Analysis of Benchmark 2 Results[1]

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Abstract

The code GEANT315 has been compared to different codes in two benchmarks. We analyze its performances through our results, especially in the thick target case. In spite of gaps in nucleus-nucleus interaction theories at intermediate energies, benchmarks allow possible improvements of physical models used in our codes. Thereafter, a scheme of radioactive waste burning system is studied.

Analyse des résultats des benchmarks[1]

Résumé

Le code GEANT315 a été confronté à différents codes au cours de deux intercomparaisons de codes. Nous analysons ses performances à travers nos résultats, en particulier dans le cas de la cible épaisse. Malgré les lacunes des théories d'interaction noyau-noyau aux énergies intermédiaires, les intercomparaisons de codes nous indiquent des améliorations possibles aux modèles physiques utilisés dans nos codes. Nous étudions ensuite un schéma de système d'incinération des déchets nucléaires.

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1. Introduction

Neutron leakage out of a thick target (made of lead or tungsten) has been simulated for 800 MeV incident protons with the code GEANT 315 from CERN. GHEISHA[2] and FLUKA[3] interfaces have been used to describe hadronic collisions. The hardware part consists of a parallel computer, a T-Node. Its working set is divided into one "master" and 64 "slave" transputers. The global power is around 100 Mflops.

1.1 Parallelised GEANT Code

GEANT 315, result of the work of many international teams of physicists, has been created for the high energy physics needs. It was aimed at the simulation of fundamental physical processes (event generators), simulation of detectors, event reconstruction and analysis. The main method is based on Monte-Carlo calculations. Presently GEANT 315 with EGS, GHEISHA and FLUKA interfaces includes 250.000 lines (Fluka interface only: 50.000 lines). The interest of these benchmarks is the validity test of a large code, used by many laboratories although its use would be preferentially in the energy range from 1 to 100 GeV. However the limitations of detectors take into account reactions in lower energy ranges.

The hadronic collisions are processed (for neutrons) by GHEISHA below a threshold of 50 MeV and by FLUKA beyond this value in the frame of GEANT 3.15. After the two benchmarks, another code created by B.Lefièvre, has been added for the tracking of thermal neutrons.

The main physical models in GHEISHA are the INC (intra-nuclear cascade), evaporation model and fission; elastic and inelastic scattering, neutronic capture and nuclear fission i.e. generation of photons and neutrons, neutron spectrum, emission time for neutrons and photons, are processed.

The calculations of total and partial cross sections are not implemented with only one method. Sometimes, they are tabulated, or calculated with some parameters, with a semi-empirical relation or with a MC simulation.

FLUKA produces cross section calculations and generation of secondary particles from elastic and inelastic reactions. From 50 MeV to 5 GeV, FLUKA uses experimental or interpolated cross sections and the resonance production model. Between 5 GeV and 10 TeV, the multistrings fragmentation model is the reference.

Another FLUKA code exists independently of the FLUKA interface of GEANT. It has been developed by the INFN (Milano).

GEANT has been parallelised -by event-, because of the easiness of implementation, the saving of time and the fact that the modification of code is insignificant for the parallelisation.

The initialisations are carried out by the master, results are sent from the slaves to the master.

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[2] Gamma-Hadron-Electron-Interaction Shower Code

[3] Fluctuating Kascade

1.2 Difficulties with the thick target simulation

The knowledge of the practical reference system could bring a better understanding of the system geometry (meshes) to the benchmark participants.

The beam thickness parameter can be taken into account for later benchmarks because this factor seems to be important for neutron production distribution.

In order to confirm accuracy, neutron leakage distribution has been calculated for all surfaces of each mesh. The sum of neutron leakage on the external surface is equal to the neutron leakage over the whole target.

With the geometrical shape of the second benchmark, double counting of neutrons is unavoidable because of the multiple scattering of particles between the internal meshes. Table 1. shows the double counting rate, firstly for lead target bombarded with 10^6 incident protons, secondly for lead target bombarded with 10^5 incident protons and the use of Lefièvre's thermal neutrons code and thirdly for a tungsten target bombarded with 10^6 incident protons. The rate includes the number of neutron double counting per number of neutron leakage on all over a mesh.

1.3 Limitations of GEANT code

Energy limits of GEANT at low energy like a few MeV are problematic. The neutron transport code needs improvements for energies near thermal threshold.

Thermal and fast fission are described in GHEISHA with some over-simplification of the phenomena. The spallation and fission product distribution lacks in our code.

To simulate the neutron flux (number of neutrons per second and cm^2), the emission time of neutrons was needed. But all of our simulations depend only on neutron number per cm^2 without any time reference, although neutron emission time is a parameter in GEANT. Neutron production time represents a real problem only in a pulsed beam case.

Neutron production time is evaluated to a few ns; GEANT does not provide for delayed neutrons.

In the benchmark 1 case, neutron production on a lead target for 25 MeV and 45 MeV incident protons, was insignificant with GEANT whereas other codes were simulating higher values. Another difficulty is the neutron emission into the angle of 25^o for 80 MeV and 160 MeV incident protons and the neutron emission into the angle of 0^o for 160 MeV incident protons. GEANT behaves better at higher energies like 800 MeV than near 10-20 MeV. Among many results of benchmark 1, best results are probably due to codes including preequilibrium, intranuclear cascade and evaporation.

In the benchmark 2 case, the GEANT simulation curve for the neutron yield spectra below 20 MeV is located under other code simulations curves. Neutron production has been underestimated mainly because of thermal neutron transport failures and because of the previous reason. The curve dispersion is rather high. Above 20 MeV, the description of neutron yield spectra by GEANT is less scattered. Two groups of curves represent the spectra. GEANT belongs to the lowest group (cf. Figure 1.). Intermediate energy data, from several MeV to 1 GeV, such as cross section reactions are rather badly known. However, GEANT is used for most of CERN experiments, and for detector design -for which it is significant to be sure of the physical knowledge of phenomena at a few GeV

and below.
Back scattered neutrons have been studied as they go out in front of the target, pass through the window and enter in the accelerator cavity. Figure 2. indicates the number of back scattering neutrons per cm^2 and 10^6 incident protons versus the neutron energy in MeV for meshes number 1, 2, 3, 4. (lead target).
Difficulties in understanding FLUKA parameters and the algorithm have to be noticed because the FLUKA interface does not have any comments or any directions for use.

2. Proposals

2.1 Improvements on the GEANT code

After the two benchmarks and the use of Lefièvre's code use for thermal neutrons, the fission simulations in a light water reactor begins to be compared with experimental data.
Changing interpolated cross sections with experimental cross sections could be a first improvement for the description of collision reactions.
The comparison with other codes (benchmark 1) induces to add the preequilibrium model to the physical model of GEANT codes. A realistic description of the fission neutron spectrum, a better thermal fission code including a more accurate time parameter (6 delayed neutron groups), seems to contribute to better results.
Mass distribution, sequels of spallation and fission reactions, has to be integrated into our codes in order to get the radioactive balance.

2.2 Proposals of a new hybrid system

The first stage of our research is to start from a light water reactor and to see what happens if an energetic proton flux enters inside it.
During benchmark 2, the problem of back-scattered neutrons produced particularly by the heavy target (and by the walls of the vessel, by the window if we consider it also in the simulated system) has been highlighted.
The accelerator-reactor interface appears to pose problems because of the heat deposited by incident particles, of the metallical damages (broken nuclei), of the pressure difference inside the reactor and outside, the neutron absorption. One such example, illustrated by Figure 3., shows the design of the proposed system. Simulations have been processed for 1 GeV, 20 GeV and 40 GeV incident protons colliding with a small light water reactor (1 meter radius) working with U235-U238 fuel rods. The energy loss per GeV of incident beam in the window decreases with the increase of incident energy. For 1 GeV protons, 67.8 MeV are layed in the window (5 cm thickness); for 20 GeV protons, 9.5 MeV, for 40 GeV protons, 6.8 MeV. Fission reactions expand better in the core with a higher incident energy.
The aim of these simulations is to achieve some results which could answer to our questions on the nuclear waste reactor feasibility . Different parameters like the U235 enrichment, the neutron life time, the incident proton energy, the presence of a steel window or just a hole in the vessel through which protons are going, the use of incident neutrons for initiating the chain reaction are the main axes of simulation.

Reactor simulations begin with 200 incident protons on a natural uranium core (the fission neutron number $\nu = 2.5$) at 20°C. Doppler effects on the efficiency of capture cross sections will not be studied for our present simulations. In table 2., neutron fission production are mentioned for 1 GeV protons (without or with a window in the vessel) and for 20 GeV protons (with a window). Expected accuracy of these simulations is evaluated approximately to 20%. A decay factor 1.8 in the fission neutron production with 1 GeV protons between the simulations - with a window and without a window - implicates the significant rule of the window for waste burning systems. An increase by 37.5 (instead of the expected value 20) between neutron fission production with 1 GeV and 20 GeV protons, with a window, indicates that the window problem is less important when proton energy rises. The window heating decreases relatively with the increase of the reactor power.

Figure 4. shows the core geometry (in arbitrary units) of the simulated light water reactor in which fission reactions spread. A study of the distribution of the hadronic shower in the core is illustrated in Figure 5. A distribution peak is easily perceptible. It seems to be a disavantage and can provoke difficulties for neutron managing. The penetration length mean with 20 GeV incident protons (with a window) is about 18cm more in the core than with 1 GeV incident protons (with a window) and 10.7cm more in the core than with 1 GeV incident protons (without a window). Neutrons can be tracked in space and time. Simulations have been done with 1000 neutrons (10 MeV incident energy) directly created in the core. Figure 6. describes the divergence time development for an overcritical system and Figure 7. reminds of the geometry of benchmark 2 target.

3. Conclusion

Participation to the benchmarks allowed us to test the validity of a well-known code. One notices that neutron production from hadronic collisions are often underestimated at low energies (below 20 MeV). The most significant results that can be expected from a new hybrid system simulations are actually only qualitative; however studies of energetic proton incident beam seems to be a research option. The authors are deeply grateful to Professor M.Froissart for his interest and support. We would like to thank X.Tarrago and J.Vergnes for their help and advice, A.Jejcic for his stimulating discussion and F.Tembely for her assistance.

References

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[2] *Fesefeldt H.*, GHEISHA, the Simulation of Hadronic Showers -Physics and Applications - PITHA 85/02 (1985)

[3] *Ranft J. et al.*, Preprint Fluka (1993)

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mesh number	4	7	9	11	12	13
lead target	3.37	5.61	8.69	11.65	4.21	1.61
lead target + t.c.	9.87	31.91	33.16	39.31	25.33	4.50
tungsten target	13.2	21.9	31.52	38.66	18.66	9.96

Table 1. **Double counting rates (percents)**

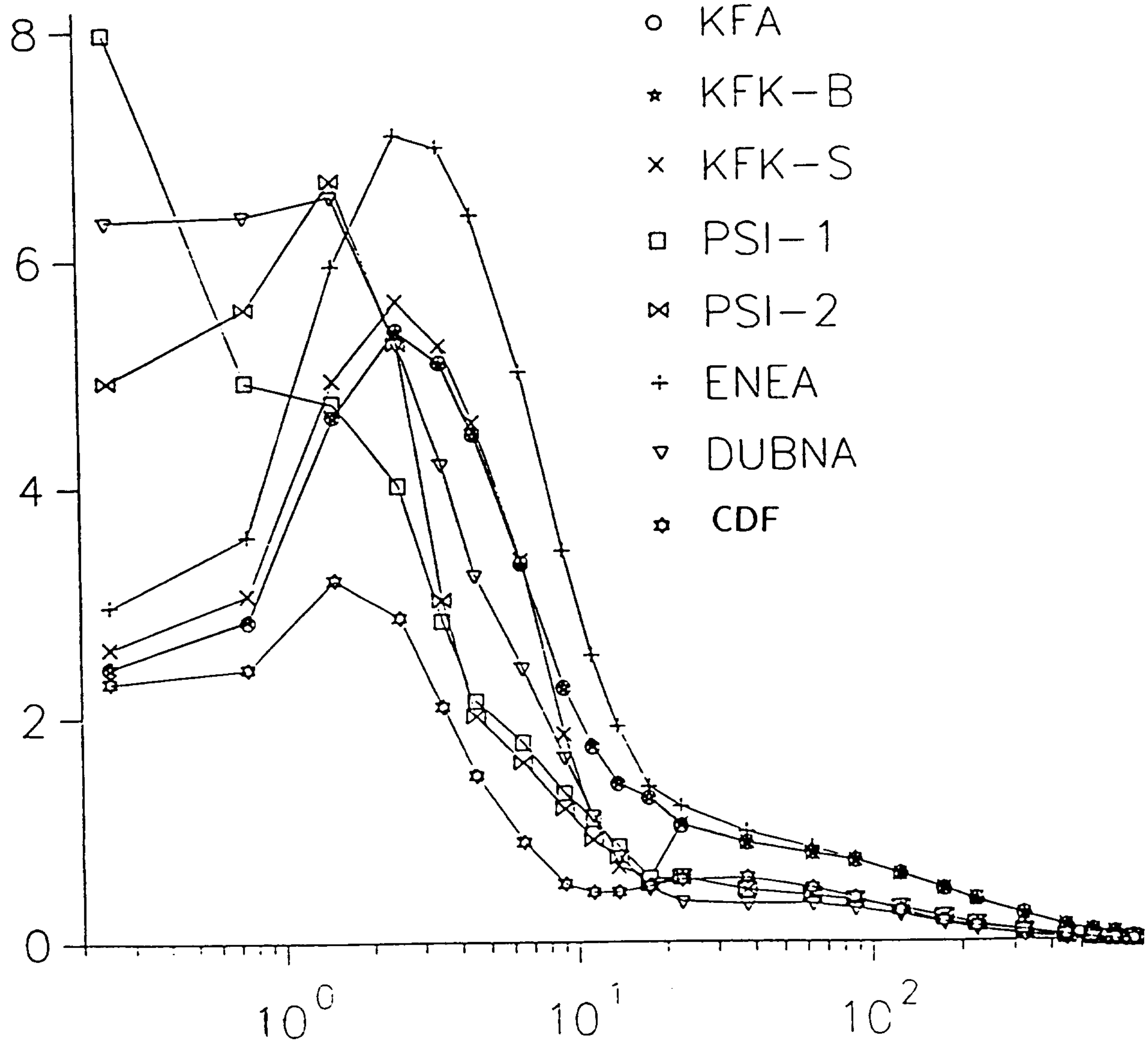


Figure 1. **Total neutron yield spectra (benchmark 2),** GEANT code –> CDF

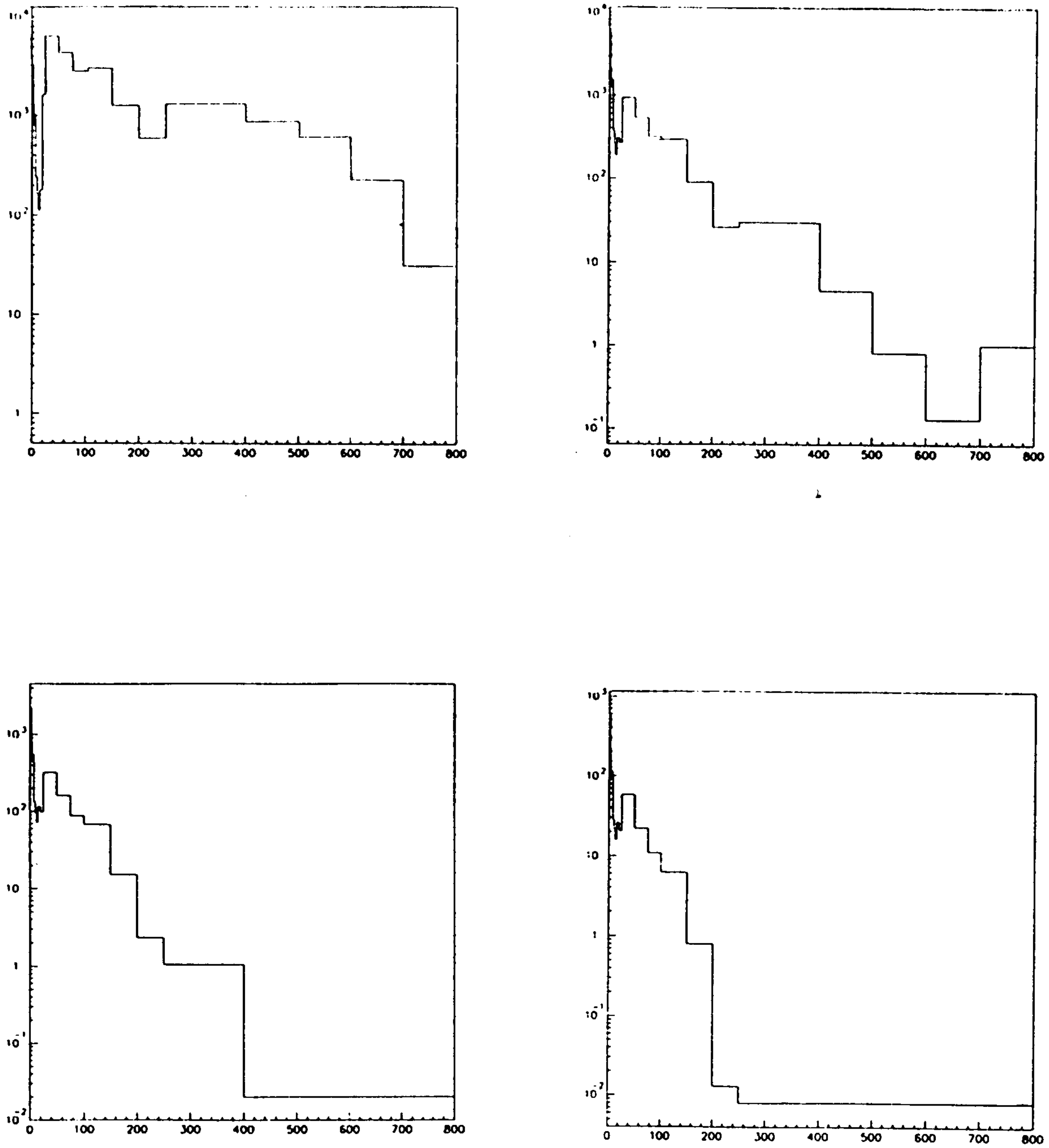


Figure 2. **neutron flux back out of the front side (Pb target and mesh number 1, 2, 3, 4)**

proton energy	1 GeV	20 GeV
with window	14523	298354
without window	7957	353084

Table 2. **Fission neutron production in the core**

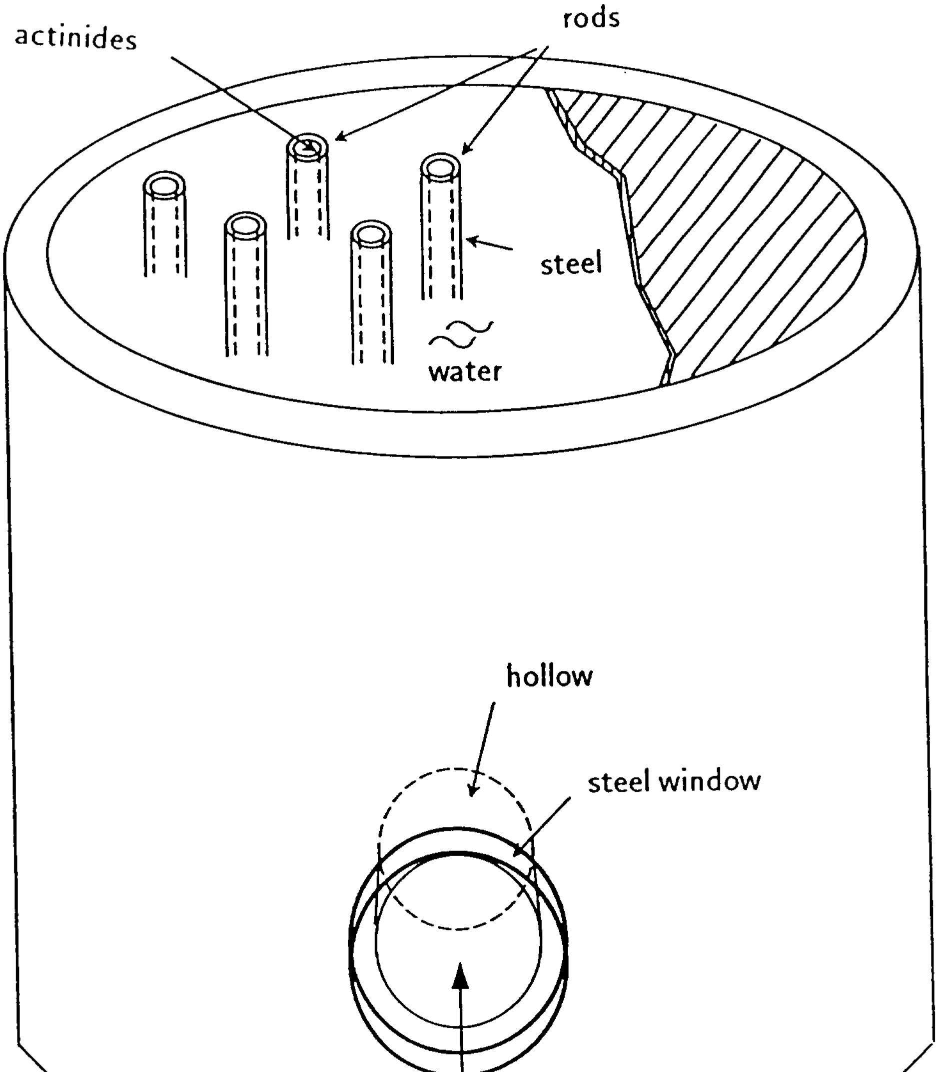


Figure 3. Draft of a nuclear waste burning system

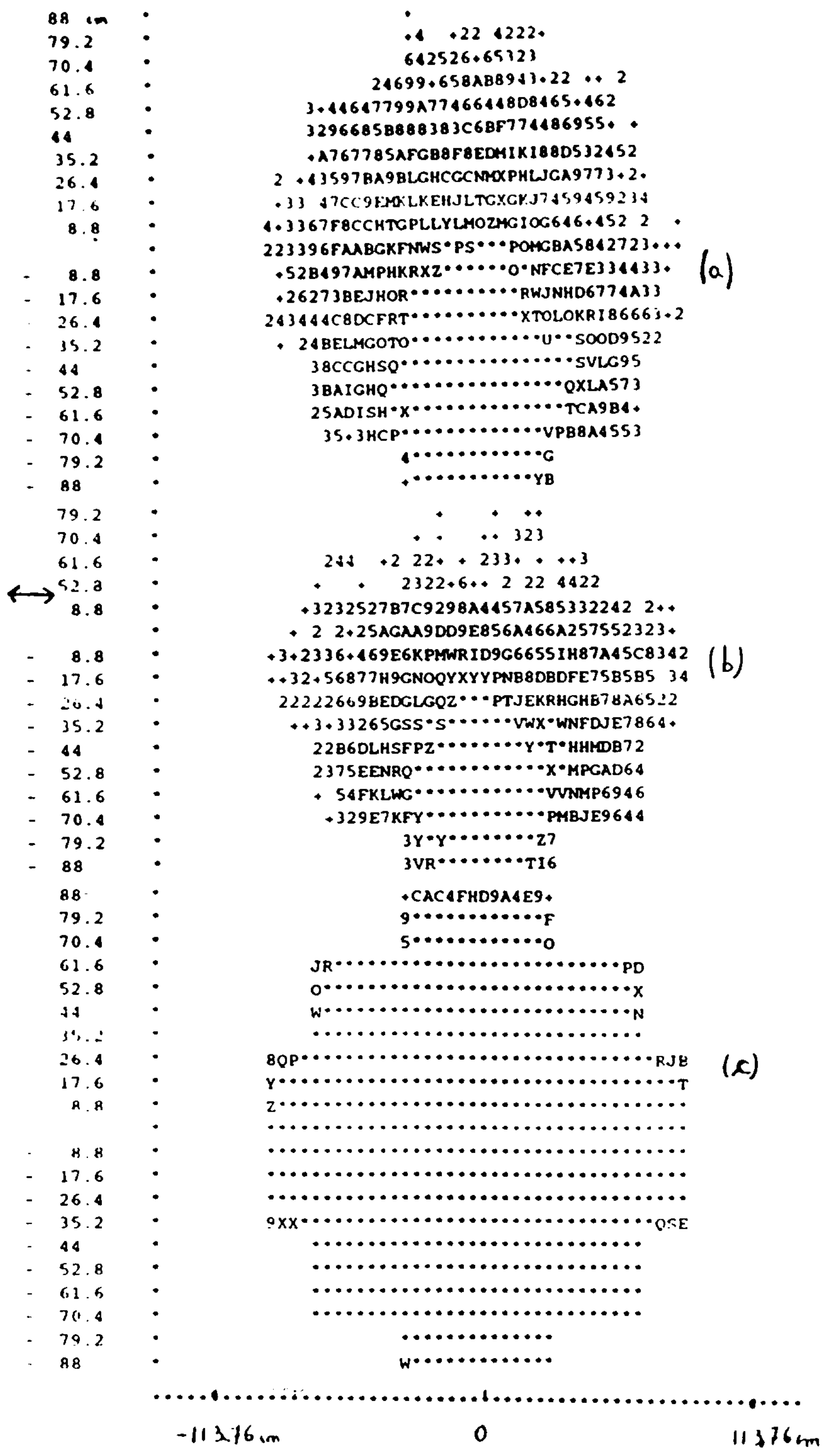
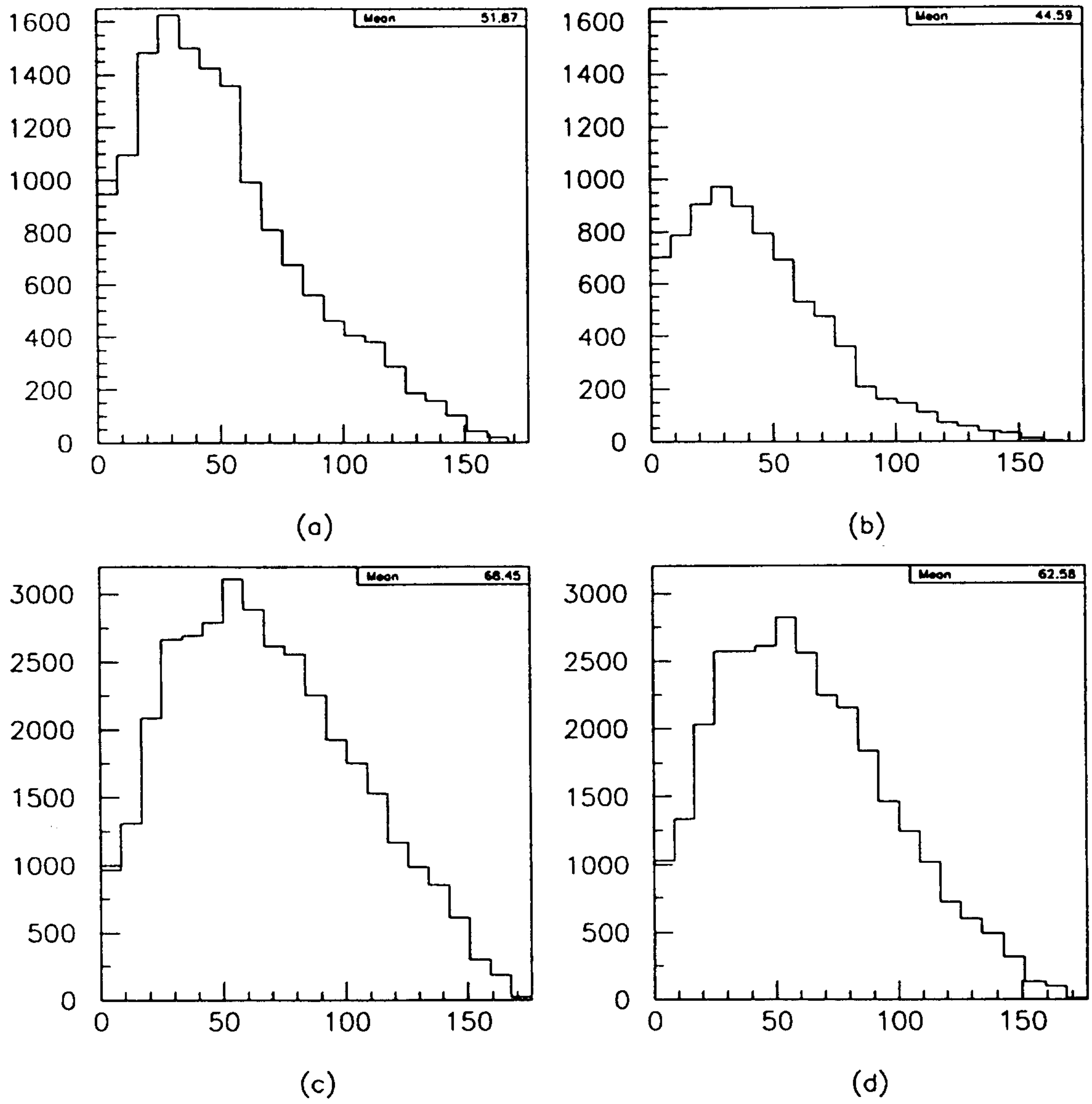


Figure 4. Fission distribution (see the * symbol) in the core with the window; (a) 1 GeV, without a window; (b) 1 GeV, with a window; (c) 20 GeV, with a window. (OX and OY represent the core geometry, OZ the intensity of fission distribution.)



(a) (b) (c) (d)

Figure 5. **Penetration of the hadronic shower; (a) 1 GeV, without a window;(b) 1 GeV, with a window; (c) 20 GeV, without a window, (d) 20 GeV, with a window. (OX represents the core length, OY, the number of neutrons produced in the shower by fission reactions.)**

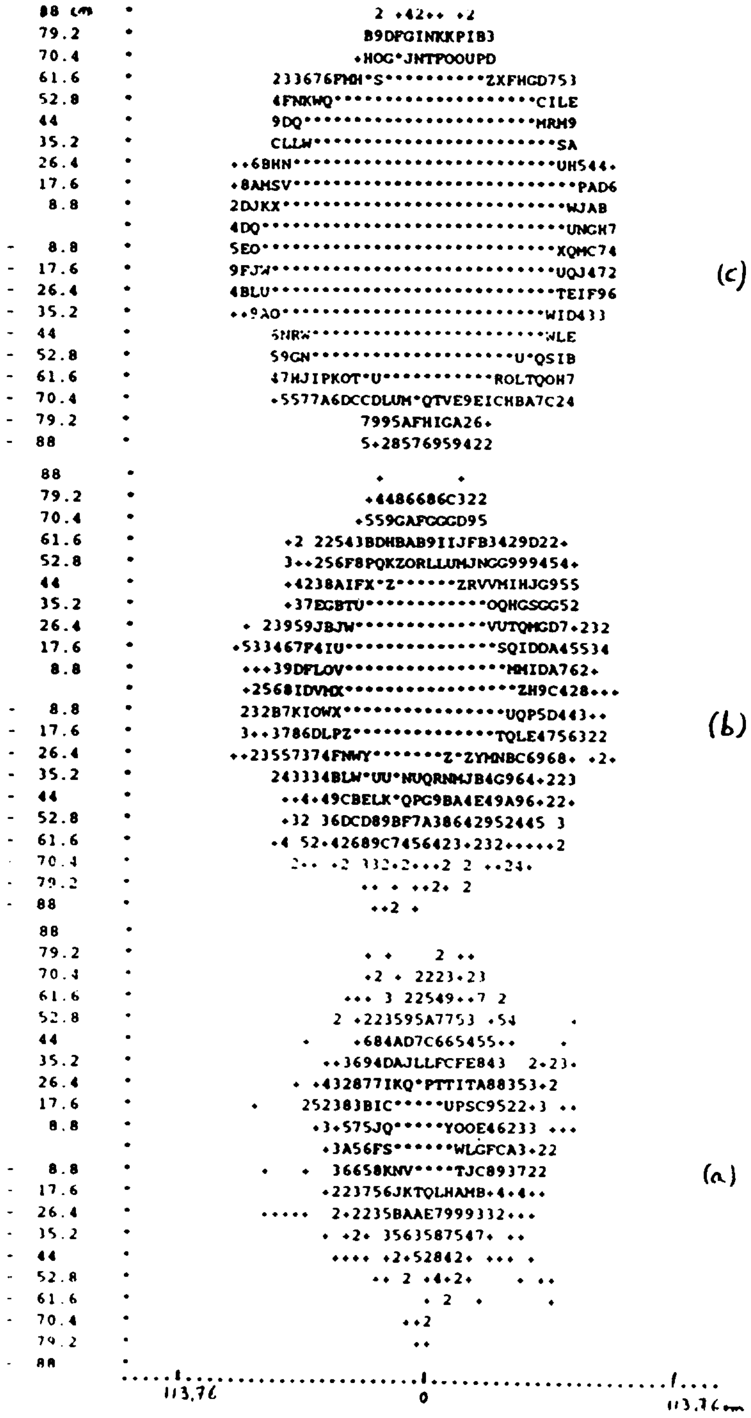


Figure 6. Fission expansion with time; (a) t= 10^{-4}s ,(b) t= 2. 10^{-4}s, (c) t=3. 10^{-4}s.

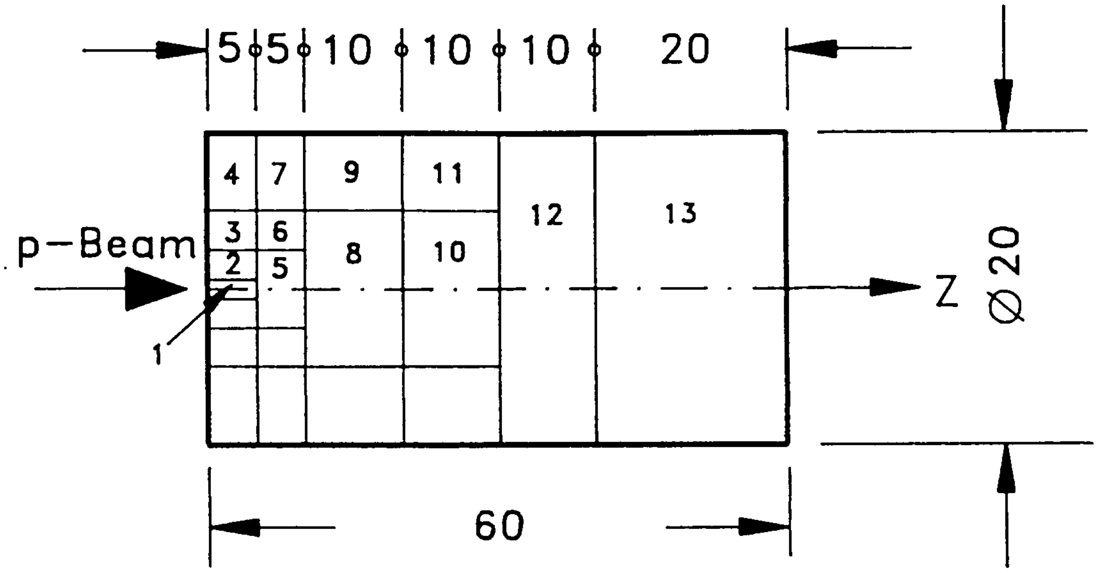


Figure 7. Geometry of benchmark 2 target