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**INTERNATIONAL EVALUATION COOPERATION SUBGROUP 9**  
**"HIGH PRIORITY REQUEST LIST FOR DATA NEEDS IN**  
**FUTURE/ADVANCED REACTORS"**  
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## **1. INTRODUCTION**

This first report is based on input coming from Japan, the US, France and the EEC (ref. 1-6), which has been made available up to now. The types of systems for which data needs have been expressed are summarized in paragraph 2. Paragraph 3 gives a broad overview of specific data fields which have been mentioned in the different contributions.

Quantitative statements in terms of present uncertainties and well documented target accuracies are still generally lacking, most of the requirements being more of a qualitative nature or without a specific sensitivity analysis.

However, it has been thought useful to give a "first iteration" list with as many as possible quantitative values, even if tentative and certainly subject to modification in a further revision of the present document.

## **2. FUTURE/ADVANCED REACTOR SYSTEMS CONSIDERED**

The systems that have been considered can be classified in the following manner :

**LWRs with extended life cycle,  
LWRs without soluble boron.**

For both the types of concepts, data needs are related to the neutron absorbers introduced to control the core, either for shutdown or to gain a longer life cycle. Most of the absorbers considered (hafnium, gadolinium, erbium, besides boron, silver and indium), have been studied in the past. Relevant data are present in the major files and some integral tests have been made. However, there is a general agreement in the different user communities that better data are still needed, in view of more stringent design requirements.

### **Pu-fuelled LWRs**

LWRs partly loaded with Pu fuel are already operating successfully. However, the increase of the Pu content in the core, and the envisaged full-Pu cores with moderator/fuel ratios different from the present standard values (around 1.1), i.e. tighter pitch lattices (of the type studied for HCLWRs) or overmoderated lattices

(with moderator/fuel ratios of the order of 3) require an improved knowledge of Pu isotope data. The strong evolution of the Pu-vector with irradiation, and its impact on the reactivity coefficients (like the local/global coolant void coefficient), requires an accurate knowledge of the higher Pu isotope data, to better define safety constraints which can limit the further reloadings of irradiated Pu fuel. A quantitative example, based on a sensitivity analysis is given in Appendix I.

Both epithermal and resonance region data are required to be known with high accuracy. This was clearly indicated by the results of the NEACRP benchmark on HCLWRs.

In the case of full-Pu loaded LWR cores, there is the requirement for data related to more effective absorbers, of the type indicated above.

### **Pu-burner fast neutron spectrum reactors**

This type of reactor is presently being actively considered both in terms of strategies for the back-end of the fuel cycle or to handle fuel stocks from former military applications.

In general this type of fast reactor concept requires as high as possible Pu enrichment or, in a more drastic solution, a Pu fuel without U-238. In that case, inert matrices should be used for the Pu fuel (like cerium or others).

Data requirements concern Pu data at high energy, like the inelastic scattering, that were of lesser concern for standard breeder fast reactors, and improved Pu isotopes capture and fission cross-section data, to which at present higher uncertainties are associated (10 % or higher).

The eventual inert matrix materials are also a source of data requirements, in particular for resonance data and the associated possible Doppler effect.

### **Fast reactors with new fuel or coolant types**

Nitride fuel is presently considered as an interesting alternative to oxide fuel for fast reactors. This requires an improved knowledge of N-14 and N-15 data, for which no integral validation is available.

Moreover lead-cooled fast reactor concepts have been proposed, which require improved Pb (and possibly Bi) data, in particular scattering data.

## Radioactive waste transmutation systems

This field is presently the focus of many theoretical studies. Data requirements in this area are related to the different strategies which are proposed.

- a) Fission reactors for the transmutation of minor actinides. Minor actinides are used as fuel, in different quantities (according to the different concepts) and data requirements are related to the standard reactor parameter performances (critical mass, reactivity coefficients, reactivity loss/cycle, etc ...).
- b) Fission reactors for the transmutation of long-lived fission products (Tc-99, I-129, etc ...). Data for these isotopes are required with high accuracy, in particular in the resonance and epithermal energy range.
- c) Accelerator-based systems. For this type of systems two distinct types of data are required :
  - 1) Neutron data for the radioactive wastes introduced in a subcritical, source driven system.
  - 2) Intermediate energy ( $E > 20$  MeV) data for nuclear reactions in the targets, which determine the energy and angular neutron source in the subcritical blanket.

For this type of data, an effort has been undertaken in the frame of the Nuclear Science Committee of the OECD-NEA, to investigate the performance of the present transport codes used to describe inter-and intra-nuclear cascades. One of the aims of the benchmark exercises is to define what data types are of relevance and how data should be defined and organized in data files, to provide input to Monte-Carlo transport codes. Data needs and requirements should result from this international effort.

As a general remark, data requirements and target accuracies to be met for transmutation studies cover a very wide range of isotopes and data types (neutron interaction data, decay data, neutron emission data, etc ...). Up to now only very general requirements have been expressed. A sound data requirement list and associated target accuracies should be established, using appropriate sensitivity analysis. A method has been proposed (ref. 7), which is essentially the method used in the past for this purpose in the standard reactor applications. The use of this method implies the definition of the relevant integral quantities for design and intercomparison of the performances of the different systems (like the source of potential radiotoxicity risk in the storage ; the neutron emission and radioactivity in the different phases of the fuel cycle, etc ...), and the definition of maximum tolerable uncertainties on these integral quantities, due to nuclear data uncertainties. This type of analysis is strongly recommended, to issue a more credible and sound data requirement list.

### **Alternative fuel cycles : the Th cycle**

The use of the Th cycle is still envisaged by some countries. Data requirements for updating the current evaluations of Th-232, Pa-233 but in particular U-233, have resulted from a few reviews of the present status of data in the current major data files.

### **Shielding applications**

Despite the fact that shielding issues are considered of relevance for future reactors (lateral/axial shield reductions, fluence decrease on pressure vessels), no specific requirements have been expressed up to now. However, structural material and photon production data improvements, that will be indicated in the next paragraph, will be necessary for future shielding designs.

### **Dosimetry and reactor decommissioning**

Data needs in these fields are not directly related to future/advanced reactors. However, specific requests could possibly arise from these advanced systems, as is the case of advanced radioactive element transmutation systems. For the first version of the present document such specific requirements have not been specified explicitly.

## **3. DATA REQUIREMENTS BY DATA AND ISOTOPE TYPES**

### **a) Major actinides**

For any future/advanced reactor concept, a selected number of issues related to major actinides do enter in a high priority request list :

- $\alpha$  and  $\eta$  values of U-235 and Pu-239. If there is a confirmation of the energy shape for the  $\eta$  (U-235) at low energy, a similar effort is needed for Pu-239. The present suggested reduction of  $\eta$ (U-235) corresponds to a modification of the moderator temperature coefficient in PWRs of  $\sim 1$  pcm/ $^{\circ}$ C, which is significant.
- Fission spectra of U-238, Pu-239 and Pu-240. In particular, uncertainties on the high energy tail of the fission spectrum can have an impact on deep penetration problems for shielding studies.
- The inelastic scattering cross-sections of U-238 and of Pu isotopes are still a recognized field for high priority requests of high precision data (5 - 10 %).
- The fission cross-section of Pu-239 from 100 eV to 100 keV can be dropped from a high priority request list, if the latest Derrien resonance analysis and the latest Geel measurements will show overall consistency.

- U-238 capture cross-section in the resonance region and up to 100 keV can also be dropped from the list, if the consensus expressed in the review work of the "ad hoc" IEC subgroup will be confirmed by integral validation (underway for most files).
- A private communication of M. DERRIEN indicates that a substantial revision of the U-233 data is needed, the present file status being unsatisfactory (e.g. in the resonance region, the formalism is not adequate ; only a partial analysis has been made of existing experimental results ; the energy domain is too limited).

#### **b) Structural materials**

Capture in structural materials, together with scattering data are still in a high priority request list. Work of evaluation intercomparison is progressing in the frame of the IEC, but measurements and evaluations are needed, in particular for total cross-sections above ~ 1 MeV.

Data requirements include photon production data, for which very limited integral tests are available.

In this field, the needs for data improvements related to present shielding and core design will also cover future advanced reactor studies.

#### **c) Fission products**

The recent specialists meeting held at Mito (Japan), has allowed to verify the good progress in this field. A coordinated integral validation effort is underway, that could lead to specific new requirements. A field which is still the object of measurement requirements is that of the even-even fission product inelastic scattering cross-sections. In general, the state of the art as documented at the Mito meeting should serve as a reference. Present reactor and fuel cycle needs (such as the ones related to criticality/safety) will probably also cover needs for future advanced reactors.

#### **d) Delayed neutron data**

The problem of the U-238 delayed neutron data has been addressed by several laboratories. Differential and integral experiments are planned to improve the data to levels required for reactor reactivity scale assessment (target accuracy :  $\pm 5\%$  at  $2\sigma$ ).

Delayed neutron data for minor actinides need further improvement, if dedicated minor actinide burner reactors have to be developed. The low delayed neutron yields for some of the most important minor actinides, have an impact on the kinetics of the proposed reactors.

**e) Decay heat**

The present status has been reviewed also at the MITO specialists meeting on fission product data. New standards have been (or are being) proposed. Discrepancies for cooling times  $< 10^4$  sec have been pointed out. Moreover, the level of the  $1\sigma$  uncertainties associated to these standard is a matter of concern, and an international consensus has to be found.

**f) Covariance data**

Covariance data, in the simplified (i.e. by broad energy bands) form requested by users, are needed to trigger better-founded data requests and target accuracies. This is shown, in the case of transmutation studies, in reference 7. Even if detailed covariance data can hardly be introduced in a high priority list for future/advanced reactors, reasonable uncertainties and correlation matrices in simplified form, can play a relevant role to better focus data fields, where new evaluations or experiments are needed as a priority.

## ANNEXE 1

INELASTIC SCATTERING DATA RELEVANCE FOR REACTOR  
PHYSICS CALCULATIONS  
SOME EXAMPLES

1. U-238 (n,n') data1.1 The impact of the uncertainty of  $\pm 10\%$  on the total (n,n') cross section has the following consequences in typical Fast Reactors

$\pm 4\%$  on a total core Na-void reactivity coefficient.

$\pm 0.4\%$   $\Delta k/k$  on the critical balance.

$\pm 1 \div 2\%$  on the control rod worths, depending on the configuration of the inserted rods.

These values have to be compared to the typical target accuracies ( $2\sigma$  values) :

$\pm 20\%$  for Na-void coefficient (negligible impact).

$\pm 0.5\%$   $\Delta k/k$  on  $K_{eff}$  (significant impact).

$\pm 6 \div 8\%$  on the rod worth (negligible impact).

The secondary neutron distribution uncertainty can also play a significant role and need to be known accurately.

The effect on the spectrum of a  $\pm 10\%$   $\sigma(n,n')$  variation is also significant. For example the spectrum index :

$$\frac{\text{Fission U-238}}{\text{Fission Pu-239}} = F8/F9$$

is changed by  $\pm 3\%$ .

1.2 In the case of MOX-fuelled LWRs from data in reference 8 one has that a  $\pm 10\%$  uncertainty of the total (n,n') cross-section has the following consequences

The  $k_{\infty}$  is changed by :

$\pm 0.45\%$  if  $V_m/V_f = 0.5$  and Pu enrichment = 8 %

$\pm 0.24\%$  if  $V_m/V_f = 1.0$  and Pu enrichment = 5 %

The void (90 %) coefficient is changed by :

$$\frac{k_{\infty}(\text{void}) - k_{\infty}}{k_{\infty}} = \begin{cases} \pm 8.4 \% \text{ if } V_m / V_f = 0.5 \text{ and Pu enrichment : } 8 \% \\ \pm 2.1 \% \text{ if } V_m / V_f = 1.0 \text{ and Pu enrichment : } 5 \% \end{cases}$$

## 2. STRUCTURAL MATERIALS (n,n') DATA

### 2.1 The impact of a $\pm 20$ % uncertainty on the total (n,n') cross-section of steel (~ 65 % Fe ; ~ 19 % Cr ; ~ 13 % Ni) has the following consequences in typical Fast Reactors.

$\pm 45$  % on a total core Na-void reactivity effect.

$\pm 0.76$  %  $\Delta K/K$  on the critical balance (Fe contribution : 0.54 %  $\Delta K/K$  ; Cr contribution : 0.14 %  $\Delta K/K$  ; Ni contribution : 0.08 %  $\Delta K/K$ ).

$\pm 1$  ÷  $-2$  % on the control rod worths, according to the configuration of the inserted rods.

Also in this case the spectrum is changed significantly. In fact the impact on the spectrum index F8/F9 of a  $\pm 20$  % uncertainty on the Fe  $\sigma(n,n')$  is  $\pm 4$  %.

### 2.2 Two examples can be given for shielding applications

a)  $\pm 20$  % uncertainty on the total (n,n') cross-section for Fe gives  $\pm 40$  % uncertainty on the  $^{58}\text{Ni}(n,p)^{58}\text{Co}$  reaction rate (representative of high energy damage rate) in the pressure vessel simulation position of the PCA experiment.

b) The same uncertainty gives a  $\pm 20$  % uncertainty in the neutron flux measured with a Hydrogen/Argon proportional counter at 50 cm penetration in an iron slab, into which a fission neutron source is inserted.



### 3. FISSION PRODUCTS (n,n') DATA

For a typical fast reactor, an uncertainty of  $\pm 20\%$  on total inelastic cross-section of the fission products built-up during an irradiation cycle of  $\sim 500$  full power days, gives an uncertainty of  $\sim \pm 5\%$  on the reactivity loss during the cycle due to fission product build-up. Because of effects of opposite sign on the reactivity with the burn-up of the fuel and the build-up of the fission products, this effect can be relevant in absolute value.

In the case of SUPERPHENIX, the reactivity loss during 480 FPD can be decomposed as follows :

- fuel burn-up :  $-1\% \Delta k/k$ ,
- fission product build-up :  $-2.3\% \Delta k/k$  (contribution of inelastic scattering :  $\sim -0.5\% \Delta k/k$ ),
- total effect :  $-3.3\% \Delta k/k$ .

In this case a  $\pm 20\%$  uncertainty on the (n,n') cross-sections of the fission products, leads to an uncertainty of  $\sim 0.1\% \Delta k/k$ .

However, in a reactor with about zero reactivity loss, this uncertainty will be significant on the control rod reactivity worth requirements.

## ANNEXE II

Pu ISOTOPE DATA SENSITIVITY IN LWR WITH MOX FUEL (from M. NAKANO and T. TAKEDA, J. Nucl. En. 610, 24 (1987))

Parameter	$K_{\infty}$		Void coefficient (spectral effect, 50 % void) (%)	
	0.5	2.0	0.5	2.0
Vm/Vf	0.5	2.0	0.5	2.0
Pu enrich. (%)	8.0	5.0	8.0	5.0
Pu-239				
capture	-0.143	-0.229	-6.8	0.05
fission	0.383	0.336	-1.8	-0.46
Pu-240				
capture	0.186	-0.028	-1.0	0.01
fission	0.116	0.077	0.4	-0.17
Pu-242				
capture	-0.017	-0.018	-1.5	0.04
fission	0.003	0.001	-0.2	-0.01

These data are energy integrated sensitivities, which, in the case of the void coefficient, result from the compensation of positive and negative contributions. Moreover, these sensitivities are burn-up dependent.

The impact of Pu-isotope data uncertainties can be significant in practical applications.

In fact, in an unpublished work, S. Cathalau of CEA-Cadarache has shown that :

- void coefficient variation with H<sub>2</sub>O content is heavily dependent on Pu isotopic composition (see for example fig. 1, where this variation is given for several types of Pu in a standard PWR lattice with Vm/Vf ~ 2. The Pu vectors being given in Table 1),
- uncertainties derived from the difference of current libraries (CEA-86, JEF-2, etc ...) can end up with an uncertainty between 1 % and 1.5 % on the maximum allowable Pu-fissile content to keep the void coefficient negative. This is very significant from the economic point of view.

In the case of the Pu-type indicated in table I as "Pu n°2", the limit which can be envisaged is 9.2 % in Pu-fissile. The contribution of the different isotopes to the void coefficient in the same case (Pu n°2), is given in figure 2.

TABLE I

	Pu n°1	Pu n°2	Pu n°3	Pu n°4	Pu n°5	Pu n°6
$^{238}\text{Pu}$	1.85	1.17	0.11	2.55	2.74	5.63
$^{239}\text{Pu}$	58.05	67.85	79.93	54.26	42.51	33.94
$^{240}\text{Pu}$	22.55	18.63	17.25	23.16	29.19	29.10
$^{241}\text{Pu}$	10.75	9.11	1.45	11.71	14.30	13.71
$^{242}\text{Pu}$	5.60	2.69	0.50	7.14	9.82	16.23
$^{241}\text{Am}$	1.20	0.55	0.57	1.18	1.44	1.39
PuFis	68.80	79.96	81.38	65.97	56.81	47.65

FIGURE 1

MAIN ISOTOPE CONTRIBUTION TO VOID REACTIVITY COEFFICIENT

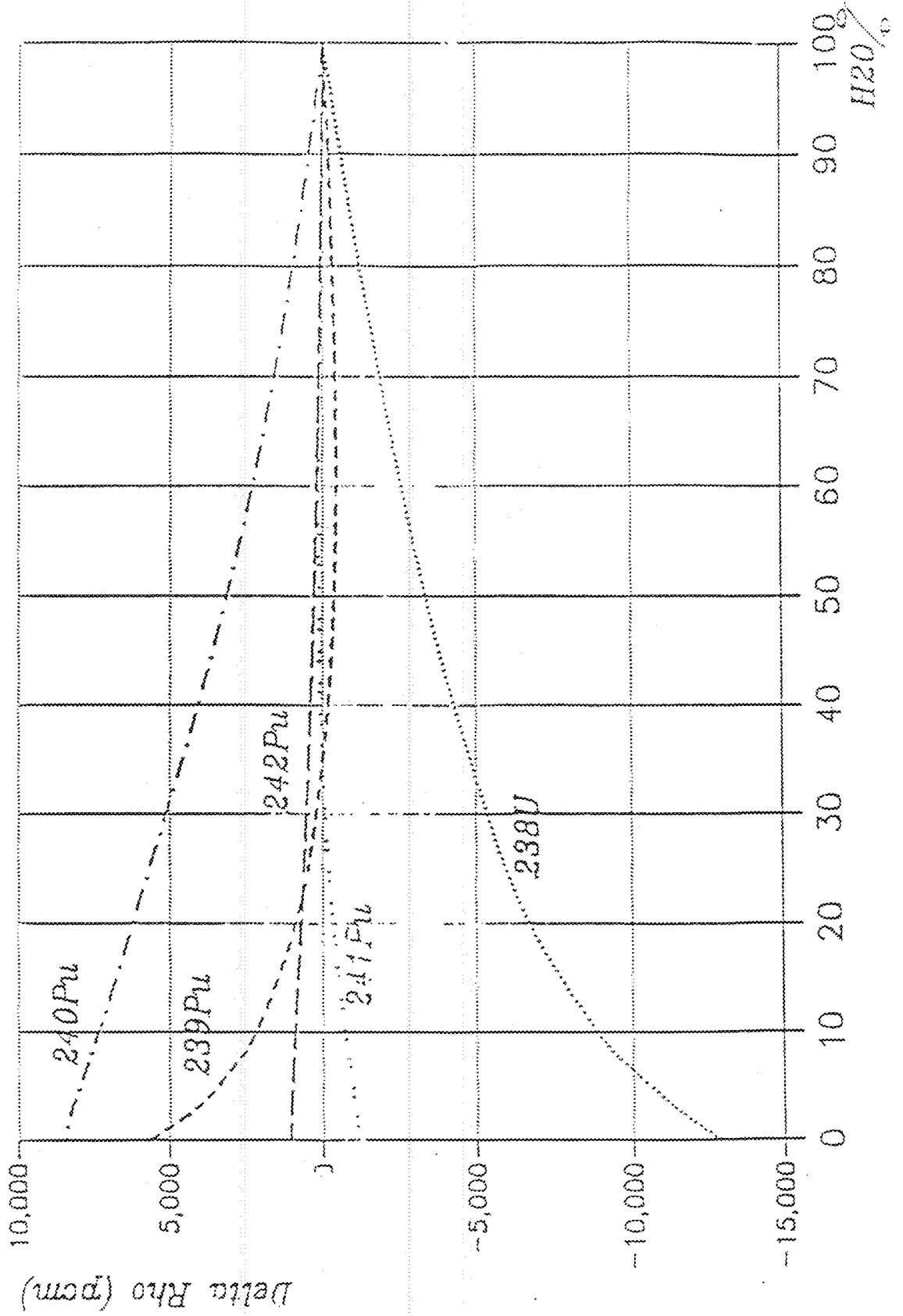


FIGURE 2

TOTAL VOID EFFECT ON  $K_{\infty}$  FOR DIFFERENT Pu TYPES

