DIVISION ETUDES ET DEVELOPPEMENT DES REACTEURS
Département des Réacteurs à Neutrons Rapides

FR 8000622

INIS

International Conference on nuclear cross sections for technology.
Knoxville, Tenn., USA, October 22-26, 1979.
CEA - CONF 4989

NUCLEAR DATA NEEDS FOR PLUTONIUM BREEDERS

Ph. HAMMER

RESUME :

This paper aims at summarizing the present major nuclear data needs for fast breeders. The corresponding requirements are deduced from the target accuracies which are associated to the design, operation and safety related parameters. Due to the fact that these target accuracies may somewhat change from one country to another the requirements quoted here must be considered more as the present order of magnitudes than as precise figures.

The maximum admissible uncertainties which are asked presently for the nuclear data are due in particular to :

. the necessity of reducing the supplementary investment coste which account the present neutronic uncertainties ;
. the necessity of improving the optimization studies devoted to the future commercial fast breeders : these studies involve the comparison of neutronics performances of new concepts, such as the heterogeneous core concept, to the classical one.

Introduction

It may appear rather surprising that there are still nuclear data needs to be expressed for the fast breeders, since several evaluated data files have been completed and several specific data sets have been adjusted these last years, which should provide all the necessary information for the neutronic calculations.

In spite of this situation, several reasons remain for asking to the nuclear and reactor physicists to improve and enlarge the nuclear data for fast breeders :

1) a benchmark exercice has been recently performed [1] on a typical power reactor : some major design parameters, such as critical mass, radial power distribution, control rod antireactivity, were calculated with various cross section sets.

The dispersion between the calculated results was in most cases significantly higher than the target accuracies for the design parameters.

Taking into account that the calculational method was the same with all the nuclear data sets, this means that these data have still to be analyzed and improved.

2) For the commercial size power plants (1200 to 1500 MWe) which are presently designed in several countries, it is necessary to reduce the investment costs with respect to the prototype situation in order to reach the industrial level. In this context, it is clear that the reduction of the uncertainties applied to the neutronic parameters can contribute directly and significantly to the cost reductions.

3) For the first fast breeders which have been built, either experimental reactors or power plans, the first requests for an improvement of the nuclear data concerned mainly the fuel investment through the core critical mass.

For the power plants which are now in operation , such as PHENIX or PFR, and for the designed commercial reactors, the requests include now :

- . the operation related problems (burnup, corrosion, contamination, handling, storage) ;
- . the fuel cycle related problems (Plutonium production, reprocessing and refabrication).

4) For the future, new concepts are studied in order to improve the fast breeder characteristics with respect to the classical two core zone concept.

To be significant such optimization studies imply that the calculated parameters are affected with low uncertainties.

Most of the requests concerning the nuclear data expressed by different laboratories are included in the world request list for Nuclear Data (WRENDA).

The requirements which are deduced from the target accuracies on design operation or safety related parameters depend upon the target accuracies choosen : therefore they may change according to each laboratory.

Nevertheless, from WRENDA and from the specialist meetings devoted to structural materials [2], fission products [3], or transactinium isotopes [4], one can deduce the present status of the main requests for nuclear data related to the fast breeder neutronic problems. Such an attempt is done is this paper which does not aim at presenting a new request list but rather to underline and to analyze the present major requests for fast breeders.

In the following sections, the main design neutronic problems which originate the nuclear data requirements are recalled, the procedure generally used to deduce the maximum admittable uncertainties on the nuclea data from the target accuracies on the design parameters is briefly described and the main nuclear data needs for fast breeders are summarized.

Nuclear data need motivations

Target accuracies for the prediction of fast breeder characteristics

In the design of a power reactor, the uncertainties which are applied to the calculated neutronic parameters are due in particular to :

- the uncertainties on the basic nuclear data ;
- the approximations included in the calculational methods.

These uncertainties are taken into account in the reactor design by the use of security margins leading to supplementary costs. A typical example of such a situation is given by the SUPER-PHENIX 1 power plant, where the global uncertainty on the start-up core critical mass : ± 1% ΔK/K leads to increase the corresponding fuel enrichments by 4% to guarantee the fulfilment of all the operation conditions [5].

The following table provides a comparison between the present uncertainties on the main neutronic parameters and the target accuracies which are expected for the next commercial fast power plants (all the uncertainties quoted correspond to 2 S.D.) :

DESIGN PARAMETERS	PRESENT ACCURACY	TARGET ACCURACY
Reactivity for a fresh core	± 0.5 % $\frac{\Delta K}{K}$	± 0.3 % $\frac{\Delta K}{K}$
Critical mass	± 1.2 % $\frac{\Delta K}{K}$	± 1 % $\frac{\Delta K}{K}$
Reactivity loss per cycle	± 0.7 % $\frac{\Delta K'}{K}$	± 0.5 % $\frac{\Delta K}{K}$
Global breeding gain	± 0.04	± 0.03
Doppler effect	±15 %	±15 %
Sodium void effect	±40 %	±20 %
Control rod antireactivity	±20 %	±10 %
$q_{max}/\overline{q}$	± 4 %	± 3 %
β_{eff}	±10 %	± 6 %
TCF	± 5 %	± 3 %
Displacement per atom (D.P.A.)	±10 %	± 5 %
Decay heat	±10 %	± 5 %

On these figures, the following comments can be made :

. The global uncertainty on the critical mass can be taken into account by defining enrichments which will be higher for the start-up core than for the nominal one.

Such a strategy has been choosen for SUPER-PHENIX 1 with the following consequences on the neutronic characteristics [5] :

	NOMINAL CORE	START-UP CORE
Volumic enrichments (%)	13.79 17.60	14.63 18.17
Total Pu mass (Kg)	5560	5780
Cycle length (days)	320	320
Rectivity loss per cycle (%) ΔK/K	1.68	2.07
Breeding gain	0.25	0.21
Linear power W/cm	455	457

One sees that higher enrichments lead to a supplementary fuel investment (220 Kg of Plutonium) and to a higher reactivity loss per cycle which must be taken into account for the first cycle operation.

. The uncertainty on the reactivity of the fresh core is mainly due to the uncertainties on the nuclear data of the main fissile isotopes and of the structural materials, and to a less extent to the design calculational method.

This uncertainty can be reduced by improving the basic nuclear data, and such an improvement can be achieved with integral experiments [6].

. The reactivity loss per cycle uncertainty is related to the uncertainties on the Fission Product capture cross-sections and to the heavy atom balance associated to the burnup. It must be noted that the reactivity loss per cycle determines the operational control requirements, so that the core is critical at the end of cycle.

In a SUPER-PHENIX type reactor, the reactivity loss due to the Fission Product amounts to 75% of the total reactivity loss per cycle. The present uncertainty on the fission product bulk reactivity is ≈ ± 15% and the target accuracy is ≈ ± 10%.(2S.D.,[32].

. The uncertainty on the global breeding gain is not independant of the uncertainty on the critical mass [7] : ± 1% ΔK/K correspond to ± 0.03 for the breeding gain. This uncertainty contributes directly to the uncertainty on the doubling time of a fast breeder.

A typical figure for given operating conditions of a fast breeder is : ± 0.04 on the breeding gain absolute value leads to ± 10 years on the doubling time (≈ 40 years).

. The Doppler effect is one of the safety related parameters which has to be known mainly to predict the reactor kinetic behaviour and the energy yield corresponding to an accidental configuration. The uncertainty on this parameter is due to :

- the uncertainties on the shapes of the fission and capture cross-sections ;
- the uncertainties associated to calculational methods.

The present accuracy given is around ≈ ± 15% to ± 30% (see for example [8], [9]) and appears to be sufficient [9].

. The uncertainty applied to the Sodium void effect -which is another safety parameter) is mainly due to the present design calculational methods [10, 11]. The target accuracy ± 20% should be reached mainly by improving these methods, and to a less extent by improving the Sodium scattering cross-sections [12].

There is no need for a better accuracy than ± 20% since the other problems related to a hypothetical accident description are very roughly described by the calculations (e.g. dynamic behaviour of the core, accident sequences).

. The uncertainty on the control rod efficiency quoted here, takes into account :

- the uncertainties on the antireactivity on each absorber rod. These are related to the usual design calculational methods [13, 14], but also to a large extent to the basic nuclear data as it appears from the discrepancies observed for the benchmark problem [1] ;
- the uncertainties on the prediction of the interaction effects between the rods, which are very important for the commercial size breeders. Recent studies [15] confirm that these interactions effects are in fact rather will predicted by the usual design calculations.

. The uncertainty on the power form factor $q_{max}/\bar{q}$ has a direct influence on the total power output as far as this total power is limitated by the temperature of the hottest subassembly. In order to respect the limites on this highest temperature, one can be led to increase the core size. In the axial direction, the power form factor is used to predict the bowing of the core subassemblies.

. The β_{eff} value has to be known in order to get significant reactivity measurements by using the calibrated control rods ; such accurate measurements are necessary to get information on the temperature and power coefficients of a power reactor and on the internal breeding gain [16].

. Both the TCF or DPA values can be used as criteria for limitating the residence time of the subassemblies.

The reduction of uncertainty margins on the DPA value involves an improvement of the damage cross-sections of the structural materials.

. The determination of decay heat of the whole core and of each core subassembly is needed to define the emergency cooling conditions and to design the appropriate systems for fuel transfer out of the core and for fuel transportration.

The problems related to decay heat will be analyzed at this conference [34].

Remarks on the procedures used to improve the nuclear data

As said before the uncertainties on the design neutronic parameters are mainly due to the basic nuclear data and to the design calculational methods.

While the design calculational methods are checked and improved with integral experiments of various types (clean experiments or mock-up ones), the basic nuclear data can be improved by two approachs :

- differential measurements and evaluation ;
- specific integral measurements on critical facilities or power reactors.

In some cases, the differential measurements and evaluations represent the only mean to determine the cross-sections :

. for all the isotopes which are not easily available in a sufficient quantity for experimental studies. Such cases occur for :

- many isotopes of each structural materials (for corrosion and contamination studies) ;
- most of the separate Fission Products: on ≈600 identified isotopes only 40 play an important part in the core physics and can be available as samples [17] ;
- most of the actinides, at least presently (for reprocessing, refabrication, storage and studies) [18].

In such cases, the nuclear data can be improved only by improving the microscopic measurements, when they are possible, or by the evaluation technics.

For the major isotopes present in fast breeder cores, the nuclear data requirements can be met by using specific integral measurements [19 to 26]. The role of such experiments has been extensively discussed in many papers, summarized in [27], and will not be discussed in detail here. Only some points will be underlined in the present paper :

1. In order to get significant informations on the nuclear data, simple integral experiments must be performed, where the integral parameters are studied parametrically VS the fuel enrichment or the diluant volumic percentage.

The media to be studied are determined by sensitivity studies so that the informations obtained cover the complete energy range of interest for fast breeders.

Moreover, one has to check that the integral parameters measured provide significant informations on the nuclear data under study. Such a verification is necessary in particular for the structural material studies where several measured parameters (k∞, reaction rate ratios) are not simply related to the structural material nuclear data.

The configurations built in critical facilities must be simple from the geometrical point of view in order to minimize the influence of the calculational methods on the result analysis and to avoid any ambiguity when determining the sources of the Calculation to Experiment deviations.

Typical examples of such specific programmes are those performed at CEA :

- R-Z programme : for the clean core neutron balance [19, 20] ;
- PLUTO programme : for the higher Plutonium isotope study [28] ;
- F.P. programm : for the F.P. capture cross-section determination [17].

2. The parameters which are measured correspond in many cases to the fundamental mode situation and provide direct informations on the neutron balance. Typical integral parameters are :

- reaction rate ratios (± 1 to 2%) ;
- material buckling (± 1%) ;
- reactivity worth measurements (± 5 to 10%) ;
- spectrum measurements (± 5 to 10%) ;
- critical mass (± 0.2 % ΔK/K).

Determination of the nuclear data requirements

In order to reduce the maximum admittable uncertainties on the nuclear data from the target accuracies wanted for the design parameters, sensitivity studies are widely performed, using the USACHEV generalized perturbation theory.

Such sensitivity studies aim at providing :

- the global accuracies which are desirable for each cross-sections in order to reach the design parameter accuracies ;
- the sensitivity profile of a given integral parameter P to a cross-section variations : $dP/P \big/ d\sigma/\sigma = f(E)$, which determines the cross-section variation VS energy and contribute directly to the definition of integral experiment study to the improvement of the cross-section under study [29].

The following figures provide as examples the sensitivity profiles of the internal breeding ratio and Keff to the Iron section for the two core zones of a 1200 MWe power plant [7].

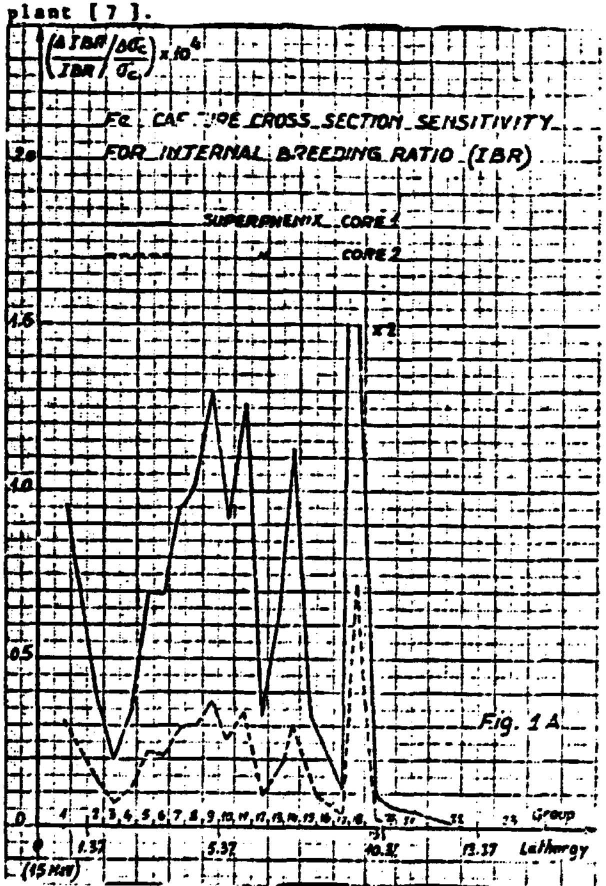


Fig. 1A

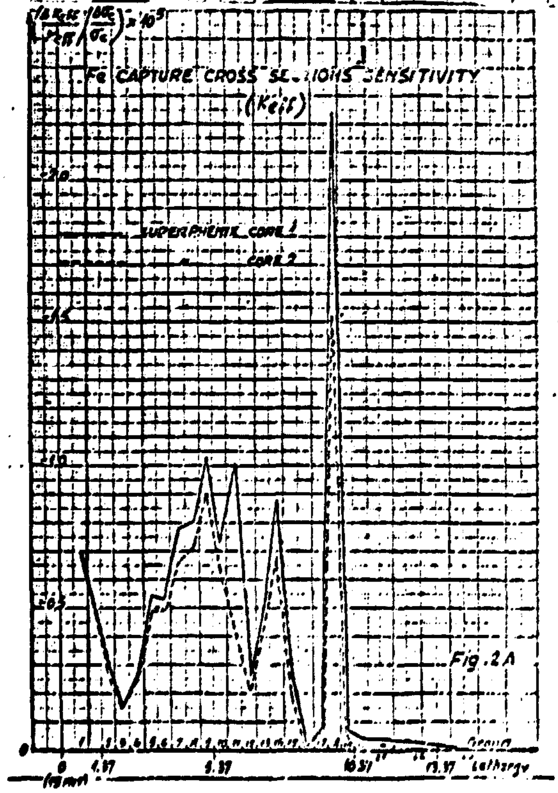
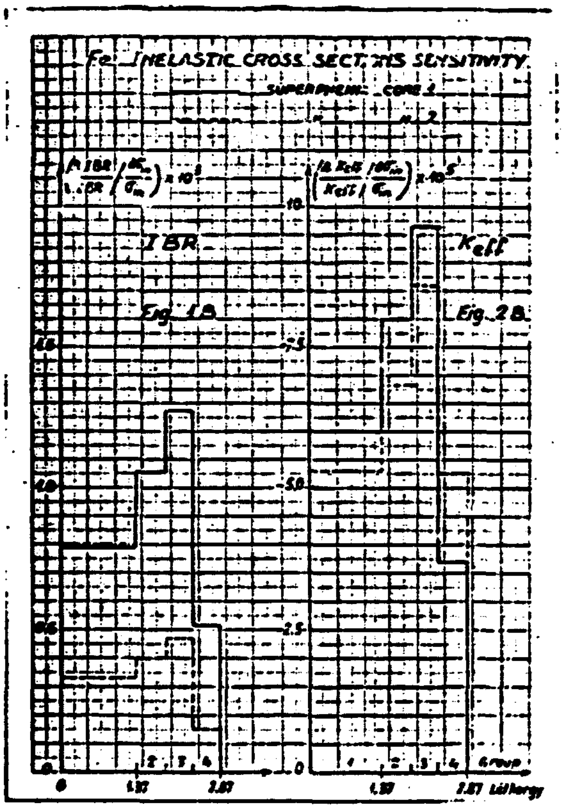


Fig. 2A


Fe INELASTIC CROSS SECTIONS SENSITIVITY

SUPERPHENIX CORE 2

Fig. 1B

Fig. 2B

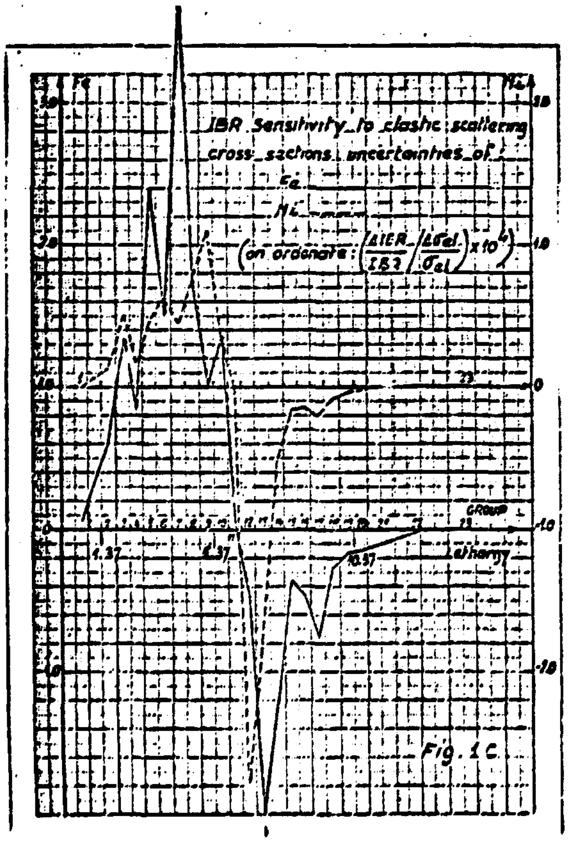
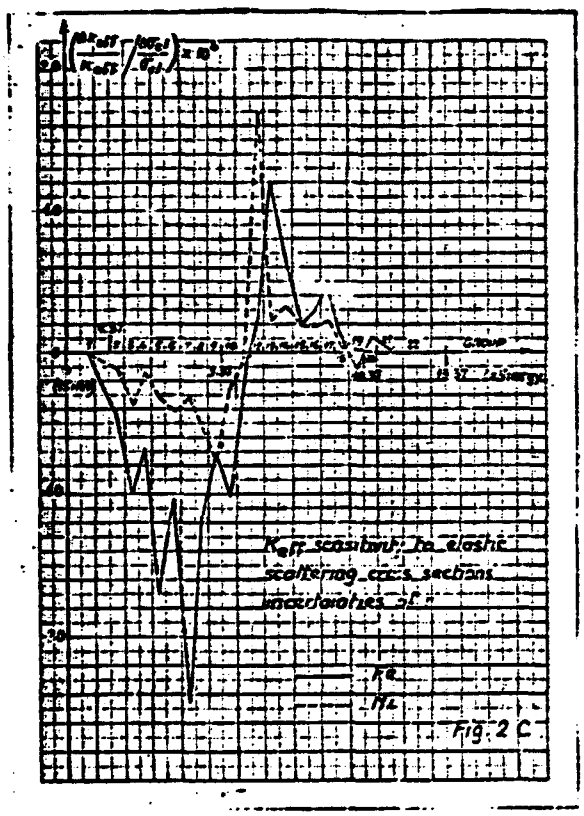

IBR sensitivity to elastic scattering cross sections uncertainties of :

Fig. 1C



Keff sensitivity to elastic scattering cross sections uncertainties of :

Fig. 2 C

In order to identify the cross-sections which play a major part in the uncertainties applied to the design parameters, the following table presents, for several isotopes, the cross-section variations which lead to a given change of two integral parameters :

- ± 0.05 % ΔK/K on the critical mass ;
- ± 0.02 % on the absolute value of the internal breeding gain.

The calculations have been performed successively for two media rather close to the inner and outer core zones of SUPER-PHENIX : the global variations indicated in the following table correspond to an uniform variation of the cross-section over the whole energy range.

One notes that the sensitivity profiles as those given on the precedent figures provides the necessary complementary informations :

- on the energy range of interest for each core parameter (e.g. for Keff or internal breeding ratio with respect to capture and inelastic iron cross-sections) ;
- on the possible compensation effects between different energy ranges (e.g. for elastic cross-section of iron and Ni).

Cross-Section Variation (%)	±0.5% ΔK/K		±0.02 on the IBG	
	$\frac{Pu}{Pu+U}$ =14%	$\frac{Pu}{Pu+u}$ =18%	$\frac{Pu}{Pu+U}$ =14%	$\frac{Pu}{Pu+U}$ =18%
ν (239Pu)	0.65	0.64	2.0	1.2
σ_f (239Pu)	0.91	0.91	20	7.6
σ_c (238 U)	2.2	2.9	4.3	5.1
ν (238 U)	4.1	4.4	9.1	12
σ_f (235 U)	6.3	7.0	13	14
σ_c (239Pu)	8.3	8.7	6.6	8.1
σ_{eR} (O_2)	10	15	21	33
σ_{inel}(238U)	10	13	22	34
σ_{tr} (238 U)	12	7.8	26	21
σ_{tr} (O_2)	13	8.2	29	23
σ_f (240Pu)	15	14	23	23
σ_f (241Pu)	15	16	110	119
σ_{tr} (Fe)	16	10	35	28
σ_{inel}(Fe)	21	25	45	66
σ_{tr} (Na)	24	15	53	42
σ_c (240Pu)	29	30	46	50
σ_c (F.P.)	3.	52	69	143
ν (235 U)	32	38	70	104
σ_c (Fe)	33	42	77	118
σ_{eR} (Na)	37	54	82	142

. One observes that the sensitivities of the integral parameters such as Keff or the Internal breeding gain to the cross-section variations may depend to some extent upon the spectrum of the medium under study.

On the other hand, the influence of a given cross-section can be much more important for one parameter than for another : a typical example is the 239 Pu fission cross-section for which a 0.9% variation leads to 0.5% ΔK/K variation whereas a 7.6% variation is necessary to change the breeding gain by 0.02.

. It must kept in mind than in such studies the cross-section variations which lead to ± 0.5% ΔK/K or ± 0.02 on the I.B.G. are considered separately.

. ± 0.5% ΔK/K target accuracy associated to the uncertainties on all the cross-sections lead to more stringent requests on the maximum admittable uncertainties of each cross-section.

Finally, the requests on the nuclear data have to take into account : the complete spectrum range of interest for fast breeders and the request issued from the most severe parameters.

Classification of the nucear data request for core calculations

From the precedent table, it appears clearly that three main kinds of requests can be distinguisted according to their contribution to the core parameter uncertainties :

1. requests on the main fissile isotopes (235U - 238U - 239Pu) ;
2. requests on the structural material isotopes ;
3. requests on the fission products and higher Plutonium isotopes.

These successive priorities are typically reflected by the successive versions of the CARNAVAL adjusted cross-section set where the efforts to meet the design requirements have concerned successively the three items indicated here above.

The following table presents the progression between the successive versions II, III et IV of the CARNAVAL, where the adjusments are done in order to meet the target accuracies on design parameters.

CARN. / ISOT.	II		III		IV	
	Data before 68	After Adjust.	Before Adjust.	After Adjust.	Before Adjust.	After Adjust.
235 U 238 U 239 Pu	EV	A	CII	A	CIII	A
240 Pu 241 Pu	EV	EV	New EV	A	CIII	A
242 Pu	EV	EV	CII	A	CIII	A
241 Am 238 Pu	EV	EV	New EV	EV	New EV	A
Fe	EV	A	CII	A	New EV	A
Cr Ni	EV		CII	EV (CII)	New EV	A
O	EV	–	CII	EV (CII)	New EV	EV
Na	EV	–	CII	EV (CII)	New EV	–
PF	EV	–	CII	CII	New EV	A

A refers to adjusted data ;
EV refers to evaluated data.

Influence of the reactor concept on the nuclear data requests :

Most of the nuclear data requests which are related to neutronic core parameters such as critical mass or internal breeding gain correspond to the fast breeders presently in operation or in construction (typically 250 MWe to 1200 MWe).

For the future, new concepts such as the heterogeneous core concept are under study. The following tables provide a comparison of the cross-section variations leading to ± 0.5% ΔK/K change to a ± 0.02 charge of the Internal Breeding gain for some typical cross-sections in threecases :

. core with low enrichment zones (9%/12%) ;
. a classical 1200 MWe core (14%/18%);
. a heterogeneous core (fissile = 20%).

The calculations are performed in a 1D cylindreicel geometry and concet only the core zones :

Fissile zone enrichment%	$\pm 0.5\ \% \ \frac{\Delta K}{K}$			± 0.02 on thé Internal Breeding Gain		
Cross-sec. variation %	10/12	14/18	20	9/12	14/18	20
σ_f 239 Pu	2.2	1.6	1.6	3.1	2.9	3.1
σ_c 238 U	2.5	2.1	2.9	2.2	2.9	3.1
σ_f 238 U	8.8	7.6	8.5		68	96
σ_c 239Pu	12	7.6	8.5	11.5	10	10.6
σ_{inel} 238U)	12	11	13.2	43	50	88
$\sigma_{el}(O_2)$	13	12	15	/	/	/
σ_f 240 Pu	19	17	17	/	/	/
σ_{fe}(Fe)	/	21	23	/	/	/
σ_c 240 Pu	/	/	/	40	35	27

One observes that the sensitivity coefficients of the critical mass and the internal breeding gain do not depend very tightly of the core enrichment. This indicates that the present requests should not be modified by the introduction of new core concepts, at least for the main isotopes.

Nuclear data requests

The main nuclear data requests have been recently reviewed by J. ROWLANDS [27] at the International Conference on Neutron Physics and Nuclear Data, held in HARWELL (September 1978). In most of the cases, the values quoted here under are close to the values given by J. ROWLANDS since no major reason has appeared since last year to modify the requests. To be consistent with the values given by J. ROWLANDS, all the figures quoted correspond to 1 S.D., in the following tables.

Fissile isotopes

Typical target accuracies for the fissile isotopes : 235U - 239Pu - 238U, given in the following table are taken from [27] :

PARAMETER	FISSILE ISOTOPES	FERTILE ISOTOPES
ν_f	0.3 %	1 %
σ_f	2 %	2 %
σ_c or α	4 %	3 %
σ_t, σ_s	20 %	5 %
σ_{inel}	10 %	5 %
$\sigma_{n,2n}$	10 %	10 %
Resonance Paremeters	10 %	3 %
ν for delayed neutrons	3 %	5 %

The safety requirements may lead to more specific requests :

. the target accuracy on the Doppler effect requires an improvement of the data on resonance parameters especially for 238 U [27] ;
. the target accuracy on the Sodium void effect can lead to an improvement of the 238 U capture cross-sections [12].

Structural and coolant materials

. The structural materials -mainly Fe, Cr, Ni- play an important part on the neutron balance (3 to 5% ΔK/K), on the internal breeding gain of the core, and their characteristics influe directly upon the residence time of the core subassemblies through the damage effects on the claddings or on the wrappers.

As an example, the following table gives the sensitivity percentage per energy range to the structural material capture cross-sections for the Keff value [7].

One observes that the energy range of interest for the capture effects lies between ≈ 0.5 KeV and ≈3 MeV :

ENERGY RANGE	Fe	Cr	Ni	Mo	Mn.
3.23MeV→14.5MeV	9	2	41	1	4
3.36KeV→3.23MeV	69	76	55	70	38
0.45KeV→3.36MeV	21	21	3	25	34
23 eV→450 eV	1	1	1	4	24

Moreover the structural material neutronic characteristics play also a major part in the propagation studies (e.g. blanket, shielding) : the corresponding request have been reviewed by J. BUTLER at the HARWELL Conference [30].

. The requests which concern all the cross-sections of each isotope (Fe, Cr, Ni) may change very significantly according to the data concerned : microscopic data, or final adjusted data. As an example the following table provides a comparison between typical requests for microscopic data (measured or evaluated) and target accuracies which are aimed at for adjusted data [7]. Such accuracies involve the use of integral experiments whenever it is possible. Improved data on the resonance structure of the cross-sections are also required for the treatment of the resonance shielding and Doppler effects.

ISOTOPE		TYPICAL REQUEST FOR MICROSCOPIC DATA	TARGET ACCURACY FOR ADJUSTED DATA
Fe	σ_c	± 10 %	± 3 %
	σ_{inel}	± 5 %	± 3 %
	$\sigma_{(n,p)}$	± 30 %	± 15 %
	$\sigma_{(n,\alpha)}$	± 30 %	± 15 %
	σ_{tot}	/	± 2 %
Cr	σ_c	± 20 %	± 6 %
	σ_{inel}	/	± 8 %
	$\sigma_{(n,p)}$	± 30 %	± 15 %
	$\sigma_{(n,\alpha)}$	± 30 %	± 15 %
	σ_{tot}	/	± 3 %
Ni	σ_c	± 15 %	± 5 %
	σ_{inel}	± 5 %	± 8 %
	$\sigma_{(n,p)}$	± 30 %	± 15 %
	$\sigma_{(n,\alpha)}$	± 30 %	± 15 %
	σ_{tot}	/	± 3 %

For the future power plants, new steel compositions are being investigated, which lead to complementary requirements for Mn, Mo, Ti isotopes. The capture cross-sections of these isotopes should be known with a target accuracy of ± 5% (1 S.D. fpr final adjusted data) [7].

Sodium

The Sodium used as a coolant in fast breeders does not have a significant contribution to the core neutronic parameters such as the critical mass on the breeding gain, but from the safety point of view, the Sodium nuclear data play a major part in the determination of the Sodium voiding reactivity effect, which is related to an hypothetic accidental boiling of the coolant.

The Sodium voiding reactivity effect is the sum of two main component contributions :

- a "central component" which depends upon the neutronic properties of the core ;
- a leakage component which depends mainly on the geometry of the voided zone.

The uncertainty applied to the central component may reach ≈ 20% [12], and is mainly due to the Sodium scattering cross-section (elastic and inelastic).

The Sodium total cross-section being well known (≈ ± 3%), the problem would be to get a better discrimination between the elastic and inelastic scattering so that each type of cross-section is known with a 10 - 15% accuracy for E > 1 MeV.

To a less extent an improvement of the Sodium capture cross-section seems desirable [12] in order to reduce the uncertainty applied to the central component.

Activations Nuclear Data

These data needs are related to the design calculations performed in order to determine :

- the contamination of various components of the reactor such as the primary circuit, the pumps and the heat exchangers ;
- the activation of subassemblies which will be handled, transported, and stored.

It must be noted that in some cases significant informations can be obtained either from integral measurements performed on critical facilities [31] or eventually from power reactors.

The required accuracies are not very high due to the fact that in many cases the calculational methods lead by themselves to rather high uncertainties.

The following table presents the major reactions involved in the activation calculations :

TYPICAL ACTIVATION REACTIONS	REQUIRED ACCURACY
54 Fe (n,p) 54 Mn	± 10 - 15 %
58 Ni (n,p) 58 Co	± 10 - 15 %
59 Co (n,γ) 60 Co	± 10 - 15 %
58 Fe (n,γ) 59 Fe	± 10 - 15 %
50 Cr (n,γ) 51 Cr	± 10 - 15 %
54 Fe (n,α) 51 Cr	± 10 - 15 %
58 Co (n,γ) 59 Co	± 10 - 15 %
62 Ni (n,γ) 63 Ni	± 10 - 15 %
58 Ni (n,γ) 59 Ni	± 10 - 15 %
54 Fe (n,γ) 55 Fe	± 10 - 15 %
22 Na (n,γ) 23 Na	± 15 %
40 Ar (n,γ) 41 Ar	± 15 %

Absorber Materials

The absorber materials used for fast breeders in operation or in design, are mainly natural and Enriched B4C (typical B 10 enrichments are for example 47% for the first PHENIX rods, 90% for the designed SUPER-PHENIX rods). To a less extent Tantalum and Eurotium oxide are also considered.

The typical requirements on the nuclear data for the absorber materials have been given by J. ROWLANDS [27] :

. ≤ ± 5% for the capture cross-sections
. ≤ 10 % for the scattering cross-sections.

. The recent results obtained on the benchmark exercice[1] seem to indicate that the complementary improvements are needed to reach these target accuracies.

Resonance shielding effect are important for Tantalum and Europium, and require an improvement of the resonance structure, as previously indicated [27]. Data are also required in order to predict the Helium production in the B4C absorber rod and the gamma-heating effects which have to be taken into account in the rod design.

Fission Product Nuclear Data Needs

The fission product build-up resulting from the fuel irradiation contributes directly to the reactivity loss per cycle (75% for a 1200 MWe power plant), influes on the Plutonium build-up during the cycle and contributes highly to the residual power after a stop of the power plant operation.

The fission product nuclear data needs have been reviewed at the HARWELL Conference [27, 32] and only the main conclusions will be summarized here.

The target accuracy on the bulk reactivity effects is : ± 5% to ± 10%.

This leads to the following typical requirements on the Fission Products, which contribute mostly to the global capture effect (a partial list of these isotopes is given in the table hereunder :

. capture cross-sections : ±5% to ±10% (± 25% is sufficient for the isotopes which do not contribute significantly to the total capture) ;
. scattering cross-sections : ±15% to ±30% ;
. fission yiedls : ±3% to ±5% ;
. decay periods : ±2% ;

The fulfiment of the two last items do not seem to give rise to major problems [17, 33].

For achieving the target accuracy on the capture cross-sections of the main Fission Products, the integral measurements on critical facilities or in power reactors -when they are possible- play a major role. This appears clearly in the following table, where one compares the target accuracies and the values obtained for data adjusted with integral experiments performed either on critical facilities or in power reactors (PHENIX) :

ISOTOPE	TARGET ACCURACY %	PRESENT ACHIEVED ACCURACY %
105 Pd	± 5	± 4.6
101 Ru	± 5	± 4.5
103 Rh	± 5	/
99 Tc	± 5	± 5
107 Pd	± 5	± 7
149 Sm	± 5	± 4.5
151 Sm	± 5	± 10
147 Pm	± 5	± 6
97 Mo	± 5	± 5
145 Nd	± 5	± 5.5
133 Cs	± 5	± 5
135 Cs	± 5	/
109 Ag	± 5	/
103 Ru	± 5	/
143 Nd	± 5	± 6
104 Ru	± 5	± 6

The fission product nuclear data required for decay heat problems will be examined in another paper at this conference [34].

Higher Plutonium Isotopes and Major Actinides (241 Am - 238 Pu)

There are important amounts of higher Plutonium isotopes and of major actinides (241 Am, 238 Pu) in the fast breeder fuels. The following table gives typical compositions for gaz-graphite and PWR Plutonium [5]:

ISOTOPE	GAZ-GRAPHITE	P.W.R.
238 Pu	0	1.7
239 Pu	76.7	56.6
240 Pu	20.1	23.6
241 Pu	2.4	10.9
242 Pu	0.4	5.6
241 Am	0.4	1.6

The higher Plutonium isotopes and 241 Am have significant effects on the core neutronic characteristics : fresh core reactivity, reactivity loss per cycle and internal breeding gain.

Moreover the 241 Am build up during the fuel storage has a quite important effect on the reactivity of this fuel :

STORAGE TIME YEARS	REACTIVITY LOSS OF A P.W.R. Pu ΔK/K
1	0.62 %
3	- 1.8 %

The target accuracies which are given hereunder are typically determined by the following criteria :

. the uncertainty on the core critical mass due to these isotopes must no exceed ± 0.2% ΔK/K ;

. the maximum uncertainty on the internal breeding gain due to these isotopes should not exceed ± 0.01 (absolute value) :

	240Pu	241Pu	242Pu	241Am	238Pu
σ_f	± 3%	± 2%	±5 to 10%	± 3%	± 4%
σ_c	± 3%	± 5%	/	± 5%	±10%

For these isotopes as for the Fission Products the internal measurement performed either on critical facilities or in power reactor permit to meet these requirements [28].

Conclusion

1. In spite of the various data libraries, evaluated or adjusted which are available for the fast breeder designs, there are still strong motivations for nuclear data requirements.

These requiremetns are related to :

. the necessity of understanding and reducing the discrepancies between the various data files. In this respect, the discrepancies which can be observed between evaluated and adjusted data files require a better understanding of the discrepancies between the microscopic and integral measurements.;

. the need of reaching the target accuracies for the design parameters by limitating the contribution of the uncertainties on the nuclear data. This perticular aspect, related to the fact that fast breeders reach the industrial level, is a strong incentive for improving the nuclear data ;

. the introduction of new concepts for commercial size breeders which aim at improving the characteristics of the future commercial power plants. The associated optimization neutronic studies require reduced uncertainties on the design parameters and consequently reduced uncertainties on nuclear data.

2. Since the design and the start-up of the prototype fast power reactor such as P.F.R. (U.K.), PHENIX (FRANCE), or BN 350 (U.S.S.R.), the need for carefully improved nuclear data has extended from the main fissile isotopes to other isotopes, mainly :

. structural materials ;

. fission products ;

. transactinium isotopes.

The corresponding requests are associated to the necessity of predicting with acceptable accuracy the design parameters related to the power plant operation, the fuel handling, storage, transportation, reprocessing and refabrication.

3. The nuclear data need have been recently precised by sensitivity studies performed in various countries, which can provide a non-refined description of the needs VS energy.

A better definition of the required accuracies implies to take into account a correlation which exist either between different cross-secti or for a given cross-section between the various ener ranges. Up to now, in most cases quite simple assumptions have been made to take into account these correlations. If this problem was not a first priority one for the main fissile isotopes due to the number of available experimental data, it becomes more important for the isotopes such as structural materiel or Fission Products for which only few experimental data exist.

4. The differential measurements and evaluations are necessary for providing the basic nuclear data for all isotopes and for providing detailed informations on particular energy ranges (such for threshold reactions or for resonance regions) : as far as they are the only mean to get the nuclear data of particular isotopes (e.g. Fission Products or Actinides) an improvement of these data requires an improvement of the microscopic data or of the evaluation technics.

Specific integral experiments are essential to achieve the requested accuracies on some major nuclear data in order to get the target accuracies on the design parameters. Moreover the integral measurements can provide mean values V.S. energy which in some case may be sufficient (e.g. activation cros sections). In this respect, the results whic have been obtained from the power reactors such as PHENIX represent clearly a perticularly valuable information.

Acknowledgments

The author wants to express his gratitude to MM. BOUGET and THEROND for performing the sensitivity studies which have been presented and used in this communication.

-oOo-

References

[1] Lesage et sl., "Assessement of Evaluated Nuclear Data files via Benchmark calculations", A preliminary report on the NEACRP/IAEA International comparison calculation of a large LMFBR ; ANS Topical Meeting on Advanced in Reactor Physics, GATLINBURG (April 1978).

[2] Böckhoff, "Neutron data of structural materials for fast reactors", Proceedings of a Specialists' Meeting held at GEEL (Belgium), (5-8 December 1977), Jointly sponsored by NEANDC and NEACRP.

[3] IAEA 213, "Fission Product Nuclear Data 1977", Proceedings of the second advisory group meeting on Fission Product Nuclear Data organized by IAEA and held at PETTEN (5-9 Septembre 1977).

[4] IAEA (to be published), "Transactinium Isotope Nuclear Data", Proceeding of the Second advisory group meeting on Transactinium Isotope Nuclear Data, organised by IAEA and held at CADARACHE (France), (2-5 May 1979).

[5] Giacometti et al., "Caractéristiques neutroniques du Réacteur SUPER-PHENIX 1 de CREYS-MALVILLE", Colloque International sur la Physique des Réacteurs à Neutrons Rapides, IAEA-SM-244/24, AIX-EN-PROVENCE (24-28 Septembre 1978).

[6] Chaudat et al., "Data Requirements for fast reactor design", ANS Winter Meeting SAN-FRANCISCO, (November 27, December 2, 1977).

[7] Filip et al., "Needs of Nuclear Data of structural materials for fast reactors" NEANDC, NEACRP Specialist Meeting on Neutron Data of Structural Materials for Fast Reactor, GEEL (5-8 December 1977)

[8] Bennet e al., "Status of Safety Related FFTF Neutronic Parameters", Internationnal Meeting on Fast Reactor Safety and Related Physics, (October 5-8, 1976), CHICAGO.

[9] Butland et al., "An assessement of methods of calculations Doppler effects in Plutonium fuelled Sodium cooled Fast Reactors, IAEA-SM-244/32, International Symposium on Fast Reactor Physics, AIX-EN-PROVENCE (France),(24-28 September 1979).

[10] Butland et al., "An assessement of Calculating Sodium Voiding Reactivity in Plutonium fuelled Sodium cooled Fast Reactors, IAEA-SM-244/39, International Symposium on Fast Reactor Physics, AIX-EN-PROVENCE, (24-28 September 1979).

[11] Lyon et al., "Etude de l'effet de Vidange Sodium dans les milieux représentatifs des centrales à neutrons rapides de type classique ou hétérogène : expériences faites au cours du programme PRE-RACINE sur MASURCA, IAEA-SM-244/23, Colloque International sur la Physique des Réacteurs à Neutrons Rapides, AIX-EN-PROVENCE, (24-28 Septembre 1979).

[12] Rimpault, Thèse présentée pour obtenir le titre d'Ingénieur-Docteur, Université de Provence (à paraître).

[13] Bouget et al., "Etude expérimentale des barres de commande pour les réacteurs de puissance à neutrons rapides dans MASURCA", IAEA-SM-244/27, Colloque International sur la Physique des Réacteurs à Neutrons Rapides, AIX-EN-PROVENCE (24-28 Septembre 1979)..

[14] Rowlands et al., "The development and validation of control-rod calculation methods", IAEA-SM-244/36, International Symposium on Fast Reactor Physics, AIX-EN-PROVENCE, (24-28 Septembre 1979).

[15] Collins et al., "Experimental studies of 350 MWe heterogeneous LMFBR cores at ZPPR, IAEA-SM-244/70, International Symposium on Fast Reactors Physics, AIX-EN-PROVENCE, (24-28 Septembre 1979).

[16] Hammer, "Requirements of delayed neutron data for the design, operation, dynamics and safety of fast breeder and thermal power reactors", Consultent Meeting on Delayed Neutro Properties, VIENNE, (26-30 March 1979).

[17] Coppé, "Etude de la représentation des produits de fission dans les réacteurs de la filière à neutrons rapides", Thèse présentée à l'Université de PARIS-SUD, Faculté d'ORSAY, le 28 Juin 1978.

[18] Bouchard, "Revue des besoins en données nucléaires des isotopes de Transactinium pour les réacteurs thermiques et rapides à combustible U et U-Pu, ainsi que pour les cycles associés", Second Advisory Group Meeting on Transactinium isotope Nuclear Data", AIEA, CADARACHE (2-5 May 1979).

[19] Barré et al., "Fast reactor physics at CEA : studies of the characteristics of the "clean core" cell neutron balance, control rods, power distributions", International Symposium on Physics of Fast Reactors, TOKYO, (16-19 October 1973).

[20] Barré et., "Complementary roles of Integral experiments and differntial measurements for a fast reactor project. The case of Plutonium isotopes", Conference on Nuclear Data for Reactors, HELSINKI, (June 1970).

21 Campbell et al., "The Relations ship of microscopic and integral data", Conference on Nuclear Data for Reactors, HELSINKI, (June 1970).

22 Weisbin et al., "Application of sensitivity and uncertainty methodology to Fast Reactor Integral Experiment Analysis", NSE, 66 307, (1978).

23 Kuroï et al., "Adjusted cross-section library AGL1 and the reliability analysis of integral data", International Symposium on Physics of Fast Reactors, TOKYO, (October 1973).

24 Salvatores, "Recent developments in cross-section adjustment procedures", ANS Topycal Meeting on Advanced in Reactor Physics, GATLINBURG, (April 1978).

25 Barré et al., "After PHENIX, what is the importance of nuclear data programmes for fast breeder reactor development", Conference on Nuclear Cross-Sections and Technology, WASHINGTON, (March 1975).

26 Usachev et al., "Determining the Necessary Accuracy of Nuclear Data with allowance for integral experiments", INDC Neutron Physics Conference, KIEV (1975).

27 Rowlands, "Nuclear data for reactor design, operation and safety", International Confernece on Neutron Physics and Nuclear Data, HARWELL (Sept. 1979).

28 Chaudat at al., "Integral experiments performed at CEA to improve the Pu higher isotopes nuclear data", Specialist Meeting on the Nuclear Data of Higher Plutonium and Americium Isotopes for Reactor Operations", BROOKHAVEN, (November 1978).

29 Bobkov et al., "Planning of neutron data experiments and evaluations for Reactors", OBNINSK (1974). INDC.

30 Butler, "Nuclear Data for shielding", International Conference on Neutron Physics and Nuclear Data, HARWELL, (September 1978).

31 Murphy et al., "Tests of some FDS Activation cross-sections by ZEBRA irradiations", NEANDC/NEACRP Sepcialist Meeting on Neutron Data of Structural Material for Fast Reactors, GEEL (December 1977).

32 Hammer, "Besoins en données nucléaires des produits de fission et actinides pour les calculs des réacteurs de puissance à neutrons rapides", International Conference on Neutron Physics and Nuclear Data, HARWELL, (September 1978).

33 Meek et al., "Fission product yields", Second Advisory Group Meeting on Fission Product Nuclear Data, organized by IAEA, PETTEN (5-9 September 1977).

34 , "Decay-heat", paper presented at this Conference.