Validation of TRIGA Reactivity Coefficients

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Goal: the accurate evaluation of the reactivity feedback in TRIGA cores within the ECATS project (Experiment on a Coupling of an Accelerator, a spallation Target and a Subcritical blanket) to study dynamic feedbacks in Source-Driven Sub-critical systems.

Introduction

* The suggested reactivity feedback curve (GA-General Atomic) differs from new experimental data, in particular in range of 110-150^O Celsius;

* The different scattering kernel S(α,β) parameters for the hydrogen bound zirconium hydride have noticeable effect on the negative reactivity coefficients;

* The influence of the inter-molecular forces in form of the phonon distribution function on the reactivity coefficients is introduced;

* The sensitivity of the scattering kernel's numerical treatment is presented with respect to the reactivity coefficients.

Model: description and input

TRIGA fuel assembly model

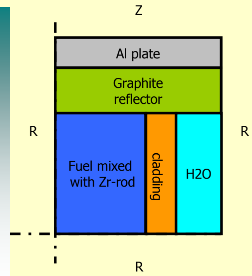
* Fuel elements are cylinders of ternary alloy uranium zirconium hydride with H-to-Zr ratio 1.7 and total Uranium of 8,5% of the mixture by weight and 20% enriched U -235

* Fuel cladding – stainless steel AISI 304

* Two graphite cylinders at the top and the bottom of the fuel rod

* Two aluminum plates at the top and the bottom of the fuel rod

R – reflective boundary condition
Z – zero flux boundary condition



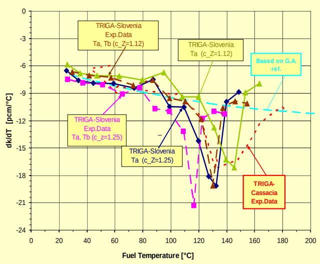
Experimental Results

* The reactivity measurements were carried out in two similar TRIGA cores:
- TRIGA RC-1 Cassacia, Italia with burned-up fuel – since 1967 -115FA
- TRIGA Mark II Ljubjana, Slovenia with fresh fuel – 47.6 FA

* In both experiments only one or two temperature measurement points were applied from which an average temperature was evaluated by the formula used in the benchmark paper

* All curves differ considerably from the General Atomic (GA) curve in range (110-150^O Celsius)
a) Two curves of the Slovenian core refer to the estimation of the total core averaged temperature based on measurements at point A in the centre of the core where the radial form value for the Ta is Ca =1.26 and the axial factor C_z has 2 values (1.25 and 1.12 applied in the benchmark paper)
b) The other two curves of the Slovenian core are based on two point measurements at the centre of the core (A -Ta) and at the first ring of the core (B-Tb) with the radial form coefficient Cb=1.22
c) The Cassacia curve was taken from TRADE report

* The sensitivity to the axial form factor and the number of measurement points is shown
* The differences between the curves emphasize the necessity of a multi-point temperature measurement to asses more accurately the influence of the spatial flux distribution and the fuel content on the reactivity feedback.



Experimental temperature dependent reactivity feedbacks of the Cassacia and Slovenian TRIGA cores

TRIGA RC-1 Cassacia

Cross section and scattering kernels processing

ENDF/B library

NJOY

RECONR
BROADR
LEAPR - generates thermal scattering data in ENDF format File 7 for various temperatures
THERMR - calculates pointwise thermal scattering cross section in PENDF format, File 3 (cross section File 6 (double differential data)
ACER - generates thermal scattering data for MCNP(X) code in ACE format

MCNPX Specific library

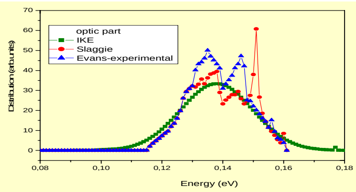
MCNPX

Phonon expansion method

Approximation for bound isotopes in molecules (Slaggie and IKE)

$$S_S(\alpha,\beta) = e^{-\alpha\lambda_S} \sum_{n=0}^{\infty} \frac{1}{n!} \alpha^n x \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{i\beta\hat{t}} [P_S(\beta') e^{-\beta'/2} e^{-i\beta'\hat{t}} d\beta]^n d\hat{t}$$

is the thermal scattering law
α is the momentum transfer, β is the energy transfer
ρ(β) is frequency spectrum, and λ is the Debye-Waller coefficient



Investigated and experimental frequency distribution of hydrogen bound in zirconium hydride

Sensitive issues for Light Isotopes

a) Face centered cubic (fcc) structure

b) Phonon frequency distribution (LEAPR)

c) Choice of energy grid in THERMR (old standard 59 points, new 118)

d) Equi-probable energy interval points in ACER

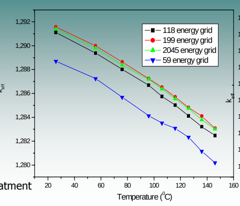
e) Number of Cosine bins in THERMR

f) Tolerance for cross section reconstruction in RECONR and BROADR

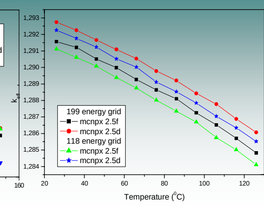
g) Free gas kernel for secondary scatterer

h) Removing numerical spikes due to S(α,β) treatment in mcnpx (beta version 2.5d versus 2.5f)

MCNPX 2.5d calculated criticality values using different S(α,β) input files for hydrogen bound in zirconium

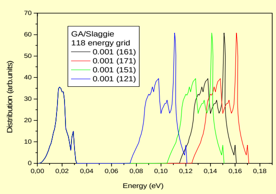


Case c)

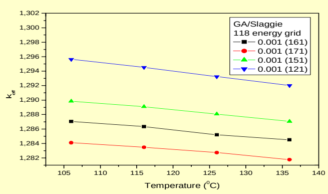


Case h)

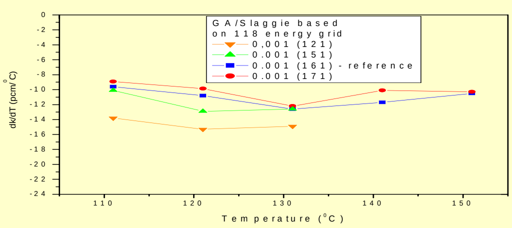
The influence of the intermolecular forces in form of the phonon distribution function variations on the reactivity coefficients



Examples of shifting the phonon spectrum (optical part) for hydrogen bound in zirconium



MCNPX 2.5d calculated criticality values



The impact of different phonon spectrum (optical part) in the reactivity feedback

Conclusions and Summary

* The current scattering kernel treatment for TRIGA fuel leads so far to accurate results up to 110^O Celsius;

* Between 100-150^O Celsius the measured enhanced temperature reactivity coefficient was reproduced by shifting the phonon optical spectrum slightly to higher energies. However there is not yet physical evidence known for such behavior;

* Additional accurate measurements are still needed for analyzing the reactivity feedback above 110^O Celsius; information about possible impact on start-up procedures for high power TRIGA cores seems to be of high interest

* Increasing the number of energy grid points for S(α,β) tables improves the linear interpolation handling of these probability tables. An alternative treatment of the linear interpolation in the MCNPX 2.5f beta version improves partially the results by eliminating flux spikes;

* The influence of the bounded hydrogen within the fuel, in addition to the zirconium, should also be investigated.

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