EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN / SPSC 98-40
SPSC / I 220 / M626
27 October 1998

ADDENDUM TO THE LETTER OF INTENT

A CERN-PS EXPERIMENTAL CAMPAIGN TO MEASURE NEUTRON CROSS SECTIONS FROM 1 eV TO 250 MeV WITH HIGH RESOLUTION.

S. Andriamonje(1,2), S. Buono(3), P. Cennini(2), F. Corvi(4), R. Del Moral(1), C. Eleftheriadis(6), A. Ferrari(2), C. Gelès(2), I. Goulas(2), Y. Kadi(2), V. Lacoste(1), P. Pavlopoulos(5), A. Plompen(4), C. Rubbia(2), A. Tzima(6), V. Vlachoudis(1,6), H. Weigmann(4)

Abstract.

In response to the request of the SPSC we elaborate on the physics interests of the proposed TOF facility (CERN / SPSC 98-15, SPSC / I 220 of 6th August 1998). The following areas of interest are discussed, as the outcome of an international Workshop held at CERN on 21-22 September to which have participated 86 representatives of European Teams interested in the use of the facility:

(1) Cross sections relevant to Nuclear Astrophysics;
(2) Neutrons as a probe for fundamental Nuclear Physics;
(3) Cross sections relevant to Dosimetry;
(4) Cross sections relevant to various fields in technology.

Transparencies of the Workshop are also included, as well as two letters of known experts in the field.

(1) CEN, Bordeaux-Gradignan, France,
(2) CERN, Geneva, Switzerland,
(3) CRS4, Cagliari, Italy,
(4) EC, Joint Research Center, IRMM, Geel, Belgium,
(5) University of Basle, Basel, Switzerland,
(6) University of Thessaloniki, Thessaloniki, Greece

TABLE OF CONTENT

1 — INTRODUCTION.

Neutron research in most of the present Neutron Facilities is centred in probing structure and dynamics of materials. Neutrons however are clearly one of the most powerful tool for understanding fundamental Nuclear and even Particle Physics. Various experimental programmes and ideas have been proposed by teams from almost all European countries at the Joint CERN-EC-GEDEON-OECD/NEA Workshop, regarding the opportunities offered by the CERN Neutron TOF Facility. These proposals are concentrated mainly in four research fields, i.e. Nuclear Astrophysics, fundamental Nuclear Physics, Dosimetry and Nuclear Technology.

Cross sections of neutron induced reactions are best measured from the attenuation or scattering of neutrons or from the intensity of the secondary radiation as a function of the energy of monochromatic neutrons. A precise neutron energy is required for the determination of the resonant structure of such cross sections and the parametrisation of such resonances. The most suitable method to achieve such high energy resolutions is the use of short neutron pulses with a broad energy distribution, where neutrons are sorted out of the continuous energy distribution on the basis of their time-of-flight (TOF). Presently only three Neutron Facilities in the world are able to deliver short bunches suitable for TOF measurements.

The GELINA Facility [1, 2] in Europe and the ORELA Facility [3] in USA are based on Electron Linacs with average energies and intensities of around 100 MeV and 70 µA respectively, providing 800 - 1000 neutron pulses per second of small, < 1 ns, width combined with TOF path lengths up to a few 100 m. The resulting neutron spectra cover energies up to several MeV. The neutron intensities of both machines are similar and their comparison with the CERN Facility is shown in Figure 1. The neutron spectra of electron linac based neutron sources are limited to below about 20 MeV. At higher energies, quasi-monoenergetic neutrons are available using the ^{7}Li(p,n) reaction e.g. at the Uppsala cyclotron. However, neutrons with a broad energy distribution from thermal up to several hundred MeV for TOF measurements can be produced by spallation reactions with high-energy protons as is done at the third facility, LANSCE/WNR at Los Alamos [4].

WNR is based on a proton accelerator of 800 MeV covering neutron energies from 500 keV to few 100 MeV (Figure 2). WNR uses one micropulse of 180 ps with $3*10^8$ protons; there are 800 micropulses per macropulse, and a macropulse repetition rate of 100 Hz.

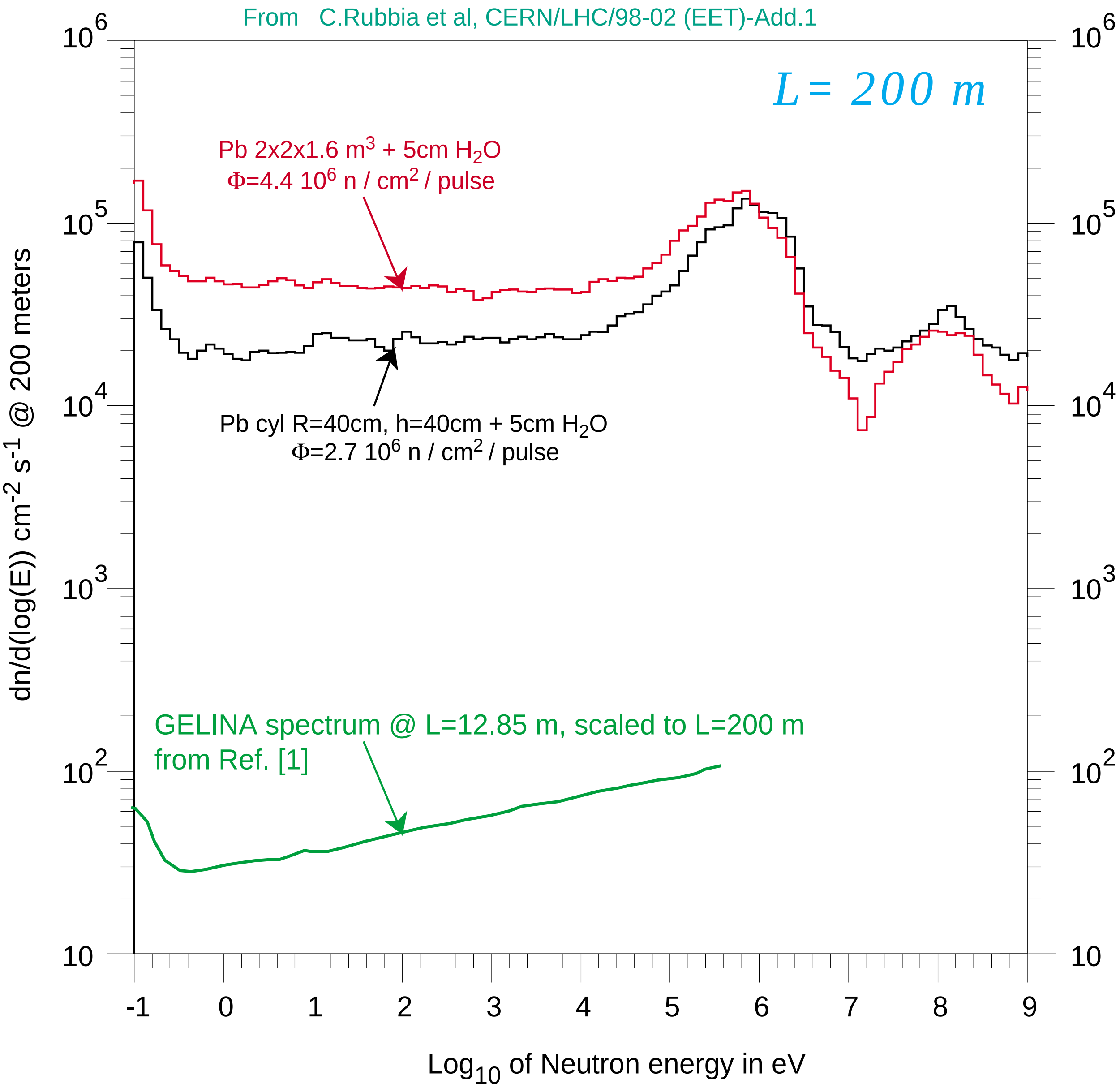

Figure 1 : The neutron energy range and the variation of the intensity of the CERN TOF spectrometer compared with that of Electron Linac Facilities.

Since the time fluctuations of the moderation process are largely independent of the chosen mechanism to produce the initial neutrons, the initial flux difference between the two methods, e.g. electrons vs. protons, reflects, at neutron energies below a few keV, directly on the counting rate - for a given TOF resolution - at the measuring station. In the higher 10 keV region, the large spatial extension of the primary neutron source in the spallation target adds to the flight path uncertainty, and from the MeV region the time duration of the proton pulse start also to contribute to the TOF resolution. Finally, at energies above ~10 MeV, the neutron flux obtained from electron linac based neutron sources drops quickly, and the proposed new facility at CERN would be unique in Europe, and still an order of magnitude more intense than the LANSCE/WNR facility in Los Alamos (Figure 2).

From the various experimental proposals presented at the Joint CERN-EC-GEDEON-OECD/NEA Workshop, we describe here only some highlights from each research field.

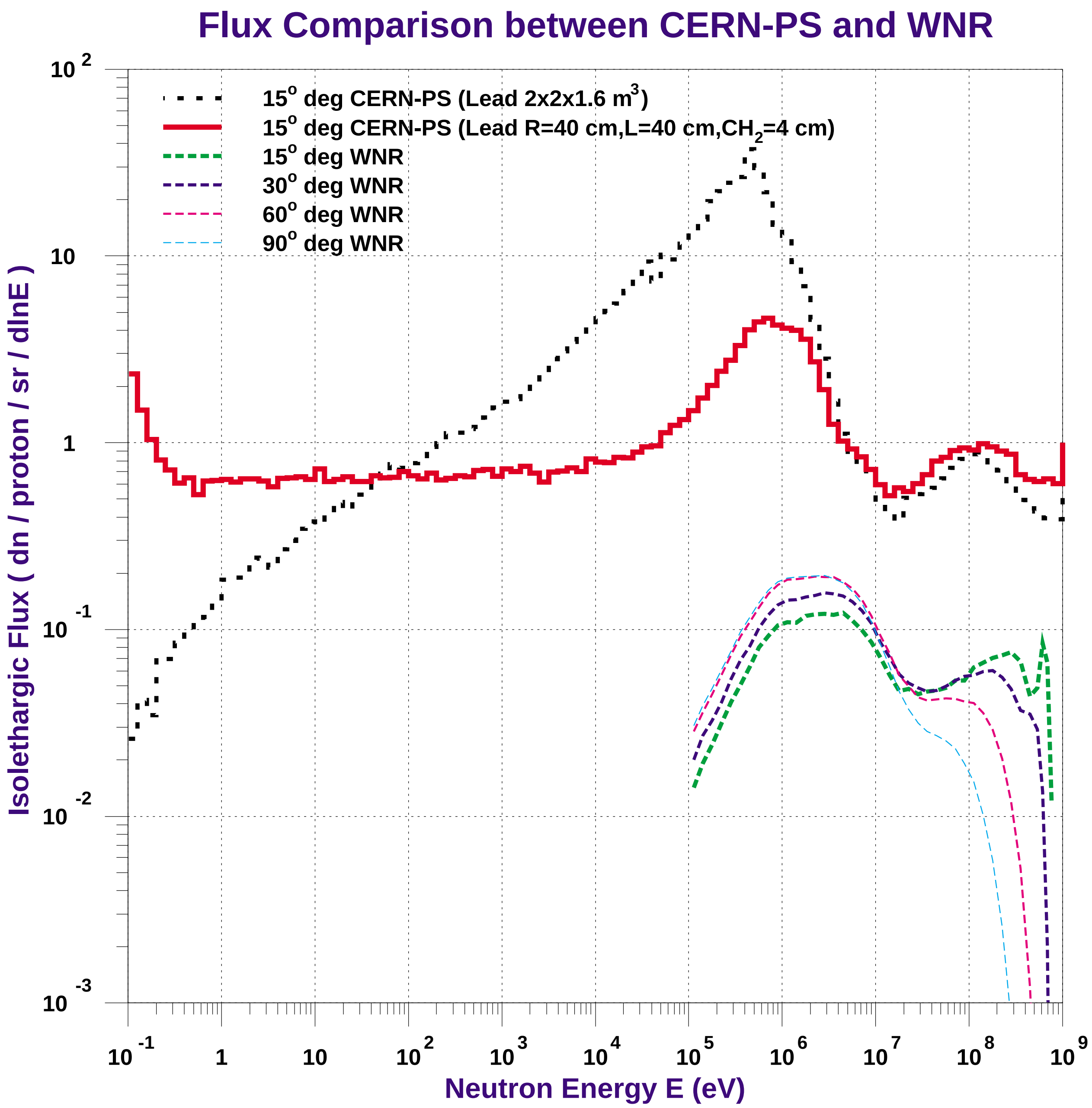

Figure 2 : Comparison of the neutron energy range and intensity between the CERN and WNR Facilitiy [4].

2 — CROSS SECTIONS RELEVANT TO NUCLEAR ASTROPHYSICS.

Neutron reactions are responsible for the formation of all elements heavier than iron. The corresponding scenarios, illustrated in Table 1, relate to helium burning in Red Giant stars (s- process) and to supernova explosions (r- and p- processes). So far, laboratory studies have concentrated on the s- process, which operates in or near the valley of β-stability. This process has produced about half of the elemental abundances between Fe and Bi, the resulting abundance distribution being essentially determined by the respective neutron capture cross sections. The accuracy of (n, γ) cross-section data for the s- process has an immediate impact on the resulting abundances.

Neutron capture nucleosynthesis in He-burning scenarios (s- process) is characterised by an almost linear relation between the stellar (n, γ) cross sections and the resulting abundances. The quantitative interpretation of the s- abundances represents sensitive tests for models of stellar He-burning [5], of the mixing mechanisms to the stellar atmosphere [6], and of the grain formation in circumstellar envelopes leading to the isotopic anomalies in presolar meteoritic inclusions [7]. Numerous new measurements helped to resolve discrepancies between older data sets, but more reliable data are still needed, particularly in the region from Mo to Pd, where large uncertainties persist. In some cases, experimental data are still completely missing, i.e. for isotopes of Ge and Se as well as for the important s- only nuclei ^{128}Xe, ^{130}Xe, and ^{192}Pt. It is also very important to measure such cross sections on isotopes produced only in the s- process (the "s-only isotopes"), especially for those elements with two or more such isotopes (Kr, Sr, Te, Xe, Ba, Sm, Gd, and Os), because they are used to precisely normalise the s- process contributions to all elements, and because the ratios of these isotopic abundances can be compared to extremely precise measurements from meteorites. In fact, the high precision of new abundance measurements of *s- only isotopes*, primarily in meteorites, is a strong motivation for new, precise measurements of neutron capture cross sections. Additionally, detailed analyses of s- process branch points - where both neutron capture and beta decay occur - provide the most sensitive probe of the astrophysical environments (temperatures and neutron densities) where the s- process occurs. These s- process branchings include the groups of isotopes ^{85}Kr, $^{134\text{-}135}$Cs, ^{147}Nd, $^{147\text{-}148}$Pm, ^{151}Sm - ^{152}Eu, ^{153}Gd, ^{163}Dy, $^{163\text{-}164}$Ho, ^{169}Er, ^{170}Tm, ^{176}Lu and ^{185}W - ^{186}Re.

Given the range of thermal energies from kT~8 keV in low mass stars up to 80 keV during carbon burning in massive stars, the relevant neutron energy range extends up to a few hundred keV. Given the range of temperatures from 100 to 300 Million K, which are characteristic for He burning scenarios, differential neutron data are needed between 0.3 and 300 keV, mostly for stable nuclei, but also for a significant number of radioactive isotopes with half-lives comparable to the typical neutron capture times of a few months. These cases are important, because the competition between neutron capture and β-decay causes the reaction path to split, resulting in very particular abundance patterns which are reflecting the stellar neutron density and temperature. Therefore, these branchings represent sensitive tests of the yet uncertain stellar models for the He burning stages of evolution.

s- process	Red Giant stars, (α,n) reactions, Fe-Bi, (n,γ) cross sections, E_n=0.3-300 keV, reaction path in stability valley.
r- process	Supernova at mass cut, neutronized matter, Fe-U, (n,γ) cross sections for freeze-out, E_n=0.3-300 keV, reaction path close to neutron drip line.
p- process	Supernova in O/Ne shell, (γ,n) reactions, Fe-Bi, (n,γ) cross sections for freeze-out, E_n up to 1 MeV, reaction path in proton rich region.

Table 1 : *Origin of the heavy elements [8].*

A satisfactory database for s- process studies should, therefore, contain experimental information over a sufficiently wide energy range, and with uncertainties of about 5 %. Beside these general requirements, data with typical uncertainties of 1% are needed for (i) the s- only nuclei, which are important as normalisation points of the s- abundance distribution and for defining the s- process branchings, and (ii) for the interpretation of isotopic anomalies in meteoritic inclusions. The cross sections of neutron magic nuclei and of the abundant light isotopes, which represent the major neutron poisons, should be known to better than 5 % despite the persisting difficulties in the investigation of these small cross sections.

Explosive scenarios are affected by neutron reactions during the freeze-out phase and require predominantly cross sections of radioactive nuclei. At traditional facilities, measurements on this species are difficult because of the limited neutron fluxes. In this respect, spallation sources offer a new and promising approach for a variety of experiments on hitherto inaccessible nuclei [8]. Neutron capture data are also important for the explosive r- and p- process scenarios, particularly during the freeze-out phase, where they lead to significant modifications of the primary reaction yields. These scenarios occurring far from stability, imply reactions on rather short-lived isotopes, however, which are much more difficult to study experimentally. Modelling r- process nucleosynthesis requires neutron binding energies and beta-decay lifetimes for thousands of nuclei close to the drip line. This necessarily requires a dependence on nuclear models, which are pushed to their limits when predicting nuclear properties near the drip line. In fact, recent work looking at systematics of r- process abundances has been used to correct inconsistencies in nuclear models; such use of astrophysical r-process abundances to check nuclear microscopic models may be expanded in the future. However, such work is possible only with very accurate s- process abundances: the intimate link between studies of the s- and the r- process is that the r- process abundances, to which calculated abundances are compared, are determined by subtracting calculated s- process abundances from the observed abundances; these r-process abundances are sometimes referred to as residual abundances. Precise r- process studies therefore require precise s- process studies, and the precision of these studies rely on accurate (n,γ) cross section measurements.

TOF techniques are most suitable for measurements on practically all stable nuclei, yielding differential cross sections $\sigma(E_n)$ for calculating the stellar average

$$\langle\sigma\rangle_{kT} = \frac{2}{\sqrt{\pi}} \frac{\int_0^\infty \sigma(E_n) \times E_n \times \exp(-E_n/kT) dE_n}{\int_0^\infty E_n \times \exp(-E_n/kT) dE_n}$$

In this type of experiments, capture events are detected simultaneously over the whole neutron energy range via the prompt γ-rays emitted in the reaction, where the neutron energy is tagged by TOF. This requires a detector that operates as a calorimeter with a γ-ray efficiency better than 90% in the entire energy range below 10 MeV. The best identification of neutron capture events is provided by the total energy of the capture γ-cascade. The high efficiency and the good resolution in γ-rays detection, as achieved by the Karlsruhe 4π BaF_2 detector [9], together with a high TOF resolution, are essential for the 1% required accuracy. For instance, such precise measurements at keV neutron energies on ^{12}C [10] and ^{16}O [11] showed only recently, that the stellar cross sections were orders of magnitude larger than previous estimates based on the 1/v extrapolation of the thermal cross sections. In the case of ^{16}O, these results, which are due to strong non-resonant p-wave captures, lead to significant consequences for the role of this abundant isotope as a neutron poison. The measurement of such small cross sections requires comparably large samples of typically 50g to 100g. Although spallation neutron sources have not often been used for astrophysical motivated measurements so far, their huge fluxes allow to reduce the sample mass by a factor of 1000 compared with the traditional facilities. This aspect becomes essential in dealing with radioactive samples, where high intensity, low repetition spallation sources provide excellent signal-to-background ratios [chapter 2 in ref. 12].

Neutron capture studies on radioactive targets are hampered by the background from the sample activity, but also because suited samples are only available at limited quantities. The discussion of experimental possibilities for measurements on short-lived branch-point nuclei showed [13] that a number of these cases can be studied with 1000 times smaller samples of a few mg using optimised TOF techniques with the much higher flux at spallation sources. Alternatively, neutron capture integrated cross-sections over quasi-stellar neutron spectra, can be extracted with the activation technique [14]. However, the activation technique is restricted to cases, where neutron capture produces an unstable nucleus, and it yields the stellar rate only for certain thermal energies.

In view of the small sample masses required in optimised experiments at the proposed Facility, such studies could benefit from the availability of radioactive ion beams with intensities of 10^9 s^{-1}, allowing to produce appropriate samples within a few hours, presumably with considerably better purity than can be achieved by radiochemical methods.

According to the last NuPECC report [15] the targets of interest are light and intermediate mass isotopes with their limited amount of available data, the branching point nuclei like ^{79}Se, ^{95}Zr, ^{107}Pd, ^{135,137}Cs, ^{141}Ce, ^{147}Pm, ^{151}Sm, ^{155}Eu, ^{169}Er, ^{170}Tm, ^{175}Yb, ^{186}Re, ^{204}Tl, ^{193}Pt and low-lying isomeric states like ^{103}Rh, ^{119}Sn, ^{169}Tm, ^{187,188}Os amd ^{193}Pt. For determining the endpoint of the s- process, neutron capture measurements are needed on the long-lived radioactive ^{210}Bi and ^{210}Po.

3 — NEUTRON AS A PROBE FOR FUNDAMENTAL NUCLEAR PHYSICS.

Even today experimental data of level densities, resonance energies and widths of giant resonances are not well understood by optical potentials for many nuclei and in particular for the higher actinides. Important additional information, presently lacking, can be extracted from measurements of the differential neutron cross sections as a function of the neutron energy with high energy resolution.

3.1 Neutron induced fission. The hybrid macroscopic-microscopic method, suggested by Strutinsky [16], can explain the neutron induced fission process by introducing a double-humped fission barrier (DHB). A good agreement between experimental data and theoretical predictions exists for the light and heavy actinides. However, nuclei with 87<Z<92 show an anomalous behaviour and question the validity of this model. In particular, experimental results on the nuclei ^{230}Th and ^{232}Th indicate a dominant second barrier, resulting in the creation of a shallow third well [17] roughly 1 MeV deep, just deep enough to accommodate some very deformed metastable states with a ratio of major to minor axis of the order 3. This effect suggests the existence of the triple-humped fission barrier (THB), predicted by A. Bohr already in 1955 [18]. Blons et al [19] showed experimental evidence for the existence of this THB in the fissioning ^{231,233}Th nuclei. The level density of the second well is hardly known. A high quality TOF neutron spectrometer permits to reveal structures of vibration resonances, directly confirming the existence of the THB for these anomalous elements. The measurement of the angular distribution of the fission fragments with an energy resolution comparable to that of the fission cross section allows the determination of spin and parity of such substructures. The double differential cross section measurement of the fission fragments of $^{231-233}$Th, will evidence the individual rotational components and extract the associated band parameters. The interesting neutron energy region lies near the fission threshold at 720 keV for ^{230}Th and at 1.4 MeV for ^{232}Th.

Even the fission cross section of ^{235}U, considered as well known, is only precisely measured for low neutron energies, while for $E_n \geq 100$ eV large fluctuations appear in the unresolved resonance region. The measurement of the fission cross section for various elements as a function of the neutron energy allows a systematic search of yet undetected resonances and therefore a precise explanation for the discrepancies between the different databases will be possible. In this respect the study of high-energy neutron induced fission of ^{209}Bi is also very interesting.

Among the many possibilities offered by neutron fission studies, of particular importance is the study of nuclear fission dynamics [20] and the associated very interesting question of the magnitude of nuclear dissipation, its temperature and/or shape dependences. The time scale for the fission process - the best example for large scale collective flow of nuclear matter - and the amount of heat residing in the separated fragments can be assessed from the pre- and post-scission light particle (n, p, α) evaporation. Nuclear dissipation from saddle to scission of relatively cold fissile nuclei from low-energy neutron induced fission could be studied for different scission configurations as signalled by the total neutron multiplicity. The charged particles can be detected in a 4π charged particle detector and the neutrons in a 4π neutron tank, both detectors being described in references [21, 22].

3.2 Neutron capture. The neutron capture process is currently well understood for thermal neutron energies. Data agree well with the theoretical predictions using a 1/v energy dependence of the electromagnetic transition matrix elements. These predictions are based on the assumption that the neutron capture process proceeds only through the capture of incident s-wave neutrons. Instead, it has been recently pointed out that the contribution of incident p-wave and higher partial wave neutrons strongly enhance the capture probability [23, 24]. In particular, for nuclei in which the ground state or some of the low-lying bound excited states is within the sd shell, electric dipole (E1) p => s or p => d transitions are possible. An example of these features is the neutron capture cross section of ^{16}O. Here, a value consistent with the 1/v extrapolation of the thermal value was provided by Allen and Macklin [25]. Recently, the Tokyo group has re-measured this cross section and found a capture component due to incident p-wave neutrons with an increase in the cross section value by a factor of about 170 at 30 keV [26, 27].

The capture and γ-ray emission cross sections in light nuclei cannot be modelled by standard statistical methods such as the Hauser-Feshbach theory. Model calculations based on the direct radiative capture (DRC) mechanism confirmed the interpretation and allowed for a re-evaluation of this important capture cross section. Similar processes have been found for the $^{12}C(n, \gamma)^{13}C$, $^{13}C(n, \gamma)^{14}C$, $^{18}O(n, \gamma)^{19}O$ and other reactions [28]. Another feature of the fast neutron capture in light nuclei is the distortion of the γ-ray spectrum [29]. Again for the same reason, the onset of p-wave capture allows for E1 transitions to low-lying levels of opposite parity as compared to s-wave capture. In the context of possible applications of nuclear data for technological as well as basic science, the suggested proposal [29] concerns three neutron capture reactions on light nuclei of relevant interest: i) $^{9}Be(n, \gamma)^{10}Be$, ii) $^{10}Be(n, \gamma)^{11}Be$, iii) $^{14}C(n, \gamma)^{15}C$. No data are available in the keV energy region and for higher neutron energies. This investigation will permit to study the nuclear structure (possibly neutron halo formation of nuclear excited states and exotic properties of neutron-rich nuclei) and is of great interest to nuclear astrophysics [29].

It is also interesting to study the contributions of higher angular momenta for intermediate nuclei by measuring the variation of the capture cross sections of ground and isomeric states as a function of neutron energy. One example is the two isotopes of natural silver, $^{107,109}Ag$. Both ^{108}Ag and ^{110}Ag formed after neutron capture have an isomer and a ground state [30]. The population of these two states is only known for thermal neutron energies.

Recent experimental work [31] using the time of flight method has revealed large discrepancies in $^{12}C(n,\gamma_0)^{13}C$ reaction cross sections in the neutron energy range from 7 to 14 MeV questioning isospin invariance. TUNL's data indicate the isospin conservation, whereas TLU's data indicate departure from isospin conservation. Clearly, these discrepancies of the data need to be clarified.

3.3 Elastic and inelastic neutron scattering. Double differential neutron cross section (DDX) measurements are important for the understanding of nuclear reaction mechanisms by fast neutrons of energies exceeding nucleon binding energies of target nuclides. For instance, neutron-induced reactions between 10 and 20 MeV incident energy exhibit the competing processes between the direct (inelastic scattering and multibody break-up), the pre-compound and the compound processes, which are reflected in the energy spectral shapes of data. Systematic comparison studies have been made [32] showing that there exist discrepancies between experiments and evaluations. To meet better agreements, more reliable experimental data are required extending to the “missing range” between 7 and 14 MeV and to higher energies, even above 20 MeV. We point out that (i) multibody direct break-up processes play a dominant role for light elements (Li, Be, C, O, F, etc.) while (ii) pre-compound and compound processes reproduce better the data for medium to heavier elements. Measurements have been intensively carried out around 14 MeV [32, 33, 34] while there exist only a few measurements below 8 MeV. However, measurements of DDX in the incident neutron energy range from 9 to 13 MeV are scarce. So far only 4 elements (Li, Be, B, and C) have been measured at 10 MeV at LANL using a H(t,n) reaction neutron source [35, 36]. Li was also measured at GELINA in the incident neutron energy bins of 9.6-11.7 and 11.7-13.8 MeV [37]. Contrary to a monoenergetic neutron source, where neutrons from break-up reactions interfere with the secondary neutrons, the use of a pulsed white neutron source is clearly superior. The secondary neutron spectrum is then obtained by unfolding the pulse height spectrum of the neutron detector.

The Uppsala group [38] motivated measurements of neutron elastic scattering at large angles for closed-shell nuclei (^{16}O, ^{40}Ca, ^{208}Pb) and semi-magic medium-weight nuclei (^{90}Zr).

3.4 The (n,2n) reactions. The (n,2n) reactions are also of great importance in the study of fission and fusion reactions. Their reaction cross sections are essential for reactor physics : for instance, in the Energy Amplifier, (n,2n) reactions account for nearly 3-5% of the total neutron induced reactions, mainly on Lead and Actinides.

For many years there has been a controversy as to whether there exist shell effects on (n,2n) cross sections between 10 to 20 MeV. The effect is manifested in maxima or minima in cross section values primarily in closed shell nuclides. Some authors claimed the existence of shell effects in measured cross sections [39]. The experimental cross sections deviate systematically from the statistical theory which implies an incomplete understanding of the mechanism of these reactions. For example, the calculated reaction cross section of ^{58}Ni is 6 times larger than the experimental result. It is believed that because the structure of this nuclide is very special, although it belongs to light nuclei, its shape is distorted by the use of the distorted wave Born approximation. It was discovered that the direct reaction fraction of the (n,2n) cross section is quite big, and when coupled with a statistical model is in consistence with experimental values.

These cross sections do exhibit a characteristic systematic behaviour. On the average, the values increase with increasing mass number A, but in more detail the cross sections vary with maxima and minima which are closely connected with the magic neutron numbers. For even-proton nuclei with neutron numbers around N=28 (A~54), there appears to be a minimum. A second minimum appears for even-proton nuclei around neutron number N=50 (A~90). In the region of the magic neutron number N=28 (A ~ 54) the thresholds lie only slightly below 14 MeV, so that the minimum of the (n,2n) cross sections in this region can be understood as a Q value effect. Around N=50 (A~90) the Q values go through a minimum and this is probably the reason for the observed striking minimum in the (n,2n) cross section for even nuclei.

The present results indicate the existence of shell effects in the cross section values for even-even closed neutron shell nuclei at 14.6 MeV neutron energy. The lack of experimental data required to normalise the cross section values to the same excitation energy hinders an accurate systematic study of (n,2n) reactions.

4 — CROSS SECTIONS RELEVANT TO DOSIMETRY.

Accurate cross-section evaluations for neutron induced reactions, including charged particle and gamma ray emission, are required for radiation transport calculations of any type of radiotherapy. The type, accuracy, and specificity of the needed information vary with the application.

Nuclear data are fundamental to our understanding of dosimetry in radiological protection (assessment of doses to aircraft crews for instance) and radiation therapy when energetic neutrons are used. Neutron therapy dosimetry and more importantly neutron transport calculations for dosimetry demand detailed microscopic charged particle production information for prediction and interpretation of absorbed dose to the patient. The same need exists for advanced proton therapy facilities, where secondary neutrons are produced with energies as high as 250 MeV. Since data above few MeV are scarce, presently, only nuclear model calculations can provide some of the needed information. Measurements of neutron interaction cross-sections for different elements, in a wide energy range, would allow to perform more accurate simulations of the moderation process for new materials being considered for accelerator-based therapies. In particular, the accurate determination of resonances of the cross section in the high-energy region could lead to the design of more efficient beam shaping assemblies, and to the setup of epithermal neutron beams of superior quality than the ones currently available in BNCT. Finally, reliable neutron interaction cross-sections are necessary to determine with high accuracy the dose produced in the therapy by the epithermal neutron beams and therefore are of fundamental importance in the treatment planning for cancer therapy.

Dosimetry					Transport		Importance* [Ref. 40]
Element	p	α	d	recoil	Element	n, γ	
H	✓				H	✓	1
C	✓	✓	✓	✓	C	✓	1
O	✓	✓	✓	✓	O	✓	1
Si	✓	✓	✓	✓	Fe	✓	2
Ca	✓	(✓)	(✓)	✓	W	✓	2
P	✓	(✓)			Si	✓	3
K	✓	(✓)			Ca	✓	3
N	✓	(✓)			Pb	✓	3
					N	✓	3

Table 2 : *Required neutron cross-section information for dosimetry and radiotherapy.*

*Importance:
(1) Need best accuracy, most complete data, small neutron energy intervals.
(2) Need good accuracy, wider spacing of neutron energies.
(3) High accuracy is not needed; approximate data are required.

Table 2, shows the principal needs organised by dosimetry and transport. As for C, N and O, there is a scarcity of microscopic cross-section information for the stated elements. A needed high priority measurement is charged particle emission spectra from neutron reactions on oxygen for wide range of emission angles. Besides C, N and O, Si and Ca require the most complete information of dosimetry. Detailed ejectile data are needed for Si to support applications in medical electronics. As bone is almost always present in the radiated field in Neutron Radiotherapy, Ca data are essential for accurate dosimetry. As P, K and N are present at less than a few percent in most tissues and dosimeters, less comprehensive data are required. For neutron transport calculations, Fe and W are the elements next in importance to C, N and O. Information about Si, Ca and N is required for transport calculations due to their presence in significant quantities in concrete and air.

5 — CROSS SECTIONS RELEVANT TO VARIOUS FIELDS IN TECHNOLOGY.

Evaluations performed on neutron induced reaction cross sections for neutron data libraries presently in use [41] are based on differential measurements. However, they rely to a large extent on theoretical model codes to complement the databases where data are lacking or inconsistent. Such model predictions are benchmarked against (i) crucial integral experiments and (ii) the available differential data, that are obtained under different conditions and in different neutron energy domains. Nevertheless, data files often show substantial differences amongst them due, on the one hand, to the lack of measurements and on the other hand to differences in fitting procedures and the use of different nuclear models. Many applications, such as fusion, fission reactors, accelerator-based systems, transmutation of nuclear waste, energy production, dosimetry and radiotherapy require nuclear data that quantitatively and qualitatively go beyond the presently available traditional evaluation. The Nuclear Energy Agency of OECD compiled these needs in the "High Priority Nuclear Data Request List". The purpose of the list is to provide a guide for those planning measurement, nuclear theory and evaluation programmes. The 1998 List includes more than 200 requests from 7 different countries [42] for Standards, Fusion, Fission, Dosimetry, Medical and Industrial applications (Figure 3).

^{9}Be is considered as one of the possible candidates for the neutron multiplying and tritium breeding zone of the fusion reactor, because nearly all reactions induced by neutrons with energies higher than the threshold for inelastic scattering lead to a decay of the compound system into two neutrons and two α particles. For this reason not only the accurate knowledge of all integral cross sections but also of the energy and angular distribution of the secondary neutrons is needed for fusion technology [43]. Up to now little experimental data exist for the cross section for the ^{9}Be(n, 2n) reaction, which is mainly responsible for the emission of secondary neutrons.

Despite the huge and well organised amount of neutron induced reaction data, the onset of new applications broadened the range of needed data beyond the canonical reactor-driven sets. For instance minor actinides, not critical for fission reactors, gained importance in Accelerator Driven Systems (ADS) for waste transmutation and energy production, as well as the unstable fission products like I, Tc, Sr and Cs. Gamma rays produced by neutron interactions as well as energy and angular distributions for secondary neutrons are a major concern for transport calculations, for instance, as a source of background in experimental nuclear and high energy physics.

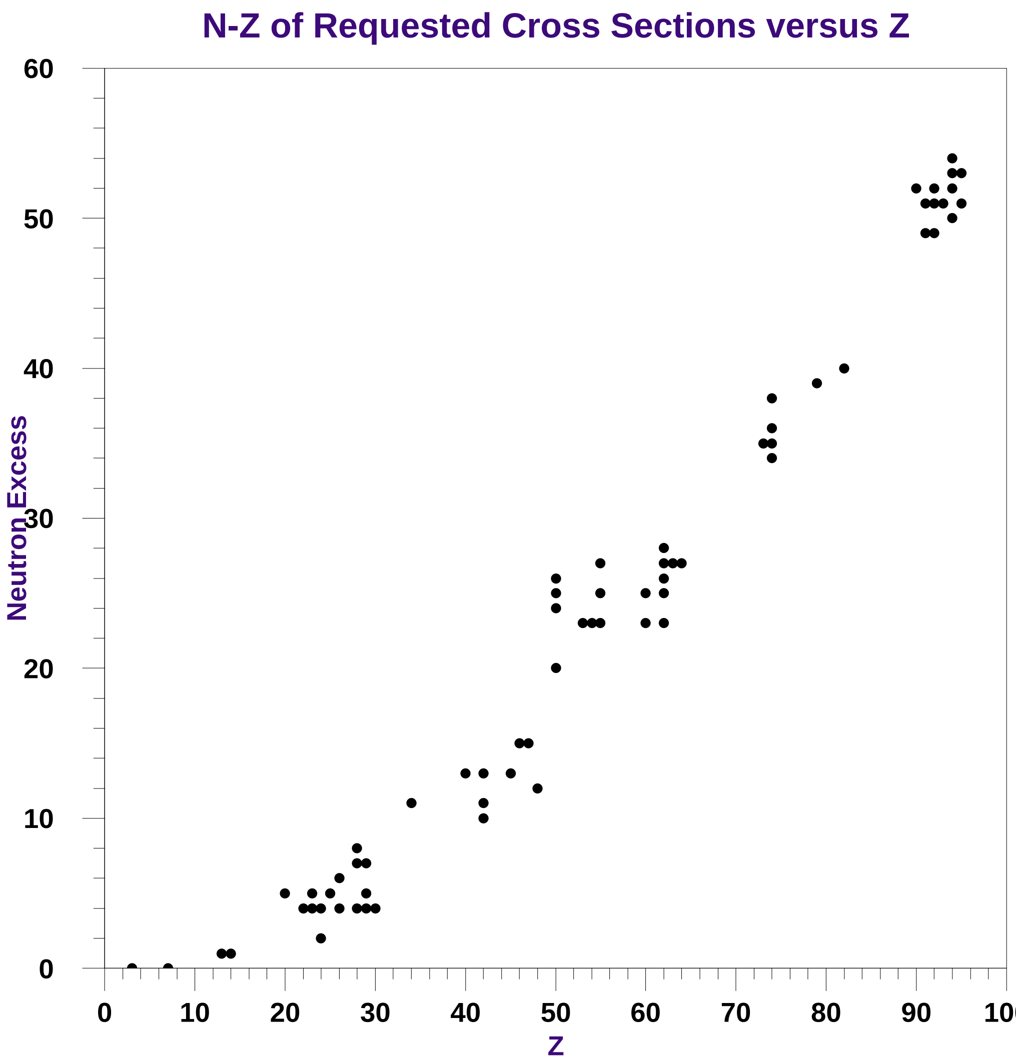

Figure 3 : The requested isotopes in the OECD/NEA 1998 High Priority List [42] as function of the charge number and the neutron excess.

The TARC experiment has directly demonstrated the success of this incineration method in the examples of several long-lived fission fragments and actinides [44]. The thorium cycle is of primary importance for the Energy Amplifier (EA), where ^{232}Th, ^{233}Pa and ^{233}U cross sections are crucial. However, the present compilation databases cannot be considered today as a totally reliable basis for designing in detail the EA prototype unit and simulating with the required accuracy the behaviour of the machine with a variety of different fuels, as required for instance when planning the incineration of radioactive waste from PWR's. Indeed, while thorium and uranium related cross sections could be considered as relatively well known, there are sometimes gigantic differences between databases when it comes to curium and americium, or more generally to minor actinides [12, 41]. Significant amounts of reactor fission products and Actinide waste are loaded into the EA incineration region. Important higher actinides are ^{232,233}Pa (for the ^{232}Th-^{233}U fuel cycle), ^{237,238}Np, $^{241-244,242m,244m}$Am and $^{242-248}$Cm.

Nuclide	Half-life	Thermal $\sigma_{n,\gamma}$ (b)	Thermal $\sigma_{n,f}$ (b)	ENDF/B-VI Quality [Ref. 45]
^{237}Np	$2.1 \cdot 10^6$ y	176 ± 3	21.5 ± 2.4	Good
^{241}Am	433 y	587 ± 12	3.2 ± 0.1	Reasonable
^{243}Am	7370 y	75.1 ± 1.8	0.198 ± 0.004	Needs update
^{242}Cm	163 d	16 ± 5	< 5	Very weak
^{244}Cm	18 y	15.2 ± 1.2	1.04 ± 0.20	Reasonable
^{246}Cm	470 y	1.22 ± 0.16	0.14 ± 0.05	Needs update
^{247}Cm	$1.6 \cdot 10^7$ y	57 ± 10	81.9 ± 4.4	Weak
^{248}Cm	$3.5 \cdot 10^5$ y	2.63 ± 0.26	0.37 ± 0.05	Needs update
^{232}Pa	1.3 d	700 ± 100	464 ± 95	None
^{238}Np	2.1 d	~ 300	2088 ± 30	Very weak
^{242}Am	16.1 h	?	2100 ± 200	Very weak

Table 3 : *Higher Actinides Transmutation candidates, heavily produced in a PWR. The cross-sections are from Mughabghab [45] comments refer to ENDF/B-VI.*

Regarding the transmutation of Actinides, data are required for nuclides important in the ^{232}Th-^{233}U energy production cycle and in burning ^{239}Pu, as well as for the higher actinides in fission reactor waste that would be introduced into the EA for destruction. A qualitative assessment of evaluated data in the ENDF/B-VI file for important higher Actinides is given in Table 3, including thermal cross-sections from Mughabghab' s compilation [45]. There are presently no evaluations in the ENDF/B-VI file for ^{232}Pa, ^{244m}Cm while the evaluations concerning ^{238}Np, ^{242}Am and ^{247}Cm are regarded as weak.

The comprehensive elimination of PWR waste implies consideration for the transmutation of several long-lived Fission Fragments into stable species as well. For such elements, the information is even more lacunary and in many important cases (^{90}Sr, ^{129}I) there are orders of magnitude discrepancies in the experimental data, mostly confined to the region of thermal or epithermal neutrons. A list of the more important long-lived fission products that are transmutation candidates is given in Table 4, together with summary information on low-energy cross sections.

In addition to the fission fragments and actinides, interest is focused to the target, beam and structural materials. All these materials are exposed to both the direct beam protons and the secondary neutrons, ranging in energy from the primary beam energy down to thermal energies. Target materials under current consideration are Pb and Pb-Bi eutectic. The structural materials (C, Al, Si, P, Cr, Fe, Mn, Ni, Zr, Mo, Sn) and liquid metal coolant (Pb, Bi) are irradiated by neutrons from (p,xn) reactions with a significant hard component near the target, which becomes a moderated fission spectrum further into the subcritical core region. Transmutation/activation cross sections are required for all nuclides that are products of spallation, fission, absorption, activation, (n,x), (n,xn) etc. reactions, including nuclides that are formed in isomeric states.

Nuclide	Half-life (years)	Thermal capture cross section (b)	Resonance Integral (b)	Resonance Parameter
^{79}Se	$6.5 \cdot 10^4$	(10) ?	-	No
^{93}Zr	$1.5 \cdot 10^6$	2.5 ± 1.5	-	No
^{99}Tc	$2.1 \cdot 10^5$	20 ± 1	340 ± 20	Yes
^{107}Pd	$6.5 \cdot 10^6$	1.8 ± 0.2	86.6	Yes
^{126}Sn	$1.0 \cdot 10^5$	(0.14) ?	-	No
^{129}I	$1.6 \cdot 10^7$	27 ± 3	36 ± 4	Yes
^{135}Cs	$3.0 \cdot 10^6$	8.7 ± 0.5	62 ± 2	No

Table 4 : *Long-lived Fission Product candidates, heavily produced in PWR. The cross sections are from Mughabghab [45] and the resonance parameter comments refer to ENDF/B-VI.*

In terms of nuclear reactions, the required data are neutron total, elastic and inelastic scattering, double differential (n,xn) and (n,xp), (n,γ), (n,f), (n,x) and (n,xγ) cross sections. Double differential cross sections with heavy products (α, etc.) would be also very useful for nuclear reaction modelling, while data on (n, x$\pi^{\pm o}$) at 600-1000 MeV even with a moderate resolution are very interesting since very scarce relevant data exist in this region. These data are of relevance to the determination of the transmutation rates, to the inventories in PWRs, PWR-MOX, PWR-MOX with multiple recycling, to the design and inventories of waste burners and to the calculations of the neutron multiplication factor, of radiation damages and of gas production in such systems.

In a recent EU meeting on Nuclear Safety [46], the priority to ADS was clearly stated and the requirement from the European Nuclear Industry for more complete and precise Nuclear Data was generally adopted.

The expertise in measuring keV neutron cross sections of stable and unstable isotopes, which was developed by the team from FZK over more than 2 decades for astrophysical problems, can be of immediate interest for reactor applications. They stated [8], that "*it is fair to say that the high intensities of spallation neutron sources bear a most promising technological potential, but one should also be aware that complementary techniques remain important* ". Already the presently available techniques allow for a number of accurate measurements, either for resolving discrepancies in existing data or for exploring terra incognita, e.g. the urgently needed neutron nuclear data for ^{233}Pa and ^{233}U. Depending on the accessible resources, this could be achieved in a foreseeable period of time and with a comparably small financial effort.

6 — REFERENCES.

[1] J.-M. Salome, "GELINA, l'accélérateur linéaire à électrons du BCMN", Physicalia Mag. 8 (1986) p 261 and private communication.

[2] J.-M. Salome and H. Weigmann, “GELINA, a powerful neutron time-of-flight facility for neutron data measurements”, Proc. 9th Intern. Conference on Emerging Nuclear Energy Systems, Tel Aviv, 1998.

[3] P.E. Koehler et al, Phys. Rev. C 54 (1996) 1463

[4] P.W. Lisowski et al, “ The Los Alamos National Laboratory Spallation Neutron Sources”, Nucl. Sci. Eng. 106 (1990) 208. P.W. Lisowski, “Nuclear Science Research at the WNR and LANSCE Neutron Sources”, Proc. Intern. Conf. on Nuclear Data for Science and Technology, Gatlinburg 1994; ANS, Laa Grange Park, Ill, 1994.

[5] R. Gallino, M. Busso, and M. Lugaro, in Astrophysical Implications of the Laboratory Study of Presolar Material, edited by T. Bernatowitz and E. Zinner (AIP, New York, 1997), p. 115.

[6] G. Wallerstein et al., Rev. Mod. Phys. 69, 995 (1997).

[7] S. Amari and E. Zinner, Nucl. Phys. A 621, 99c (1997).

[8] F. Käppeler, Contribution to the Joint CERN-EC-GEDEON-OECD/NEA Workshop, CERN, 21-22 September 1998.

[9] K. Wisshak et al., Nucl. Instr. Meth. A 292, 595 (1990).

[10] T. Ohsaki et al., Ap. J. 422, 912 (1994).

[11] M. Igashira et al., Ap. J. 441, L89 (1995).

[12] C. Rubbia, S. Andriamonje, D. Bouvet-Bensimon, S. Buono, R. Cappi, P. Cennini, C. Gelès, I. Goulas, Y. Kadi, P. Pavlopoulos, J.P. Revol, A. Tzima, V. Vlachoudis , “A high resolution Spallation driven Facility at the CERN-PS to measure neutron cross sections in the interval from 1 eV to 250 MeV”, CERN/LHC/98-02 (EET)

[13] F. Käppeler, in Radioactive Nuclear Beams, edited by T. Delbar (Adam Hilger,Bristol, 1992), p. 305.

[14] H. Beer, Ap. J. 375, 823 (1991).

[15] NuPECC Report December 1997, "Nuclear Physics in Europe : Highlights and opportunities", p.106

[16] V.M. Strutinsky, Nucl. Phys. A95 (1967) 420

[17] P. Moller and J.R. Nix, Proc. Int. Conf. on physics and chemistry of fission, Rochester, 1973 (IAEA, Vienna, 1974) p. 103

[18] A. Bohr, Proc. Int. Conf. on peaceful uses of atomic energy, Geneva, 1955 (United Nations, New York, 1956) vol. 2 p. 220

[19J Blons et al, Nucl. Phys. A414 (1984) 1

[20] D. Hilscher and H. Rossner, Ann. Phys. Fr. 17 (1992) 471.

[21] J. Galin and U. Jahnke, J. Phys. G: Nucl. Part. Phys. 20 (1994) 1105.

[22] D. Hilscher et al, Nucl. Instrum. Meth. A 309 (1991) 530.

[23] T. Otsuka et al, Phys. Rev. C 49, R2289 (1994).

[24] A. Mengoni et al, Phys. Rev. C 52, R2334 (1995).

[25] B. J. Allen and R. L. Macklin, Phys. Rev. C 3, 1737 (1971).

[26] M. Igashira et al, Nucl. Phys. A 536, 285 (1992)

[27] M. Igashira et al, Astrophysical Jour. 441, L89 (1995)

[28] T. Kikuchi et al, Phys. Rev. C 75, 2724 (1998).

[29] A. Mengoni, Contribution to the Joint CERN-EC-GEDEON-OECD/NEA Workshop, CERN, 21-22 September 1998.

[30] H. Beer et al, Nucl. Instr. Meth. A337, 492 (1973)

[31] H. Zhengde et al., in Proc. of Int. Symp. on Fast Neutron Physics, Beijing, China, 9-13 September 1991.

[32] A. Takahashi, in Proc. of Int. Symp. on Fast Neutron Physics, Beijing, China, 9-13 September 1991; see also, A. Takahashi et al., J. Nucl. Sci. Technol. 26 (1989) 15.

[33] M. Baba et al., Proc. of Int. Conf. on Nucl. Data for Sci. and Tech., Mito, Japan, 1988, p 209.

[34] H. A. Obiesi et al., Proc. of Int. Conf. on Nucl. Data for Sci. and Tec., Jülich, Germany, May 1991.

[35] D. M. Drake et al., Nucl. Sci. and Eng., 63 (1977) 401.

[36] M. Drosg et al., Rad. Effect, 92 (1986) 145 and P. W. Lisowski et al., LANL, LA8342 (1980).

[37] E. Dekempeneer et al., Nucl. Sci. and Eng., 97 (1987) 353.

[38] J. Blomgren and N. Olsson, Contribution to the Joint CERN-EC-GEDEON-OECD/NEA, CERN, 21-22 September 1998.

[39] S. L. Sothras and J. Inorg, Nucl. Chem. 40 (1978) 587.

[40] M. B. Chadwick et al, Rad. Protection Dos., Vol 70 (1997), p.1

[41] JENDL-3.2, OECD NEA Data bank (1996); JEF-2.2, OECD NEA Data bank(1996); ENDF/B-VI, OECD NEA Data bank (1996); BROND-2, OECD NEA Data bank (1996). See also J. Cobo et al, "Notes on the Study of the Most Reliable Neutron Cross Section Data", CERN/AT/95-035 (ET).

[42] "The NEA High Priority Nuclear Data Request List", Status in May 1998, OECD-NEA Nuclear Science Committee.

[43] H. Leeb for the team from TU of Wien, Contribution to the Joint CERN-EC-GEDEON-OECD/NEA Workshop, CERN, 21-22 September 1998..

[44] A. Abánades et al., in preparation.

[45] S. F. Mughabghab, M. Divadeenam and N.E. Holden, Neutron Cross sections V. 1 Part A, Zz 1-60 (Academic Press Inc., 1981); S. F. Mughabghab, Neutron Cross sections V. 1 Part B, Zz 61-100 (Academic Press Inc., 1984)

[46] EU Workshop on P&T Strategy Studies and Transmutation Experiments, European Commission, DG-XII, FZK Karlsruhe, 17-19 June 1998, Karlsruhe, Germany.

APPENDIX 1 — LETTER FROM DR. S. GANESAN.

Dear Colleagues,

Thanks a lot for asking me to read the following reports and comment.

1. C. Rubbia et al., "A High Resolution Spallation Driven facility at the CERN-PS to Meaure Neutron Cross sections in the Interval from 1 eV to 250 Mev" Report No. CERN/LHC/98-02 (EET), May 30, 1998
2. C. Rubbia et al., "A High Resolution Spallation Driven facility at the CERN-PS to Meaure Neutron Cross sections in the Interval from 1 eV to 250 Mev: A Relative Performance Assessment" Report No. CERN/LHC/98-02 (EET)- Add-1, June 15, 1998

I greatly enjoyed going through the reports. I have the following comments based on my first impression.

First of all, the authors deserve congratulations for making this proposal to measure neutron cross sections from 1 eV t0 250 MeV. The facility is expected to provide 3 orders more fluxes of neutrons or 1000 times smaller targets for equivalent neutron induced reaction rates. It is very likely that many new and interesting results will come out. One can greatly improve the resolution for a given flux. Personally, I am excited and welcome this proposal for the following reasons:

It is useful to send a copy of these reports to scientists like D. L. Smith, Duane Larson F. H. Froehner and D. W. Muir for their comments and suggestions.

Most of the high resolution cross section measurements have been reported using the Oak Ridge ORELA Linear electron accelarator facilty. These data have been incorporated in the internationally distributed evaluated data files which cover the energy region for the neutrons from 10 ** -5 eV to 20 MeV. For the accelerator based energy amplifier and such concepts, there is no way by which these computerized data files generated in various countries such as JENDL-3.2 (Japan), ENDF/B-VI (USA), JEF-2.2(Europe), BROND-2 (Russia) in ENDF/B format can be improved further without such new and high resolution measurements. Despite 5 decades of data efforts and fission reactors operating, the microspic data has not converged in these files even for major isotopes. The discrepancies are worse in the case of minor actinides and fission products. The cross sections in many cases are based upon theory which is only as good as the normalizing measured data if it exists.

Over the years, indeed, the high resolution measurements at Oak Ridge and in Europe have helped improve the quality of the neutron cross section data in the resolved resonanace energy region. For example, for U-238, the major fertile isotope the resolved resonance region was about 4 keV in the ENDF/B-IV file released in 1975 and the resolved resonance region has been extended to about 10 keV for s and p waves in ENDF/B-VI released in the nineties. For Pu-239, the resolved resonance region has been extended, thanks to high resolution measurements , to about 2 keV in -VI from the earlier 300 eV in -IV. This has helped reduce the uncertainty in the prediction of resonance Doppler broadening and self shielding. (See for example:S. Ganesan, " A sensitivity study on the influence of the choice of the mean resonance data set in the unresolved resonance region on the Doppler effect calculations," Nucl. Sci. Eng., 74, 49-51 (1980). S. Ganesan, "On the need for changing ENDF/B convention for the representation of cross sections in the unresolved resonance region of fertile and fissile nuclei," Annals of Nuclear Energy 9, 481-487 (1982).)

The high resolution measurements which is expected to provide 3 orders better energy resolution than the best ones available today are very much required to extend the resolved resonance region of the isotopes of thorium fuel cycle as the isotopes Th-232 and U-233 and other isotopes of this fuel cycle did not get the same priority in the measurements in the last 5 decades. This is evident from the fact that the evaluated data files ENDF/B-VI and JENDL-3.2 show much larger spread in cross sections of isotopes of thorium fuel cycle as compared to isotopes of U-Pu cycle. For instance (see for example: S. Ganesan and P. K. MacLaughlin, "Status of Thorium Cycle Nuclear Data Evaluations: Comparison of Cross Section Line Shapes of JENDL-3 and ENDF/B-VI Files for 230Th, 232Th, 231Pa, 233Pa, 232U, 233U, and 234U," Report INDC(NDS)-256, Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria), the spread in the capture cross section data of Th-232 is an order of magnitude larger than for U-238. Similar is the case for the fission cross section of U-233 as compared to U-235 and Pu-239. In the data files released in the nineties, the resolved region for Th-232 is still about 4 keV (the last resonance energy is 3997.60 eV) compared to 10 keV for U-238; the resolved resonance region of U-233 is very low, the last resonace energy in the data file of ENDF/B-VI being 62.69 eV and in JENDL-3.2 it is 356 eV.

The safety related reactivity coefficients such as the Doppler reactivity and coolant void reactivity effects can be accurately predicted if the resolved resonance region is extended with high accuracy. This remark applies to all actinides, uranium or thorium fuel cycle, major or minor isotopes. In fact, elimination of the unresolved resonance region was achieved to some extent for many isotopes in ENDF/B-VI by extending the resolved resonance region by making high resolution measurements. The present proposal of Carlo Rubbia will significantly improve the quality of existing data in the resolved resonance region, extend the energy range of resolved resonance region, in addition to generating new data up to 250 MeV.

Most importantly, we will be able to converge the various countries' data files into a single universally acceptable basic evaluated data files. It is a sad fact that there are so many data files for the same isotope providing different numerical values for the same physical quantity (example: capture cross section at a given energy). The quality assurance in design and safety studies in nuclear energy in the next few decades and centuries require new and improved data with high accuracy and energy resolution. Resonance cross section curves cannot be predicted theoretically by models to such accuracy with the prsent day understanding of nuclear physics.

<u>There are some minor suggestions</u>:

The report provides a few cross section comparisons. These could have been shown better with the ratio also. The comparison in the logrithmic scale is OK but not impressive. I use the prepro code system COMPLOT for such comparisons. Also one must be careful about giving a general index of variance. The values of cross sections at/near the threshold energies differ between evaluated data files by orders of magnitude but do not matter unless the flux in the application peaks at/near the threshold. Another point not covered in the reports is that the specification of uncertainty is not there presently in the evaluated data files such as ENDF/B-VI and JENDL-3.2 The numerical values given in these data files are expectation values (mean values) for use in applications. If two data files agree it does not mean that both are correct. The true value may be off by a systematic error. The specification of uncertainty/covariance error matrix) is a complex task and the evaluated data files do not contain the eroor descriptions interms of covariance error matrix except in the case of doimetry reactions where about 75% of the reactions have been covered in the specification of errors. Hope that these first impressions/comments are useful.

Best regards,
..Ganesan
Sunday, July 19, 1998, 1118 hrs.

____

Office: Dr. S. Ganesan,
Reactor Design and Nuclear Data Section
Theoretical Physics Division,
Central Complex, 5th Floor,
Bhabha Atomic Research Centre,
Trombay, Mumbai 400 085-INDIA

Residence:
NANDADEVI-17A
Anushakti Nagar
Mumbai-400 094

Office
Phone: 0091-22-556 3060 ext. 2729/2766
0091-22-551 9946
Fax : 0091-22-556 0750 or
0091-22 556 0534/5564921/5565204
Email:ganesan@magnum.barc.ernet.in

Residence:
Phone: 0091-22-556 4709
Email address at my residence:
ganesan@bom2.vsnl.net.in

APPENDIX 2 — LETTER FROM PROF. H. CONDE.

CERN-EC-GEDEON-OECD/NEA Workshop 21-22 September 1998 CERN-GENEVA

Comments to the proposal of a neutron facility at the CERN-PS

H. Conde
Dept. of Neutron Research, Uppsala University

General comments :

The proposed neutron facility at the CERN-PS will have very interesting characteristics to meet the requests for neutron cross section measurements for a number of applications. The expected high neutron flux and the very good energy resolution open new possibilities to measure cross sections mainly in the thermal, epithermal, resolved and unresolved resonance energy regions for stable as well as radioactive targets with high precision.

However, there will be limitations to what cross sections can be measured with reasonable accuracy due to a comparatively low neutron flux in the very high energy region (~50-250 MeV). The experience from the measurement program at the WNR/target-4 of LANSCE, which has about the same neutron flux in the high energy region, shows that double differential cross section measurements with a neutron in the outgoing channel (e.g. neutron elastic and inelastic scattering) are hampered by the low neutron flux in combination with the white neutron spectrum.

Another limitation is the accuracies of the present standard reference neutron cross sections internationally adopted for different types of measurements (fission, capture, scattering etc). The standard data base is in a relatively good shape up to about 20 MeV, but above that energy there are severe problems.

The evaluated neutron cross section data files ENDF IB-VI, JEF 3.2 and JENDL-3 have large discrepancies for most isotopes which are not of central interest for the present generation of thermal fission power reactors.

However, also for the most important fissile and fertile isotopes for thermal reactors and, in particular, for different fast reactor concepts, the data requests are not fulfilled in the resonance and unresolved resonance regions.

The neutron cross section data requests for ADS include a large number of elements and reactions over a wide energy range from thermal to several hundred MeV. Most cross sections in the ADS data base are calculated using existing nuclear reaction model codes. The errors might range from 20-30 % up to several orders of magnitude. It might be argued that the present data base for this application is adequate for conceptual studies of different concepts but it will certainly not be accurate enough for the design ofcommercial ADS facilities.

Other important applications which would benefit by a neutron cross section measurement program at CERN-PS are the medical field, in particular for dosimetry calculations in cancer therapy and for shielding calculations. Futhermore, nuclear astrophysics would also benefit by this program. in particular for studies of the synthesis of elements by the s- and r-processes in the universe.

Priorities

The initial priorities in a neutron cross section measurement program for ADS might be given the improvement of the capture and fission cross sections for the minor actinides and capture cross sections of the main long lived fission products in the thermal, epithermal, resolved and unresolved energy regions. A high prority could also be given measurements of important cross sections, mainly fission and capture cross sections, for the thorium/233U fuel cycle,

Collaboration

A neutron cross section measurement program at the CERN-PS would benefit by a collaboration with several European laboratories which have a long experience in neutron data measurements. While the development of the collimated neutron beam facility at the CERN-PS is best handled by CERN experts, the use of already existing detectors and the expertise around those detectors at other European laboratories would give the program a flying start. The production and fabrication of radioactive targets (minor actinides, long lived fission products) require the involvement of special facilities and expertise. Because international tranportations of such materials are troublesome and time-consuming it would be of great value if PSI (or LLL) could undertake that effort.

In particular, the GELINA group at the Joint Research Centre, Geel Establishment is the most obvious counterpart in a collaboration. The know-how they have of measurements in the low-energy regime can probably be tr anfered to CERN, which also include detectors, which have been developed at JRC-Geel, for the same energy region and for studies of the neutron induced reactions in mind.

Other potential European collaborators are PSI (neutron spallation source, neutron measurements), KfK-Karlsruhe and KfK-JUlich (neutron measurements and evaluations), Harwell (neutron measurements, linac7), CEA/Saclay, SATURNE, CEA/Bruyeres-le-Chatel and CNRS/INZP3 (neutron measurements, evaluations), ECN-Petten (data evaluations and requests) etc.

The Department of Neutron Research at the Uppsala University is also a potential collaborator of the CERN-PS neutron program with special focus on the measurements in the high neutron energy region. Two facilities have been developed for the research within this Department, namely a 7Li(p,n)-neutron facility at the cyclotron of the The Svedberg Laboratory (TSL) and an isotope separator on-line the R2-0 reactor at Studsvik. Further details of these facilities are being presented to this workshop by Jan Blomgren. The first facility is used for neutron cross section measurements in the 50-200 MeV energy region for different applications as ADS and fast neutron capture therapy, the second facility for studies of decay properties of fission products. A fruitful collaboration could be a simultaneous neutron cross section measurement in the high energy range with the white neutron source at the CERN-PS and with the semi-monoenergetic source at the TSL for the same isotope. Agreement between the two measurements which would be using quite different experimental techniques, gives a lot of confidence to the result.

Of course, there are several laboratories outside EC which could be potential collaborators to the CERN-PS neutron program. 1 will not try to cover all these laboratories only to mention that the capabilities of the neutron sources at LANSCE/LANL (spallation source for neutron scattering and WNRI target-4) are very similar to the expected capabilities of the CERN-PS neutron source (see the added figure) and that an exchange of experiences could be very fruitful

Finally, I just like to point to an experimental group at the Khlopin Radium Institute in S:t Petersburg, Russia, which are experts in fission cross section measurements. They have developed a thin-film-break-down counter with very good discrimination capabilities between alpha-particles and fission products. The detector might be a candidate for fission cross section measurements of radioactive minor actinides at the CERN-PS neutron facility.

My last word will be to wish you all success in the development of the CERN-PS neutron source which could be very useful in providing one of the corner stones to the development of ADS but also be very useful for other important applications in medicine and astrophysics.