ANALYSIS OF UNCERTAINTY PROPAGATION IN NUCLEAR FUEL CYCLE SCENARIOS

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Background

- Nuclear Energy/Engineering curriculum still under development in Estonia
- Erasmus Practical Internship


UNIVERSITY OF TARTU

Master of Science in Engineering

NUCLEAR ENERGETICS AND NUCLEAR SAFETY

The master's programme educates students to contribute to the international field of nuclear science and engineering. It is jointly delivered by the leading Estonian academic institutions[1] – University of Tartu (UT) and Tallinn University of Technology (TUT). The programme is based at the UT Institute of Physics, which carries out internationally competitive research including activities in the EURATOM programme.

Overview

The curriculum covers Nuclear Energetics and Nuclear Safety in a comprehensive manner, incorporating several natural and social scientific fields, including physical, chemical, environmental, ecological, geological, economical, legal and political aspects. This multidisciplinary *Universitas* approach provides students the specialized knowledge and professional skills necessary to enter a wide range of careers, for example enterprises or institutions associated with nuclear fuel cycle or radiation activities, or related regulatory bodies.

Students tour the AS ALARA radioactive waste facility near Paldiski, also the former site of two nuclear submarine training reactors. Field trips are arranged to various nuclear- and energy-related sites in Estonia.

Hands-on training at an operational nuclear research reactor is part of the curriculum.

Career prospects

The career prospects for graduates to find work in any nuclear related disciplines are highly encouraging. Nuclear power is foreseen as a future energy source in Estonia. Also regional job opportunities are expected to increase: in Finland one reactor is under construction and two more are planned, and in Lithuania one new nuclear power plant (NPP) is planned. Globally 1000s of nuclear workers are retiring per year, and it is a great challenge for universities to meet current demand. The job market for nuclear graduates is expected to improve further as 127 new NPPs will be built by 2020 to supplement the existing 439 NPPs (*Nature*, 458, 2009).

The highest safety and security are necessary to protect humans and the environment. Programme manager Dr. Alan Tkaczyk makes radiation measurements in a research reactor hall.

UT graduate Marti Jeltsov measures the neutron flux in a nuclear training reactor core. He now works at the KTH Nuclear Power Safety Division in Stockholm, Sweden.

[1] http://www.nature.com/nature/supplements/regionalreport/estonia

www.ut.ee/nuclear

The programme is supported by the European Social Fund. The Estonian energy company Eesti Energia is a programme partner.

Nuclear Energetics

http://www.ut.ee/nuclear

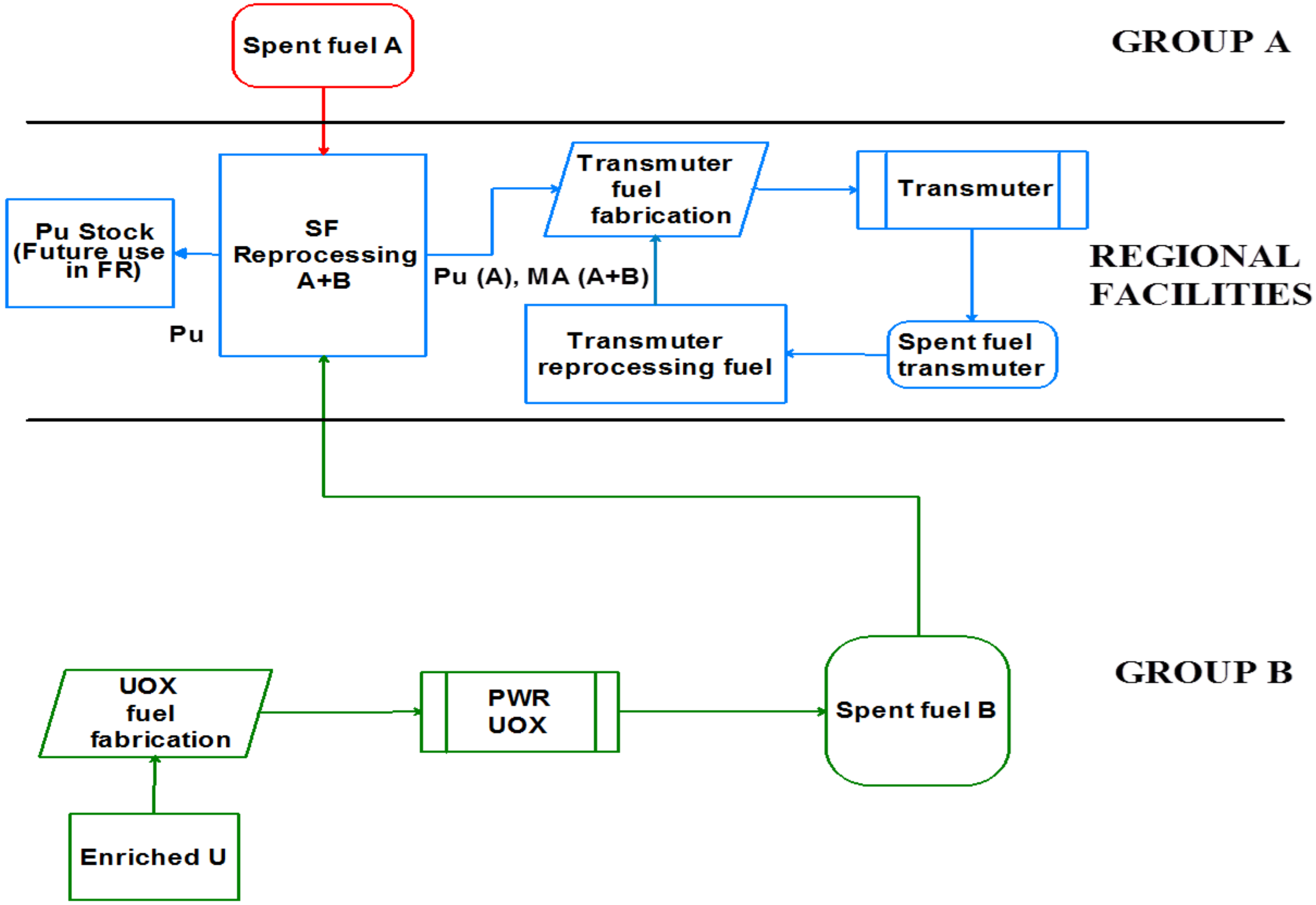
Background (cont)

- Builds on prior research at the Institute for Nuclear and Energy Technologies (IKET), KIT (Karlsruhe Institute of Technology)
- “Comparative study of fast critical burner reactors and subcritical accelerator driven systems and the impact on transuranics inventory in a regional fuel cycle”
- “Impact of nuclear data uncertainties on closed fuel cycle scenarios”
- Working team
  - Dr. Vincenzo Romanello, Dr. Massimo Salvatores, Dr. Giuseppe Palmiotti

Scenario description

- Two groups of nations considered:
- Group A is in a stagnant or phase-out scenario for nuclear energy and has to manage its spent fuel (Belgium, Czech Republic, Germany, Spain, Sweden and Switzerland)
- Group B is in a continuation scenario for the nuclear energy and has to optimize the use of his resources of plutonium for the future deployment of fast reactors (France)
- The deployment of a group of transmuters shared by countries A and B is considered
- The transmuters use the Plutonium of Group A and transmute the minor actinides of the two groups (A and B)
- The transmuter considered here is a critical burner fast reactor (CR=0.5)

Scenario scheme



Simplified mass flow scheme in the regional scenario until the full consumption of TRU from Group A

Scenario objectives

- to decrease the stock of spent fuel of countries A down to 0 by the end of the century;
- to stabilize the MA inventory of Group B within the end of the century;
- to investigate the required number of transmuters to be deployed;
- to determine the number and capacities of the fuel cycle facilities needed;
- to stabilize the Pu inventory of Group B.

Key idea

- Sensitivity to uncertainties in input quantities.
  - Cross sections (fission, capture) of selected nuclides

Relevant nuclides	Heat load	Ingestion radiotoxicity	Spontaneous fission rate	Gamma dose rate
Am-241	X	X		X
Am-242				X
Am-242m				X
Cm-243				X
Cm-244	X		X	

From "IMPACT OF NUCLEAR DATA UNCERTAINTIES ON CLOSED FUEL CYCLE SCENARIOS: PRELIMINARY ASSESSEMENT", V. Romanello et al., IEMPT-12, September 2012 (Prague)

- Integral quantities
  - Decay heat
    - Fabrication plant (2050), Reactor (2149), Repository (2199)
  - Neutron emission
    - Fabrication plant (2050)

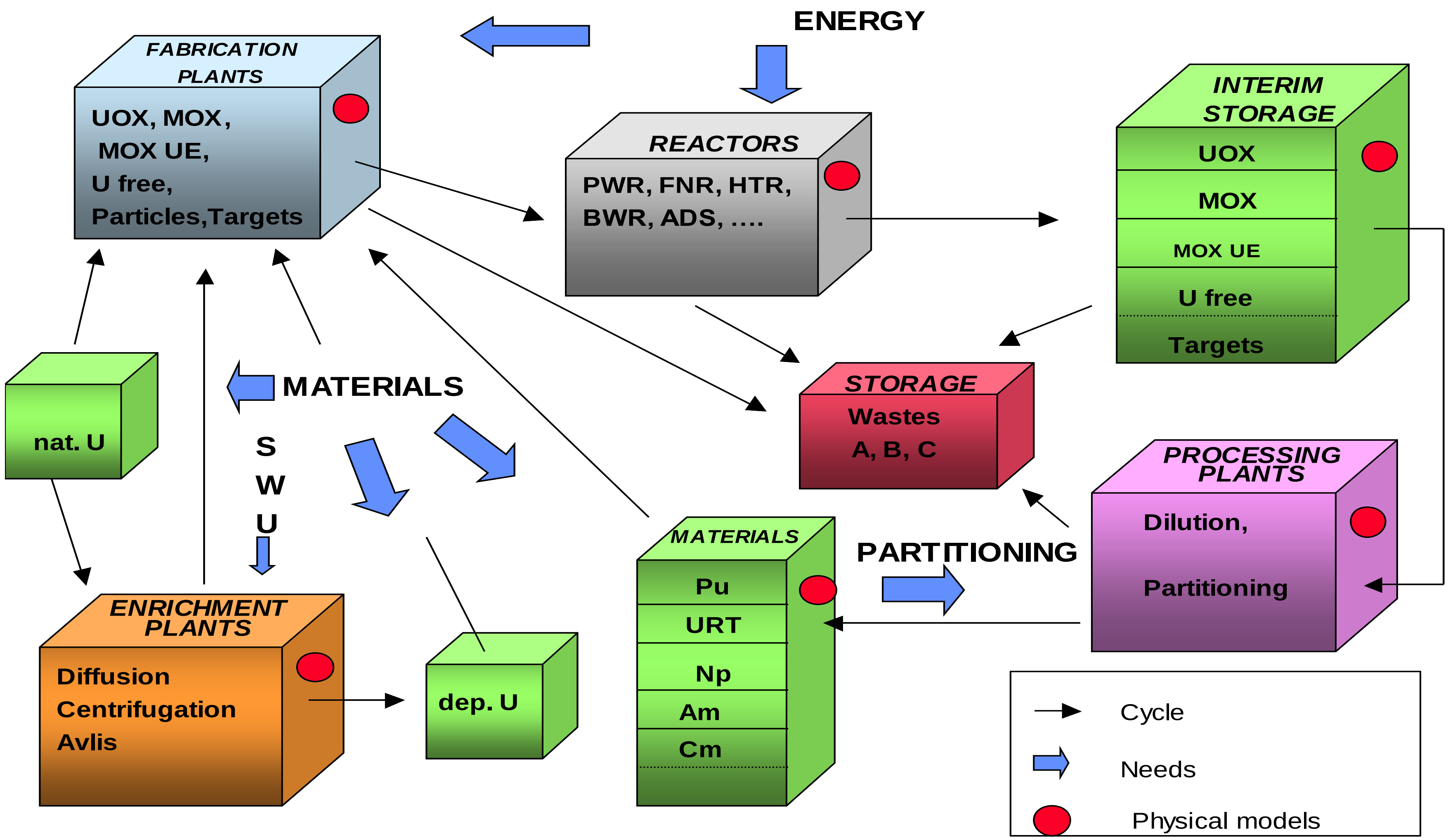
COSI 6

- The COSI code (COmelini-SIccard) was developed by CEA (Commissariat à l'Energie Atomique) starting from 1985;
- COSI6 simulates the whole nuclear fleet:
  - reactors, enrichment, reprocessing, fuel fabrication plants, stocks, transports;
- The simulations are time dependent;
- The results are the mass flows between facilities and the isotopic compositions;
- The proliferation risk parameters estimation, the fuel cycle cost analysis, etc.

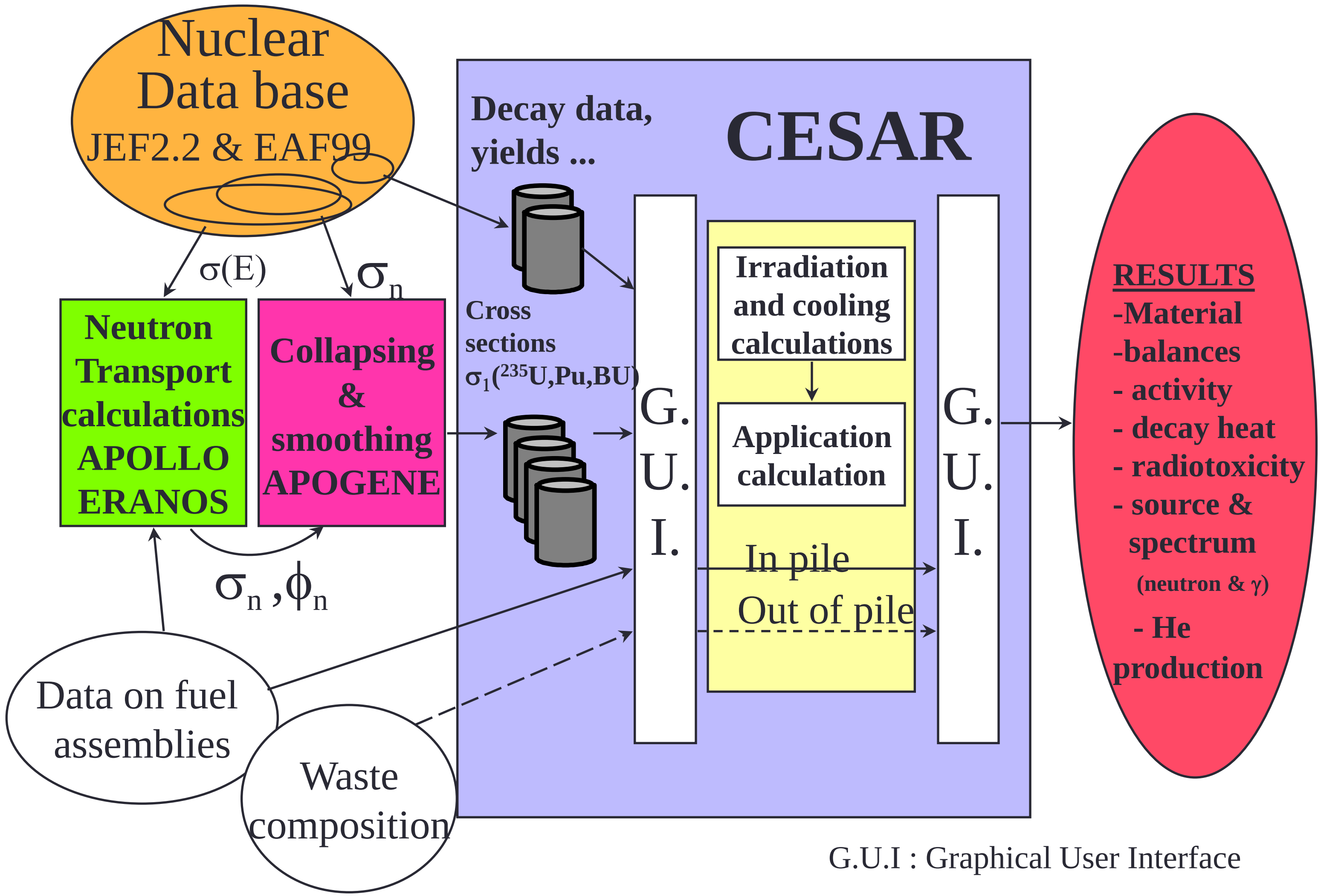
COSI 6 (cont)

- Facilities of the fuel cycle:
  - mines, enrichment, fabrication facilities, reactors, reprocessing facilities, stockpiles, waste storages
- Input data for the simulation:
  - energy demand, fuel and nuclear materials, requirements
- Transfers of nuclear materials (thin black arrows in figure)
- Change in isotopic composition of materials using physical modeling (full red circles)

COSI 6 (cont)


ENERGY
FABRICATION PLANTS
UOX, MOX, MOX UE, U free, Particles,Targets
REACTORS
PWR, FNR, HTR, BWR, ADS, ….
INTERIM STORAGE
UOX
MOX
MOX UE
U free
Targets
nat. U
MATERIALS
S
W
U
STORAGE
Wastes
A, B, C
PROCESSING PLANTS
Dilution,
Partitioning
MATERIALS
Pu
URT
Np
Am
Cm
PARTITIONING
ENRICHMENT PLANTS
Diffusion
Centrifugation
Avlis
dep. U
Cycle
Needs
Physical models

Fuel depletion calculation in COSI 6



G.U.I : Graphical User Interface

Apogene code

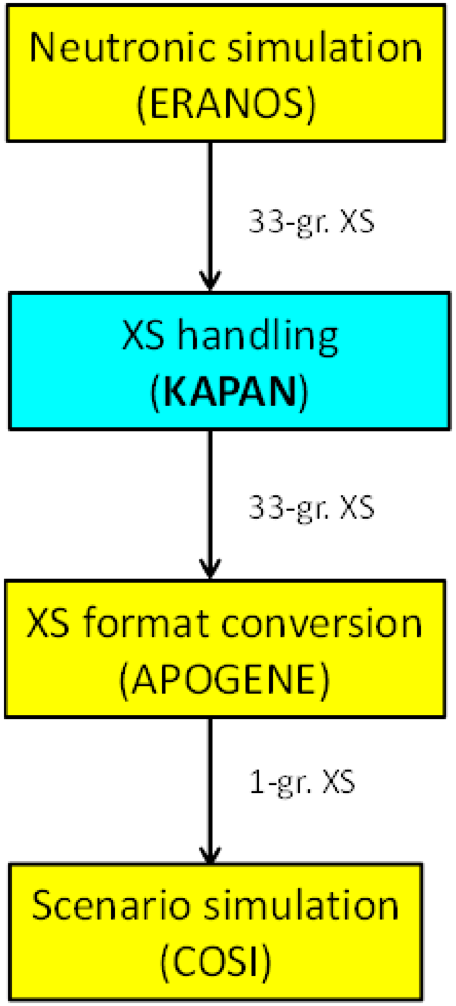
- Collapses 33-groups output cross-sections coming from the neutronic code (ERANOS) into 1-group cross sections;
- Performs a smoothing procedure, i.e. interpolates the cross-sections vs. burnup (Lagrange polynomial);
- The resulting library of nuclides cross-sections interpolated values vs. burnup is ciphered (in order to avoid non authorized access).

Need for additional tool

- Eranos output – AP2PEP files:
  - Huge size
    - 33 energy groups x 23 nuclides x 23 burnup points x 3 cross section types;
    - Thousands lines of data;
    - Very time consuming to handle manually;
  - Necessary output
    - Clone the file with some of the cross section values modified in a specified way;
    - (e.g. change only fission cross sections of Pu-239);
    - Multi-group cross sections collapsed into one-group;
    - Depicts lethargy plot.

Overview of used codes

- General procedure overview:



K. Atabekjan, V. Romanello

KAPAN code

- Script in Octave ver .0.10.1 (Matlab open-source analog)
- Processing cross sections / neutron flux data file

```
 source ("KAPAN_1_9_5.m")
>>>
*************************************************************
*                                                           *
*              KIT KAPAN                                    *
*              combined with Lethargy Plot construction     *
*              and Reaction Rate % Factors calculation      *
*                                                           *
*              by K. Atabekjan, V. Romanello                *
*                                                           *
*              KIT - IKET                                   *
*                                                           *
*              ver.1.9.5 - 10  September 2012               *
*                                                           *
*************************************************************

Enter the file name, which contains the original cross section values (e.g., OX
IDE_MAPU1_CR05_AP2PEP or data.txt

Command line>>
```

KAPAN terminal window output

KAPAN input/output fragment

AM241
SECABS
33
2.388775E+00
1.628491E+00
1.843773E+00
3.972604E+00
1.400941E+01
4.986491E+01
3.357246E+02
SECFIS
33
2.383011E+00
1.293549E+00
1.274156E-02
2.767596E-02
1.125852E-01
2.704898E-01
2.088666E+00

AM241
SECABS
33
2.865377E+00 2.408058E+00 2.125893E+00 2.228426E+00 2.243556E+00
1.887201E+00 1.042817E+00 9.897609E-01 1.220326E+00 1.520328E+00
1.846321E+00 2.144901E+00 2.609287E+00 2.900446E+00 3.310278E+00
3.978139E+00 4.934781E+00 6.403689E+00 8.232362E+00 1.070928E+01
1.403193E+01 1.803013E+01 2.360765E+01 3.822836E+01 2.681539E+01
4.991901E+01 6.679854E+01 3.019912E+01 3.639021E+01 5.664915E+01
3.361423E+02 7.114512E+02 4.964676E+02
SECFIS
33
2.859613E+00 2.397338E+00 2.108447E+00 2.200643E+00 2.175007E+00
1.552259E+00 3.212664E-01 7.569499E-02 2.923673E-02 1.841843E-02
1.528987E-02 1.573303E-02 1.719682E-02 2.033165E-02 2.541949E-02
3.321115E-02 4.366012E-02 5.898169E-02 7.753445E-02 1.022496E-01
1.351022E-01 1.743434E-01 2.304551E-01 1.784585E-01 2.059874E-01
3.245878E-01 4.684312E-01 1.751502E-01 2.699780E-01 5.550787E-01
2.506399E+00 6.059027E+00 3.168218E+00

KAPAN one-group cross sections

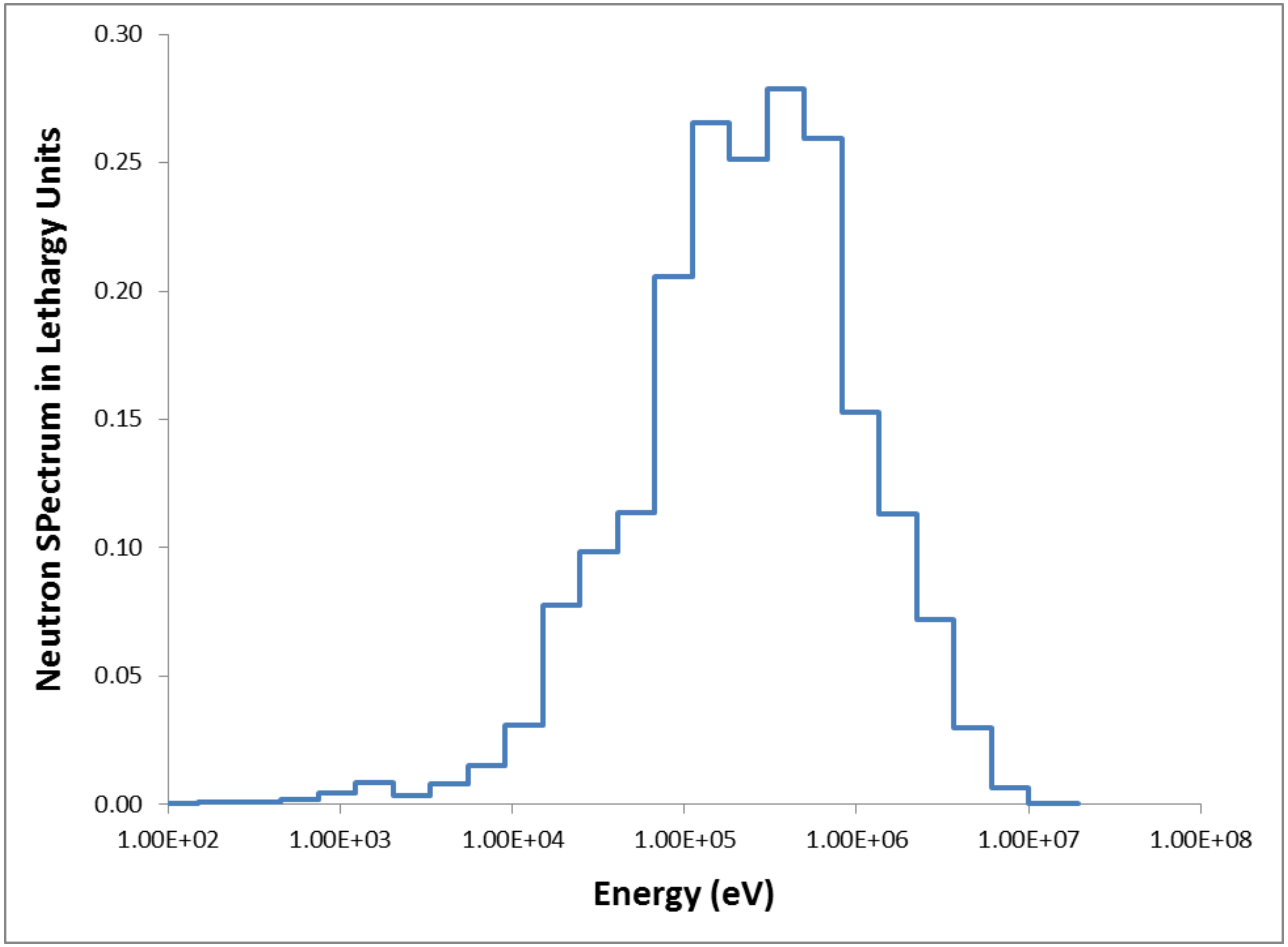
- One-group cross sections (b):

AM241		AM241	
ABSORPTION:	1.720590	ABSORPTION:	1.791484
FISSION:	0.354469	FISSION:	0.425363
CAPTURE:	1.366121	CAPTURE:	1.366121

- Spectrum indices:

Am-241 capture / Pu-239 fission:	0.810094
Am-241 fission / Pu-239 fission:	0.210196
Am-241 capture / Pu-239 fission:	0.810094
Am-241 fission / Pu-239 fission:	0.252236

Lethargy plot



KAPAN mathematics

- One-group cross section for a certain radionuclide
- $\sigma_B = \frac{\sum_i \phi_i \sigma_{i,B}}{\sum_i \phi_i}$

- Variations in Capture Cross Section Values
- $\sigma'_{ABS} = \sigma_{ABS} \pm p \cdot (\sigma_{ABS} - \sigma_{FIS})$

- Variations in Fission Cross Section Values
- $\sigma'_{FIS} = (1 \pm p) \cdot \sigma_{FIS}$
- $\sigma'_{ABS} = \sigma_{ABS} \pm p \cdot \sigma_{FIS}$

Work outcomes

- Script and documentation ready in ~1 month
  - Working correctly and is used for research
  - Lots of small details
- Some initial results obtained
  - 5% variation in Am-241 fission cross sections resulted in < 2% change in output fuel cycle parameters
- Future work perspectives
  - Add support for N2N cross section modification
  - Obtain results for all the nuclides of interest
  - Test different variation magnitudes

Acknowledgements

- Erasmus traineeship grant
- KIT summer internship grant

END OF PRESENTATION

Questions/Comments?