
- Contains additional EAF2001 69 group cross sections for depletion and activation calculations for ≈700 isotopes
- Well validated for a broad range of applications with different fuel, moderator and coolant in thermal, epithermal and fast neutron spectra
- Validation efforts still in progress

Generation of coarse multi-group cross sections (I)

- Coarse group constant sets (≈10 groups) still recommended for dynamic reactor simulations

- Coarse group constant generation is sensitive to the weighting spectrum
  ⇒ dependant on reactor system and on the state of the system

- Commonly used methods for coarse multi-group generation:

  - Application of few group microscopic libraries in standardized format (SIMMER)

  - Collapsing of many-to-few group macroscopic cross sections

- New master library collapsing procedure COLLIB in KAPROS;
  existing multi-group procedures applicable for collapsed libraries

Generation of coarse multi-group cross sections (II)

New procedure COLLIB in KAPROS applying two-step procedure:

- **Step 1: Well validated complete microscopic master library (with 69 groups)**
- **Step 2: Collapsing to system dependant coarse group cross section library with same microscopic library structure as master library:**
  - **Use of representative weighting spectrum for collapsing**
  - **Materials and data-types selectable for planned application**
  - **Group boundaries selectable (problem dependant)**
  - **Collapsing procedure straight-forward, but care is required for self-shielding tables and threshold reactions**

Improvement of up-scattering data

- **Status 2002: 69 group library with up-scattering data from external resources (WIMS, IKE Stuttgart)**

- **TRADE project needs additional data for up-scattering from hydrogen bounded in Zirconium Hydride**

More details in next presentation

Reactor calculations with KAPROS/KARBUS (I)

Several options for reactivity and flux calculations:

- **KAPROS modules strongly coupled with KAPROS:**
  - **WEKCPM (1-d collision density method from WIMS)**
  - **ONETRA (1-d S_n transport method)**
  - **DIXY2, including evaluations (2-d diffusion)**
  - **D3D/AUDI3 (3-d diffusion)**
  - **HEXNODK (3-d nodal transport/diffusion)**

Reactor calculations with KAPROS/KARBUS (II)

- **Stand-alone codes loosely coupled with KAPROS**
  - **DANTSYS (3-d S_n transport)**
  - **CITATION (3-d diffusion)**
  - **VARIANTK/DIF3D (3-d Hex-Z nodal transport)**
  - **HEXNODYN (HEXNOD successor currently developed at SCK/CEN)**
  - **MCNP and MCNPX Monte Carlo Codes**

Burn-up and depletion calculations in KAPROS

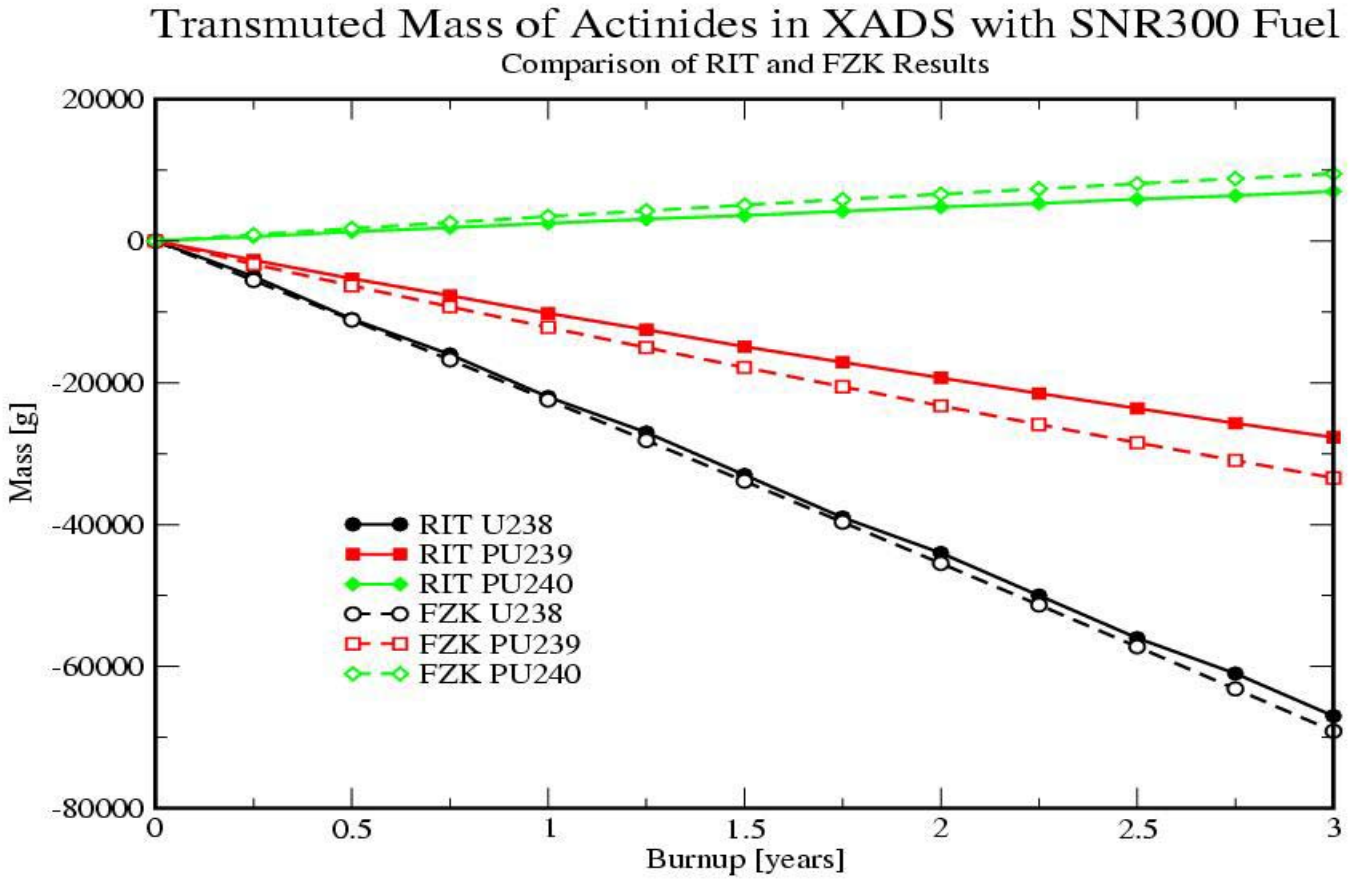
The KArlruher Reactor BUrn-up System KARBUS is a KAPROS sub-system developed for burn-up and depletion calculations of nuclear reactors since early eighties. Important KARBUS modules and procedures are

- **The main KAPROS burn-up module BURNUP is based on the formalisms of the KORIGEN code, developed at FZK from ORIGEN**
- **The early developed procedure BURN0D enables burn-up investigations with the help of fundamental mode calculations**
- **The procedure KARBUS enables complicated burn-up calculations for reactor unit cells or for reactor systems**

Burn-up investigations for an XADS benchmark core with SNR300 fuel

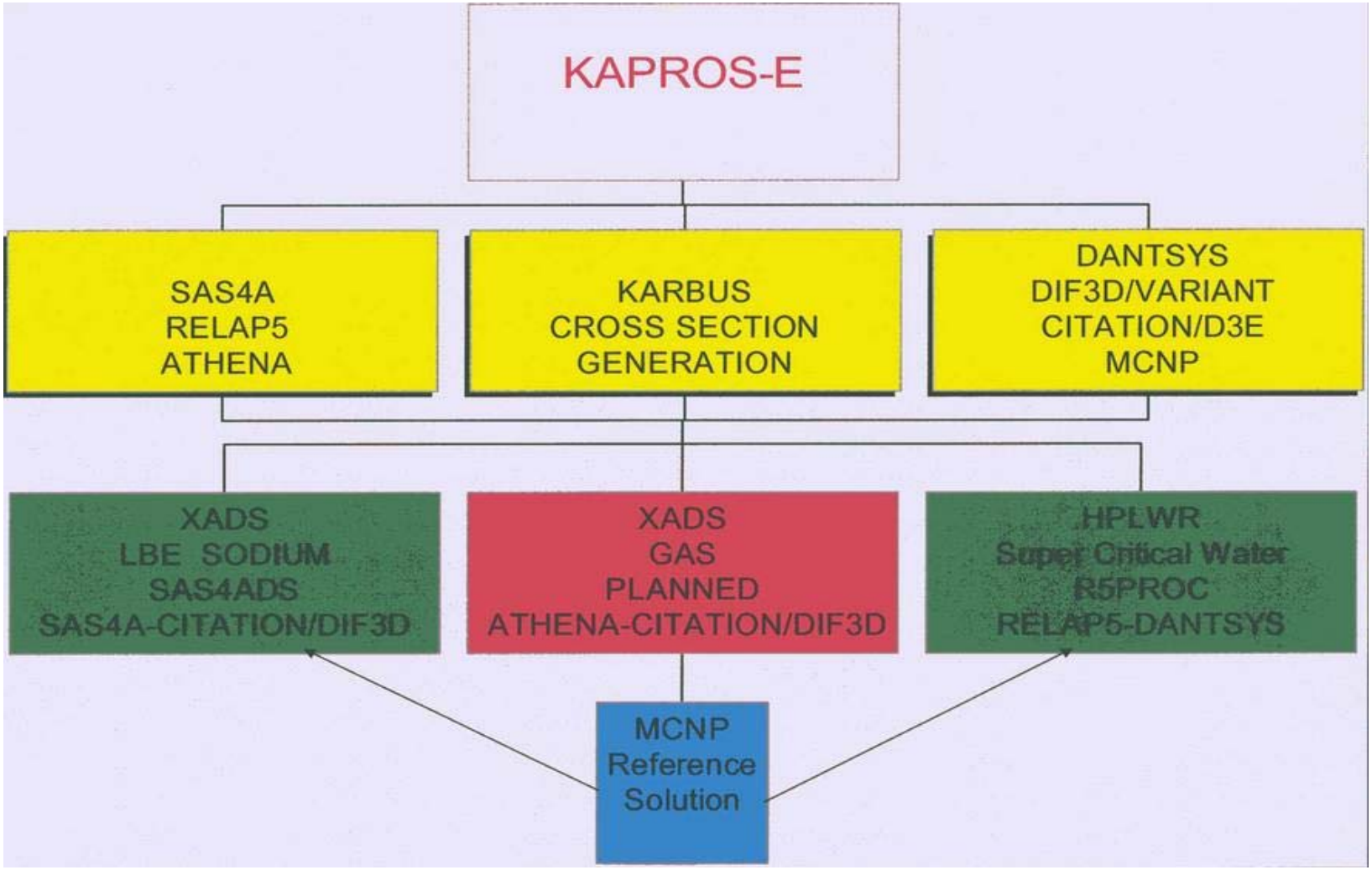
- Applied calculation methods
  - Monte Carlo code MCB1C by KTH Stockholm
  - Procedure BUTWOD of deterministic multi-group code system KAPROS
- Calculation model
  - Appropriate (R-Z) geometry in both calculation methods
  - Three radial and eight axial burn-up zones same in both methods
- Mostly same JEF2.2 data base for cross section data
- Detailed source from MCNPX calculation in Monte Carlo method, simplified constant source treatment in deterministic code
- Satisfactory agreement in preliminary results; reactivity loss 6..7 pcm/fpd

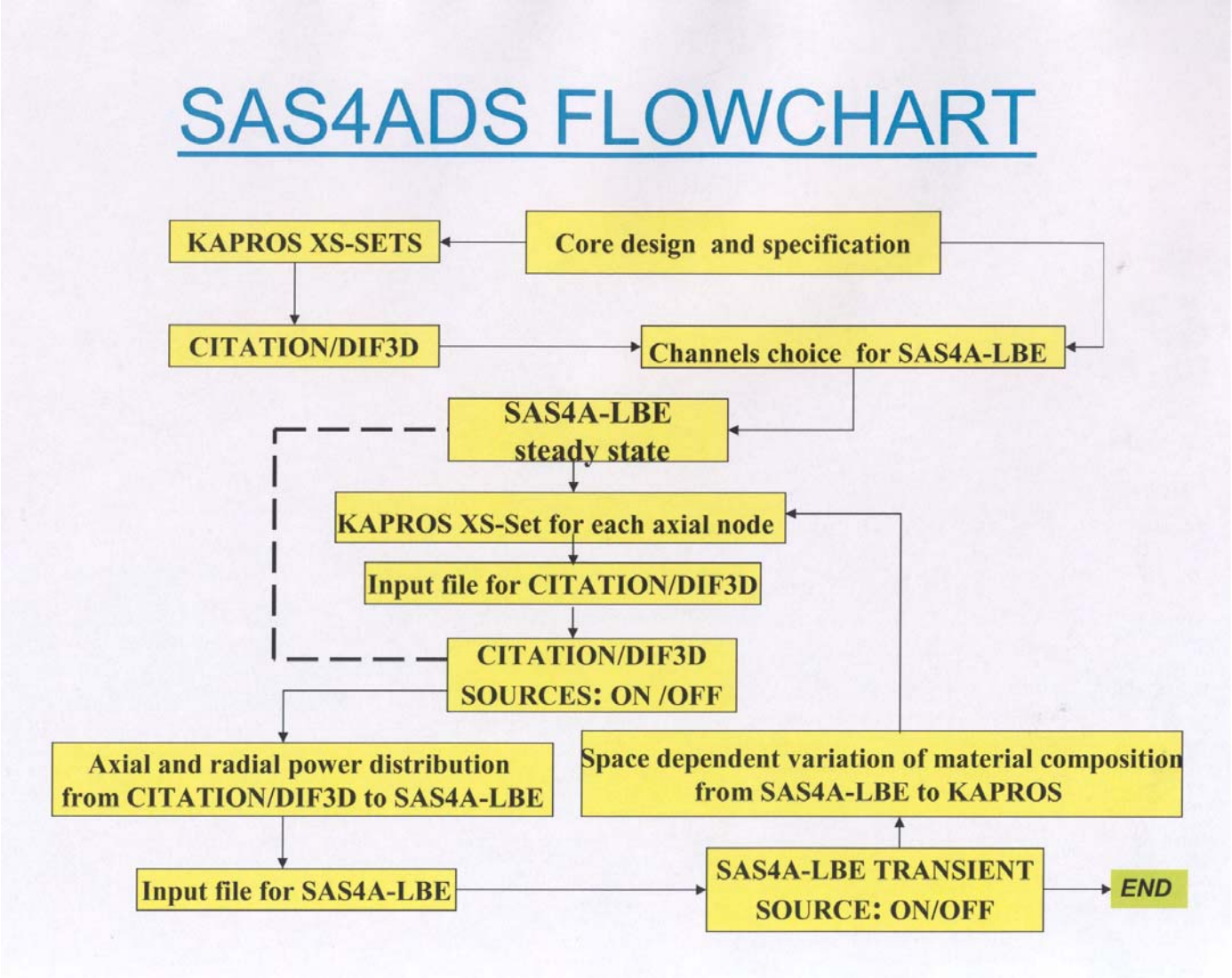
Burn-up investigations for an XADS benchmark core with SNR300 fuel



Comparison of KTH Monte Carlo and FZK deterministic results for burn up dependant mass change

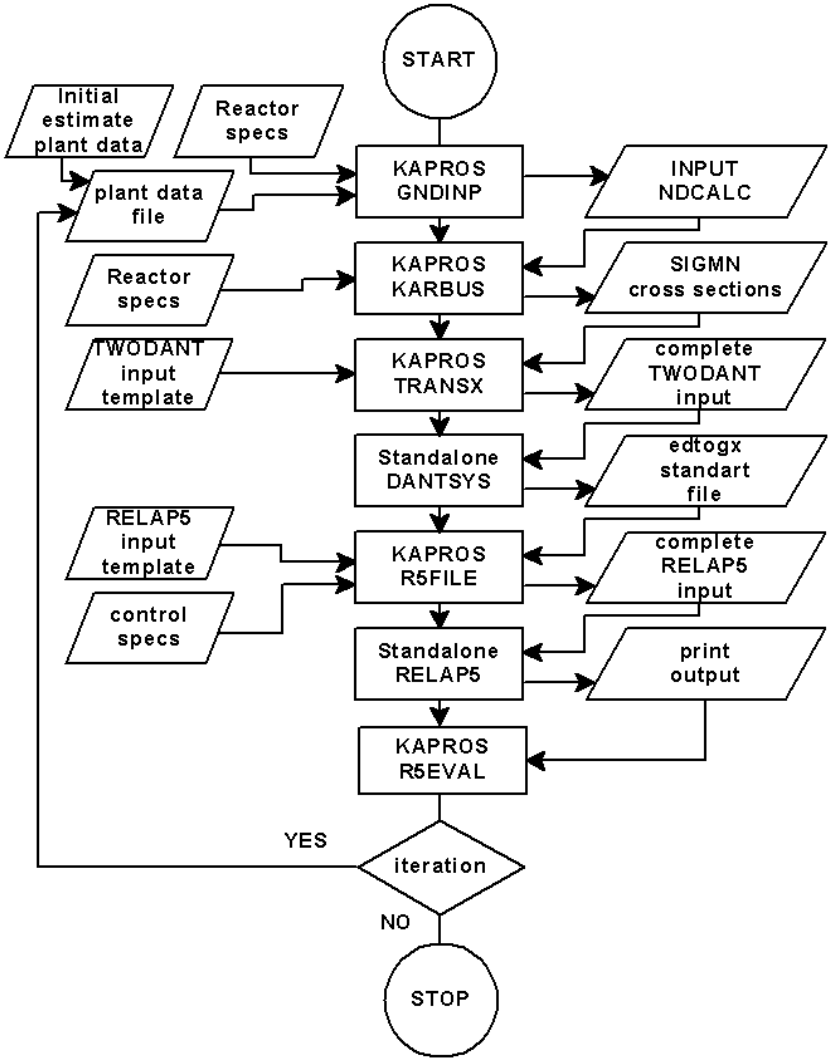
Current couplings in KAPROS-E of system, cross section generation and neutron flux distribution codes




SAS4ADS FLOWCHART
KAPROS XS-SETS
Core design and specification
CITATION/DIF3D
Channels choice for SAS4A-LBE
SAS4A-LBE
steady state
KAPROS XS-Set for each axial node
Input file for CITATION/DIF3D
CITATION/DIF3D
SOURCES: ON /OFF
Axial and radial power distribution
from CITATION/DIF3D to SAS4A-LBE
Space dependent variation of material composition
from SAS4A-LBE to KAPROS
Input file for SAS4A-LBE
SAS4A-LBE TRANSIENT
SOURCE: ON/OFF
END

KAPROS Procedure R5PROC for coupling of KAPROS cross section generation, TWODANT flux and power density calculation and RELAP5 thermo-hydraulic system calculations for HPLWR designs.

The procedure was developed in the framework of the HPLWR project in the 5. ECFP for the analysis of the characteristics of innovative LWR with water coolant and moderator at super-critical conditions

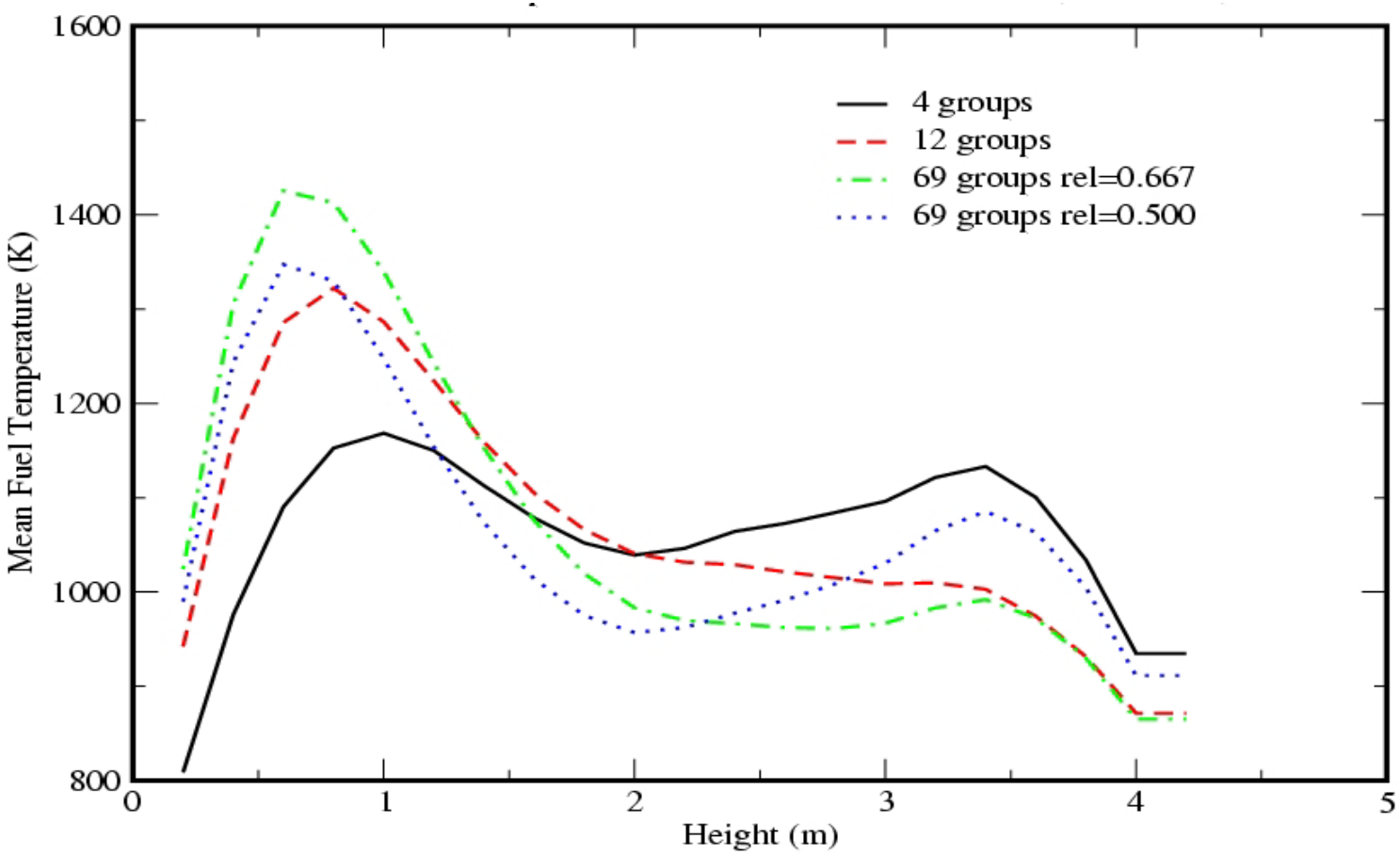


Procedure R5PROC for KARBUS / RELAP5 Coupling

Example: Current coupling of codes for HPLWR investigations

- **Neutron physics code: KAPROS/KARBUS modular system developed at FZK with large efforts since mid-seventies:**
  - **Cross section generation with procedures developed and validated for Tight Lattice Light Water Reactor investigations**
  - **Super-cell (R-Z) calculations with loosely to KAPROS coupled TWODANT transport code**
- **Thermal-hydraulic code: RELAP5 version improved at FZK for HPLWR investigations**
  - **Integral plant simulation**
  - **One channel core representation**

Results of coupled RELAP5 / KARBUS calculations



Axial distributions of the mean fuel temperature after 8 iterations

Summary and outlook

- The basic concept of the modular system KAPROS is well suited to develop complicated variable sequences of calculation tasks. It survived several development stages of computer hardware and software systems
- In the early stage of KAPROS development, modules were strongly integrated and were mainly restricted to neutron physics calculations
- The version for UNIX workstations facilitates loosely coupling of KAPROS with international available stand-alone codes and standard interfaces
- The current system is running on LINUX workstations without problems. Several powerful stand-alone codes, including thermo-hydraulic and transient codes, are loosely coupled to the extended version KAPROS-E
- Principles of, and experiences with KAPROS are a good basis for participation in projects for development of future coupled code systems. The 6. ECFP proposal NURESIM could be a good platform for such developments.