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A GROUP LIBRARY FROM JEF 1.1 FOR FLUX CALCULATIONS IN THE LHC MACHINE DETECTORS

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Abstract

A neutron and photon group library has been prepared for flux calculations in the LHC (Large Hadron Collider) machine of CERN at Geneve. The library includes data for 68 materials averaged over a structure of 72 neutron and 22 photon energy groups with Legendre angular momentum $l=5$ and three temperatures of 0, 87 and 293 ^0K. The weighting function of VITAMIN-J (Maxwellian + 1/E + Fission Spectrum + Fusion Peak) has been adopted. The basic data were taken mainly from JEF 1.1 and have been processed by NJOY 89.62. The library is given in the DTF (ANISN) format and besides the usual quantities, includes kerma (*K*inetic *E*nergy *R*elease in *MA*terial) and all reaction cross sections.

Introduction

Extensive simulations of the radiation environment for the proposed new collider at CERN, LHC, are of great importance for estimating its effect both on machine components and on particle detectors. Very stringent constraints about radiation hardness of all components arise from the high luminosity foreseen for the machine.

As far as the particle detectors is concerned, these constraints can largely affect many technological choiches, particularly for readout electronics and active media: a careful estimate of the radiation fluxes in real detector geometries is therefore mandatory. However such an estimate can only be achieved through extensive computer simulations based on the best physics knowledge about hadronic and electromagnetic shower interactions in matter, since of course no experimental data is available for this energy range. Despite the very large energies of the colliding beams (8 TeV protons on 8 TeV protons), a significant amount of the radiation effects will be produced by the large number of medium-low energy neutrons generated by the hadronic cascade. The particular geometry of a typical calorimeter for particle detection (see fig. 1), is very effective in giving rise to intense low energy neutron fluences because of the albedo caused by the central cavity of the detector. Since silicon based chips are known to be very sensitive to neutrons with energies larger than about 100 keV (and GaAs based components could be sensitive even to thermal neutrons), a suitable simulation of the radiation environment must cover energy ranges where only a transport strategy based on accurate nuclear data can give reliable results.

Similar considerations apply also to the studies required for the machine components, the main topics being:

1. estimate of the maximum tolerable beam losses to avoid quenching in the superconducting magnets;
2. estimate of the reliability and lifetime of the active and passive electronic components of the machine, particularly important for the quench protection diodes;
3. estimate of the radiation levels outside shielding, both for an assessment of the environmental impact of the machine and of the radiation doses in occupied areas.

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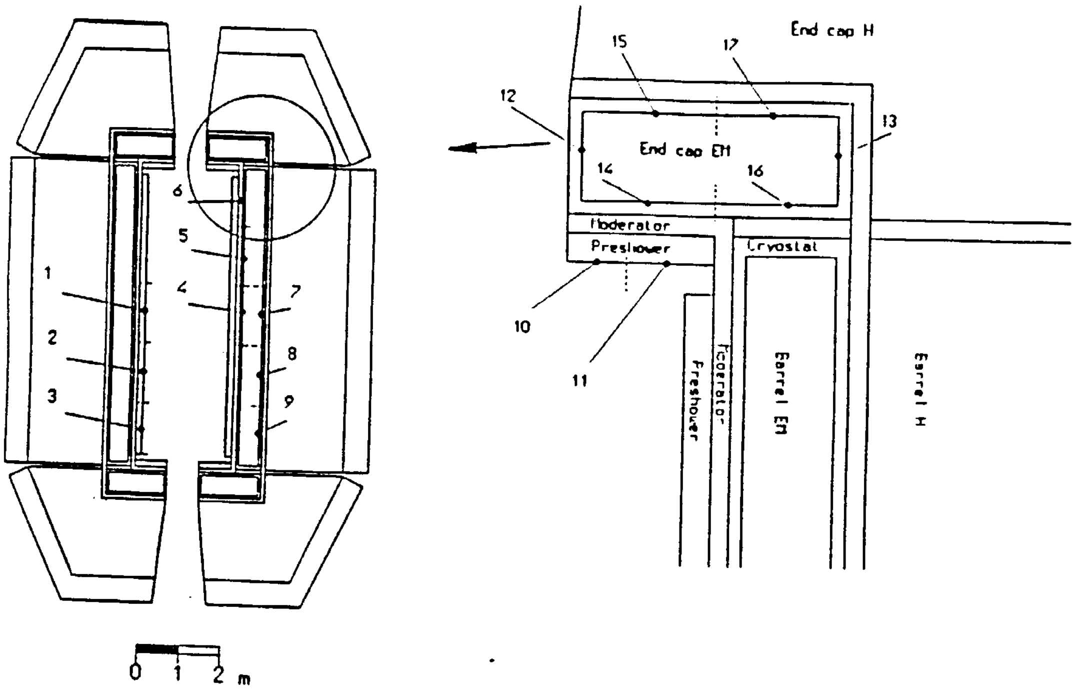

Figure 1. The geometry of a detector. The numbers show the points where the flux has been computed.

While for point 1 "low" energy neutrons play a minor role, their effects are the dominant ones in considering 2 and 3.

Another field where such nuclear data could be required in the next future is the simulation of hadronic showers in the detectors. Up to now none of the code used for such purposes included a detailed treatment of the less energetic neutrons, mainly because of the response time of the electronics (which usually is enough short to make the detector insensitive to the lowest energy neutrons) and of the lack of the necessary expertise in obtaining and treating nuclear data.

For LHC detectors the response time will be even shorter than in the past but the extremely high intensity of the machine will make important pile-up effects, for which of course the effect of low energy neutrons is surely very significant: furthermore the intense neutron fields will result in a significant activation of the experimental devices which must be accounted for when evaluating the background/noise level.

All these tasks require nuclear data for a large set of material, moreover for many of them it is necessary to have data weighted at different temperatures since cryogenic temperatures are of course present in the most critical machine components (the superconducting dipoles and quadrupoles) and possibly in the particle detectors (for example if the liquid Argon technology will be used).

The group library

INFN Milano is charged, among others, to simulate the neutron flux in order to investigate both the damage and the background noise which are generated. In the high energy region (above 50 MeV) Montecarlo techniques are used, while at lower energies

	MAT	Material	γ ray prod.	Temperatures $({}^{0}K)$	Source
1	4011	H-1	*	87, 293	JEF 1.1
2	4012	D-2	*	87, 293	JEF 1.1
3	4013	T-3		87, 293	JEF 1.1
4	4023	He-3		0, 87, 293	JEF 1.1
5	4024	He-4		0, 87, 293	JEF 1.1
6	4036	Li-6	*	87, 293	JEF 1.1
7	4037	Li-7	*	87, 293	JEF 1.1
8	4049	Be-9	*	87, 293	EFF 1
9	4050	B-10	*	87, 293	JEF 1.1
10	4051	B-11		87, 293	JEF 1.1
11	4060	C	*	87, 293	JEF 1.1
12	4074	N-14	*	87, 293	JEF 1.1
13	4086	O-16	*	87, 293	JEF 1.1
14	4099	F-19	*	87, 293	JEF 1.1
15	4113	Na-23		87, 293	JEF 1.1
16	4120	Mg	*	293	JEF 1.1
17	4137	Al-27	*	0, 87, 293	JEF 1.1
18	4140	Si	*	87, 293	JEF 1.1
19	1525	P-31	*	293	ENDF/B-VI
20	1600	S	*	293	ENDF/B-VI
21	4170	Cl	*	87, 293	JEF 1.1
22	4186	Ar-36	*	87, 293	JEF 1.1
23	4188	Ar-38	*	87, 293	JEF 1.1
24	4180	Ar-40	*	87, 293	JEF 1.1
25	4190	K	*	293	JEF 1.1
26	4200	Ca	*	293	JEF 1.1
27	4220	Ti	*	0, 293	JEF 1.1
28	4240	Cr	*	0, 87, 293	JEF 1.1
29	4260	Fe	*	0, 87, 293	JEF 1.1
30	4279	Co-59	*	293	JEF 1.1
31	4280	Ni	*	0, 87, 293	JEF 1.1
32	4290	Cu	*	0, 87, 293	JEF 1.1
33	4310	Ga	*	0, 87, 293	JEF 1.1
34	4322	Ge-72		87, 293	JEF 1.1
35	4323	Ge-73		87, 293	JEF 1.1
36	4324	Ge-74		87, 293	JEF 1.1
37	4326	Ge-76		87, 293	JEF 1.1
38	4335	As-75		87, 293	JEF 1.1
39	4359	Br-79		293	JEF 1.1
40	4351	Br-81		293	JEF 1.1

Table 1. : Materials included in the library (cont. on next page)

	MAT	Material	γ ray prod.	Temperatures (°K)	Source
41	4413	Nb-93	*	0, 293	JEF 1.1
42	4477	Ag-107		293	JEF 1.1
43	4479	Ag-109		293	JEF 1.1
44	4480	Cd		87, 293	JEF 1.1
45	4493	In-113		87, 293	JEF 1.1
46	4495	In-115		87, 293	JEF 1.1
47	4513	Sb-121		87, 293	JEF 1.1
48	4514	Sb-123		87, 293	JEF 1.1
49	4533	I-127		87, 293	JEF 1.1
50	4542	Xe-128		87, 293	JEF 1.1
51	4543	Xe-129		87, 293	JEF 1.1
52	4544	Xe-130		87, 293	JEF 1.1
53	4548	Xe-134		87, 293	JEF 1.1
54	4541	Xe-136		87, 293	JEF 1.1
55	4565	Ba-135		293	JEF 1.1
56	4566	Ba-136		293	JEF 1.1
57	4567	Ba-137		293	JEF 1.1
58	4568	Ba-138		293	JEF 1.1
59	4731	Ta-181	*	293	JEF 1.1
60	4742	W-182	*	87, 293	JEF 1.1
61	4743	W-183	*	87, 293	JEF 1.1
62	4744	W-184	*	87, 293	JEF 1.1
63	4746	W-186	*	87, 293	JEF 1.1
64	4797	Au-197		293	JEF 1.1
65	4820	Pb	*	87, 293	JEF 1.1
66	4839	Bi-209	*	87, 293	JEF 1.1
67	4925	U-235	*	87, 293	JEF 1.1
68	4928	U-238		87, 293	JEF 1.1

Table 2. : Materials included in the library

standard transport calculations are carried out and then group constants and transfer matrices are required.

This report describes the features of a nuclear data group library produced in cooperation between ENEA Bologna and INFN Milano to be used in the computations described above for the LHC machine.

Specifications of the library

Source of data

JEF 1.1 has been adopted as main source of basic data; it has been selected being the last official release of the european data base for nuclear data; an improvement with successive JEF versions is foreseen.

Materials

The processed materials, the source and the temperature values are listed in Table 1 and 2 ; although in the list of requested materials, no data were found in literature for Ne-20 and Ge-70. Moreover two materials (P-31 ans S) have been taken from ENDF/B-VI since no data are exist for them in JEF. In addition the Tables shows wether γ production data are available for each nuclide.

The natural element was requested instead of the separate isotopes for some Z values, but only isotopic data were found so as the mixing is expected to be performed at the transport code level.

Photon production of argon for which no data is provided in JEF 1.1 has been computed from LNL (Livermore National Laboratory, USA) data library ENDL in which the natural element only is given (MAT 7824).

Problems were encountered in processing some materials because of non standard format features: small programmes have been written to modify the data structure or to include missing information; the main modifications are listed below:

B-10	data for angular distributions of p and α in the (n,p) and (n,α) reactions are missing: isotropic distributions are supplied;
O-16	as for B-10;
N-14	as for B-10;
Argon	(all isotopes): besides the γ production data, secondary neutron energy distributions are missing for (n,np) and $(n,n\alpha)$: the distributions of neutrons in the continuum of the reaction (n,n') are used;
Bi-209	missing secondary neutron energy distributions for (n,np) and $(n,n\alpha)$ reactions; the continuum (n,n') is used.

Temperatures

Doppler broadening at three temperatures of 0, 87 and 293 ^0K has been performed over the data before processing: the temperatures of each material appear in the Tables.

Processing code

All the data have been processed with the standard code NJOY /1/ Version 89.62 without particular problems. Negative kerma values have been substituted by NHEAT, the high limit of the total kinematic kerma.

Group structure

The group structures for neutrons and photons are listed in the following pages.

Neutron groups

```
                 NEUTRON GROUP STRUCTURE (eV)

       1      1.0000E-05  -    4.1400E-01
       2      4.1400E-01  -    6.8257E-01
       3      6.8257E-01  -    1.1254E+00
       4      1.1254E+00  -    1.6374E+00
       5      1.6374E+00  -    2.3824E+00
       6      2.3824E+00  -    3.4662E+00
       7      3.4662E+00  -    5.0435E+00
       8      5.0435E+00  -    7.3375E+00
       9      7.3375E+00  -    1.0677E+01
      10      1.0677E+01  -    1.5535E+01
      11      1.5535E+01  -    2.2603E+01
      12      2.2603E+01  -    3.7267E+01
      13      3.7267E+01  -    6.1442E+01
      14      6.1442E+01  -    1.0130E+02
      15      1.0130E+02  -    1.6702E+02
      16      1.6702E+02  -    2.7537E+02
      17      2.7537E+02  -    4.5400E+02
      18      4.5400E+02  -    6.8871E+02
      19      6.8871E+02  -    1.0446E+03
      20      1.0446E+03  -    1.5846E+03
      21      1.5846E+03  -    2.3054E+03
      22      2.3054E+03  -    3.3546E+03
      23      3.3546E+03  -    4.8809E+03
      24      4.8809E+03  -    7.1018E+03
      25      7.1018E+03  -    1.0332E+04
      26      1.0332E+04  -    1.5034E+04
      27      1.5034E+04  -    2.1852E+04
      28      2.1852E+04  -    3.1828E+04
      29      3.1828E+04  -    5.2475E+04
      30      5.2475E+04  -    8.6517E+04
      31      8.6517E+04  -    1.2277E+05
      32      1.2277E+05  -    1.4996E+05
      33      1.4996E+05  -    1.8316E+05
      34      1.8316E+05  -    2.2371E+05
      35      2.2371E+05  -    2.7324E+05
      36      2.7324E+05  -    3.3373E+05
      37      3.3373E+05  -    4.0762E+05
      38      4.0762E+05  -    4.9787E+05
      39      4.9787E+05  -    6.0810E+05
      40      6.0810E+05  -    7.4274E+05
      41      7.4274E+05  -    8.2085E+05
      42      8.2085E+05  -    9.0718E+05
      43      9.0718E+05  -    1.0026E+06
      44      1.0026E+06  -    1.1080E+06
      45      1.1080E+06  -    1.2246E+06
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NEUTRON GROUP STRUCTURE (eV) (cont.)

46	1.2246E+06	-	1.3534E+06
47	1.3534E+06	-	1.4957E+06
48	1.4957E+06	-	1.6530E+06
49	1.6530E+06	-	1.8268E+06
50	1.8268E+06	-	2.0190E+06
51	2.0190E+06	-	2.2313E+06
52	2.2313E+06	-	2.4660E+06
53	2.4660E+06	-	2.7253E+06
54	2.7253E+06	-	3.0119E+06
55	3.0119E+06	-	3.3287E+06
56	3.3287E+06	-	3.6788E+06
57	3.6788E+06	-	4.0657E+06
58	4.0657E+06	-	4.4933E+06
59	4.4933E+06	-	4.9659E+06
60	4.9659E+06	-	5.4881E+06
61	5.4881E+06	-	6.0653E+06
62	6.0653E+06	-	6.7032E+06
63	6.7032E+06	-	7.4082E+06
64	7.4082E+06	-	8.1873E+06
65	8.1873E+06	-	9.0484E+06
66	9.0484E+06	-	1.0000E+07
67	1.0000E+07	-	1.1052E+07
68	1.1052E+07	-	1.2214E+07
69	1.2214E+07	-	1.3499E+07
70	1.3499E+07	-	1.4918E+07
71	1.4918E+07	-	1.7500E+07
72	1.7500E+07	-	1.9600E+07

Photon groups

PHOTON GROUP STRUCTURE (eV)

1	1.0000E+04	-	1.0000E+05
2	1.0000E+05	-	2.0000E+05
3	2.0000E+05	-	4.0000E+05
4	4.0000E+05	-	1.0000E+06
5	1.0000E+06	-	1.5000E+06
6	1.5000E+06	-	2.0000E+06
7	2.0000E+06	-	2.5000E+06
8	2.5000E+06	-	3.0000E+06
9	3.0000E+06	-	3.5000E+06
10	3.5000E+06	-	4.0000E+06
11	4.0000E+06	-	4.5000E+06
12	4.5000E+06	-	5.0000E+06
13	5.0000E+06	-	5.5000E+06
14	5.5000E+06	-	6.0000E+06
15	6.0000E+06	-	6.5000E+06
16	6.5000E+06	-	7.0000E+06
17	7.0000E+06	-	7.5000E+06
18	7.5000E+06	-	8.0000E+06
19	8.0000E+06	-	1.0000E+07
20	1.0000E+07	-	1.2000E+07
21	1.2000E+07	-	1.4000E+07
22	1.4000E+07	-	2.0000E+07

Weighting function

For the averaging of the data in the group library the VITAMIN-J weighting function has been adopted which includes, from low to high energies, a Maxwellian computed at

°*T*, a 1/E behaviour, a fission spectrum, 1/E again and finally a fusion peak at 14.7 MeV. The values of °*T* are the basic ones of the library (0, 87 and 293 °*K*).

A graph of the weighting functions is given below.

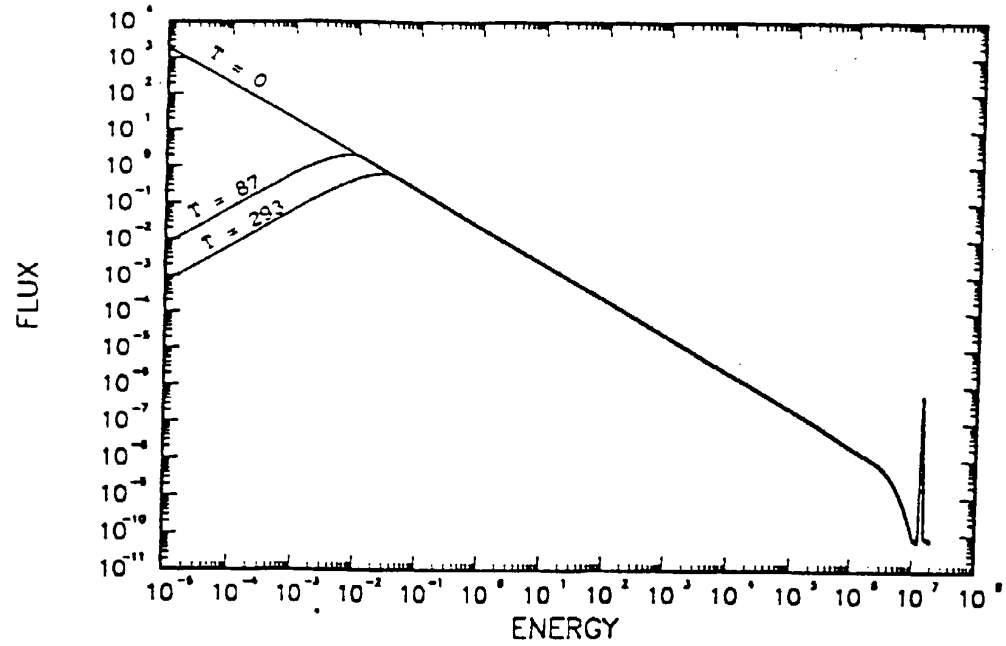

Figure 2. The adopted weighting functions.

Reactions included in the library

All reactions of the basic JEF 1.1 data base have been averaged over the group structure and included in the library. In addition the following quantities have been computed:

- the diffusion matrix which includes all reactions emitting neutrons as primary or secondary product, even with multiplicity factor (es.: (*n*,*n*) , (*n*,*n*′), (*n*,2*n*) , (*n*,*n*α), (*n*, α*n*) etc.);
- photon production matrix obtained from the reactions in which γ production can not be neglected (e.g.: (*n*, γ) and all reactions in which γ are emitted as secondary reaction product);
- kerma computed with the energy balance method.

Format of the library

The group library is built up by materials shared into 6 blocks (neutron + photon data times 3 temperatures); the DTF structure (ANISN format) has been adopted in the Fixed FIDO version: in the card image form this ensures the maximum portability.

All reaction cross sections plus kerma are put in the top positions of the DTF matrix as shown in the Table 3, so as the total cross section is in position 22.

Data of the diffusion matrix are *not* multiplied by the (2*l* + 1) factor.

Position	Contents
1	(n, n)
2	(n, n')
3	(n, 2n)
4	(n, 3n)
5	(n, fission)
6	(n, n α)
7	(n, 2n α)
8	(n, n p)
9	(n, γ)
10	(n, p)
11	(n, d)
12	(n, t)
13	(n, ^3_2He)
14	(n, α)
15	(n, 2α)
16	(n, 2p)
17	(n, pα)
18	(n, t 2α)
19	Neutron kerma
20	Absorption
21	ν -fission
22	Total
23	($g \rightarrow g$)

Table 3. : Positions in the DTF matrix

Neutron flux calculations

The calculations were performed using a "ad hoc" developed version of the code FLUKA (a CERN code used for any kind of radiation transport calculations), where the standard code, which is able to treat hadrons down to a few tens of MeV, has been coupled to a low energy transport module, modeled on the MORSE one, which is able to make use of the nuclear data set to follow neutrons down to thermal energies. The spectra clearly show the importance of the low energy neutron contribution to the total fluence (one has to take into account that the starting particles are the secondary ones resulting from p-p collisions at 16 TeV c.m. energy in the middle of the detector).

A special version of the Monte-Carlo code FLUKA has been developed to study the low energy neutron distributions in detectors proposed for the new generation of hadron colliders. At energies of less than 50 MeV use has been made of group libraries: the influence of the LAr temperature on effective neutron cross-section and on resonance widths at low energies has been taken into account.

Three main topics have been investigated:

- Code benchmarking
- Comparison with previous estimates of neutron fluence in collider detectors based on simple models
- Calculations in "real" detector geometries

The first topic will be discussed elsewhere: to date, all comparisons with experimental data have confirmed the accuracy of the code.

Concerning the second topic it is only important to note that actual simulations predict neutron fluences up to a factor ten larger in the low rapidity regions than previously estimated /2,3/. The reason of this effect have been extensively investigated and are believed to rely on a larger albedo fluence (recent experimental measurements also suggest a factor of two increase in the albedo and maximum neutron fluences) than the one used in the SSC Task Group report /2/ and subsequent work for the LHC, and in the effect of neutron multiple scatterings inside the central cavity.

Finally neutron fluxes have been investigated in a detector geometry illustrated in fig. 1 which represents a realistic guess for a LHC detector. Fluxes have been scored at 17 surfaces (shown in fig. 1) around the detector at different depths and rapidities.

Four different combinations of materials were used (the EM calorimeter was always assumed to be of Pb-LAr, 46 cm thick):

- a Pb-LAr hadronic calorimeter
- a Fe-LAr hadronic calorimeter
- a Pb-LAr hadronic calorimeter with 10 cm of polyethylene moderator between the silicon preshower detectors and the EM calorimeter
- a Fe-LAr hadronic calorimeter with 10 cm of polyethylene moderator between the silicon preshower detectors and the EM calorimeter

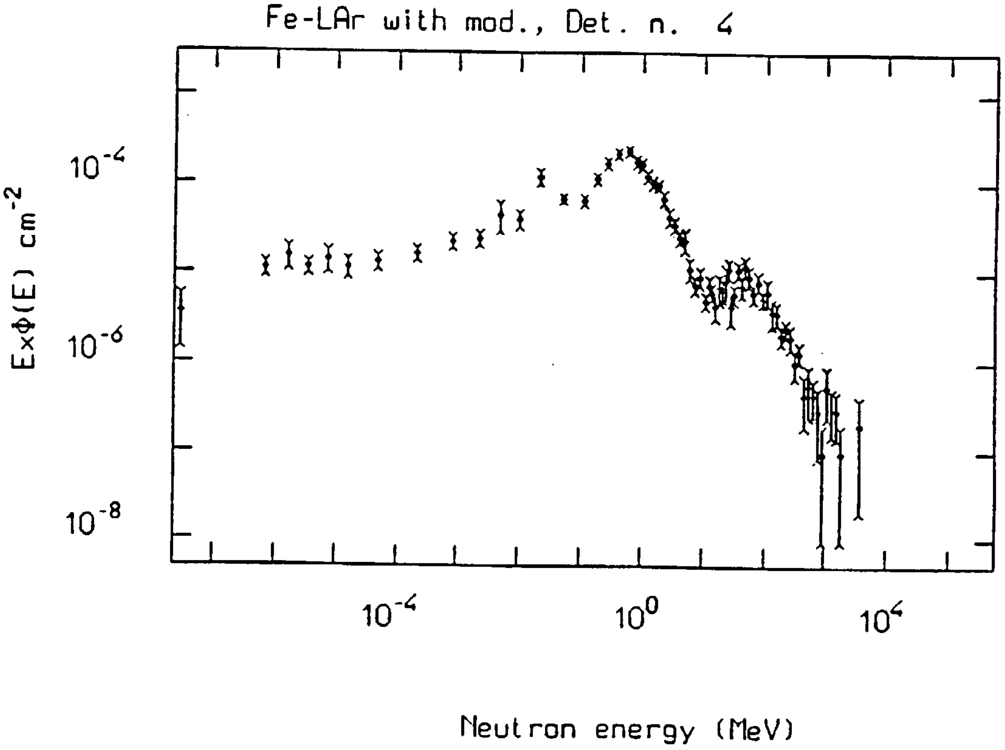

Figure 3. The neutron spectra at position 4 with moderator.

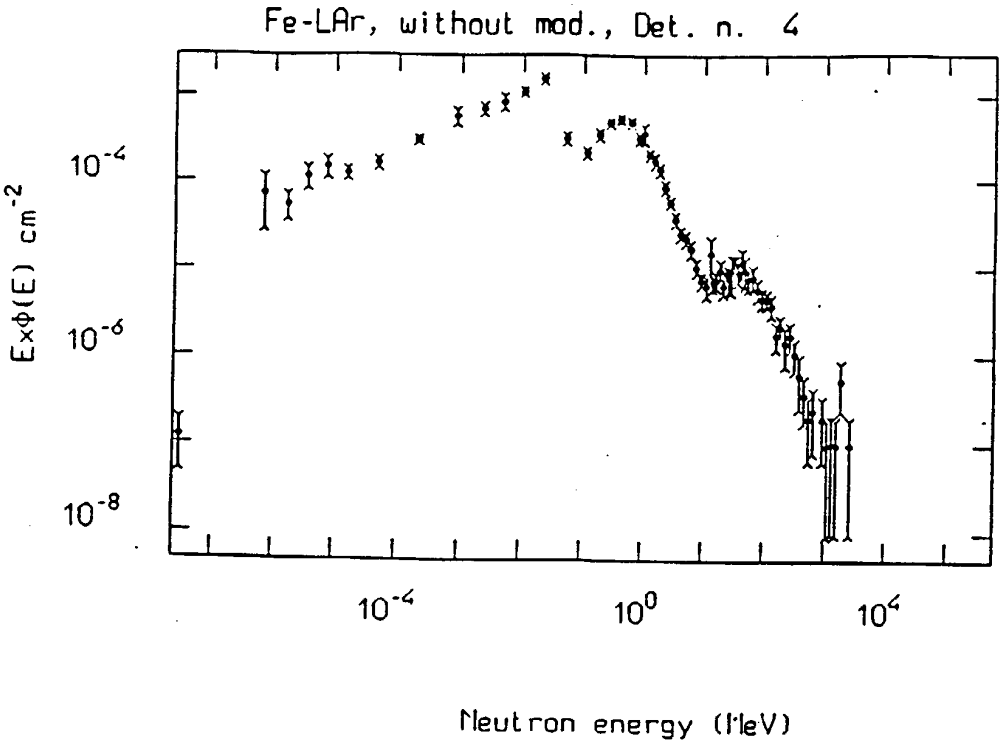

Figure 4. The neutron spectra at position 4 without moderator.

In figs. 3 and 4 the neutron spectra at position 4 of fig. 1 are shown for a Fe-LAr hadronic calorimeter with and without the moderator (note that they are normalized to one event): spectra scored in different positions look like very similar, so these two are representative of all.

References

1. R.E.MacFarlane, D.W.Muir and R.M.Boicourt, "The NJOY Nuclear Data Processing System" - LA-9303-M (ENDF-324) (1987)
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