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NUCLEAR ASPECTS OF THE SNQ TARGET DESIGN

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Very detailed nuclear aspects for the SNQ target-moderator-reflector systems were studied for engineering and safety purposes. In this paper only some important aspects are shown. For further details see Ref. /1/.

Computational Models and Methods

The latest state of the art of radiation transport codes and methods treating the various types of interaction mechanisms were further developed and now in such a state that very sophisticated and detailed nuclear aspects can be considered. The scheme of performance with the capabilities is given in Figure 1. The most advanced Monte Carlo codes like a special version of the high energy transport code HETC-KFA and MORSE are running on KFA's CRAY-XMP. 3-D computer models of the SNQ target-moderator-reflector system for the calculations were used taking into account all necessary material and geometrical conditions /2/. A vertical cut is shown in Figure 2.

Energy Deposition for SNQ Targets

Spatial dependent energy deposition calculations in fine radial and axial mesh intervalls for tungsten and uranium target systems were performed to assist in designing cooling circuits and thermal cycling calculations. In Figure 3 a horizontal and vertical cut of the mesh grid is given. In Table 1 and 2 the total energy deposition and the peak energy deposition for 1100 MeV proton beam energy for a SNQ tungsten and uranium targets are given. Figure 4 shows the depth dependent energy deposition in the target wheel for two radial intervalls (radius = 0.0 - 1.0 cm and radius = 1.0 - 2.5 cm) about the proton beam axis.

Table 1: Total energy deposition in target for 1100 MeV proton beam energy

	Deposition Power MeV per Proton		Total Power
	High Energy $E > 15$ MeV	Low Energy $E \leqq 15$ MeV	MW per 5 mA
U_{dep}-Target	945	1263	11.4
W-Target	620	65	3.4

Table 2: Peak* energy deposition in target for 1100 MeV proton beam energy

	Deposition Power MeV per Proton		Total Peek Deposition
	High Energy $E > 15$ MeV	Low Energy $E \leqq 15$ MeV	kJ/cm^3 per pulse**
U_{dep}-Target	2.62	0.73	0.168
W-Target	2.04	5.0×10^{-2}	0.105

* for radial intervall about beam axis $r = 1.0$ cm

** assumed $\hat{I} = 200$ mA, pulse width 250 μs pulse frequency 100 s^{-1}

Induced Radioactivity and Afterheat Production of Uranium Target Wheel

A detailed procedure to calculate in a spallation facility the time behaviour of radioactivity, thermal power, nuclide numbers etc. caused by a proton beam on a uranium target has been developed /3/.

All calculations were performed for the target area of the SNQ. This means that the target wheel contains depleted uranium, that the proton beam energy is 1100 MeV, and that the beam current is 5 mA. The geometry of the target station - consisting of target wheel, D_2O-tank, neutron beam tubes, moderators etc. - used for the Monte-Carlo-calculations is described above.

For the calculations of the nuclide generation and depletion the codes ORIGEN /4/ and ORIHET /5/ were used. Only the geometry of the wheel is of interest. The model for this target wheel is shown in Fig. 5. It can be seen that the active target zone has a height of 10 cm and a depth of about 40 cm. In Fig. 5 this zone is described by the regions 1 to 4. It should be mentioned that the active target zone consists of uranium pins with aluminum cladding. These pins have got diameters from 1.824 cm up to 2.4 cm. The pins are surrounded by the cooling water. In the calculations the uranium, the aluminum, and the water are described as one homogeneous mixture of the target region /3/.

For the SNQ target wheel an irradiation time of two years is proposed with two operation periods of about 6000 hours. The calculations were performed assuming 12000 hours of operation without any shutdown of the beam. This procedure leads to the highest possible values of radioactivity and of afterheat production. The results are separately given for the products arising from spallation effects, i.e. calculated by code HETC, and those arising from the neutron flux with neutron energies less than 15 MeV, i.e. calculated by code MORSE.

Integral results after 1200 hours at operation are given in Table 3 and zone dependent results after 1200 hours of operation are given in Table 4. From Table 3 the total amount of radioactivity for t=0 is 45.1 MCi, where 7.5 MCi stem from spallation and 37.6 MCi from neutron flux and here 22.5 MCi from the chain ^{239}U - ^{239}Np - ^{239}Pu. The time behaviour of radioactivity is shown in Fig. 6 for spallation, for neutron flux, and for total. It can be seen that one day after shut down of the beam the sum is decreased to 12.6 MCi.

Table 3: Integral results after 12000 hours of operation

Radioactivity total	: 45.1	MCi
- caused by spallation	: 7.5	MCi
- caused by neutrons $E_n < 15$ MeV	: 37.6	MCi
- maximum per target pin	: 21	kCi
Afterheat total	: 415	kWatts
- caused by spallation	: 120	kWatts
- caused by neutrons	: 295	kWatts
- maximum per target pin	: 0.19	kWatts
Gaseous products		
- total amount	: 3.42	g-atoms
- maximum per target pin	: 1.6×10^{-3}	g-atoms

Maximum thermal power (after heat) is 415 kW, were 120 kW stem from spallation and 295 kW from the neutron flux. The time behaviour of the thermal power for spallation reactions, for the neutron flux reactions, and for the total thermal power is shown in Fig. 7. From this figure it can be seen that the total thermal power after 1 day (10^5 sec) is decreased to 49 kW.

From Table 4 it can be seen that in region 2, i.e. about 8 cm inside the target wheel, we find the maxima of the densities of thermal power, radioactivity, and gas amount. Now we can roughly estimate the maximum amounts per pin.

Table 4: Zone dependent results (zones 1-4) after 12000 hours of operation

	Target region number			
	1	2	3	4
Thermal power (kW)	15.50	133.00	228.00	38.50
Thermal power density (W/cm^3)	1.60	2.10	1.70	0.90
Activity (MCi)	1.68	14.40	24.80	4.20
Activity density (Ci/cm^3)	171.00	229.00	185.00	92.80
Gas amount (g-atoms)	0.13	1.09	1.88	0.32
Gas amount density (10^{-5} g-atoms/cm^3)	1.30	1.73	1.40	0.70

It should be emphasized once more that all results given here do not take into account the influence of cladding material (aluminum) and of the cooling water because of lack of data in the libraries of the code ORIHET.

Calculation of the Time Dependent Dose Rate of the SNQ-Target Cooling Water for Radiolysis Considerations

The irradiation history of the SNQ-target wheel cooling water is due to the motion through the radiation field in azimutal direction by the spinning of the target wheel and radially by the flow of water from the axle to the circumference and back. For the calculational procedure the wheel was azimutally divided into 200 sectors corresponding each to a time interval of 0.01 s or one proton beam pulse.

The flow path can be described by a sequence of meshes. The 200 different partial flows are described simply by rotating the azimutal indices of that mesh sequence. The turn around time of the water flow from entering the wheel into a certain sector and appearing at the outlet within an other sector is 0.56 s or exactly 56 in terms of proton pulses. In Figure 8 the mesh grid and the water flow path through the mesh grid is shown.

The necessary nuclear calculations were performed using the HETC-KFA-1 code and the evaluation code SIMPEL for the radiation energy region above 15 MeV /1/. At low energies (up to 15 MeV) MORSE was run for neutrons and gammas using the 100 neutron and 21 gamma group cross section library EPR /6/. Calculations of stopping powers were performed by the SPAR code /7/. In Table 5 the total deposition powers of different radiation types are given.

Table 5: Total deposition power of different radiation types

type of radiation	total average deposition power	energy range
neutrons	110 kW	0.41 eV - 15 MeV
γ-rays	30 kW	0 - 14 MeV
protons	68 kW	0 - 1100 MeV
*pions	2 kW	15 - 400 MeV
heavy ions	3 kW	all energies
all radiation	213 kW	

In Figure 9 the energy deposition power of neutrons are given as an example in the sectors 156-165. This is the situation when the partial flow goes through the primary proton beam near the target circumference. Figure 10 shows the averaged deposition power for neutrons over all sectors. All power deposition curves of all particle types are fed into the

FACSIMILE code in order to obtain time dependent densities of radiolysis products. This has been done by W.G. Burns, Harwell. A report about the details of these calculations will be published /8/. Figure 11 shows as an example the H_2 concentration in Mol per litre.

References

/1/ Physics for Relevant SNQ Target Systems
To be published as Jül-Report

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Proceedings ICANS-VII, 1983 Chalk River,
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/3/ H. Schaal, G. Sterzenbach
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/4/ V.J. Bell
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/5/ F. Atchison
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/6/ EPR data Package, RSIC Data Library Collection
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/7/ T.W. Armstrong, K.C. Chandler
ORNL-RSIC-228 (1973)

/8/ W.G. Burns et al.
To be published

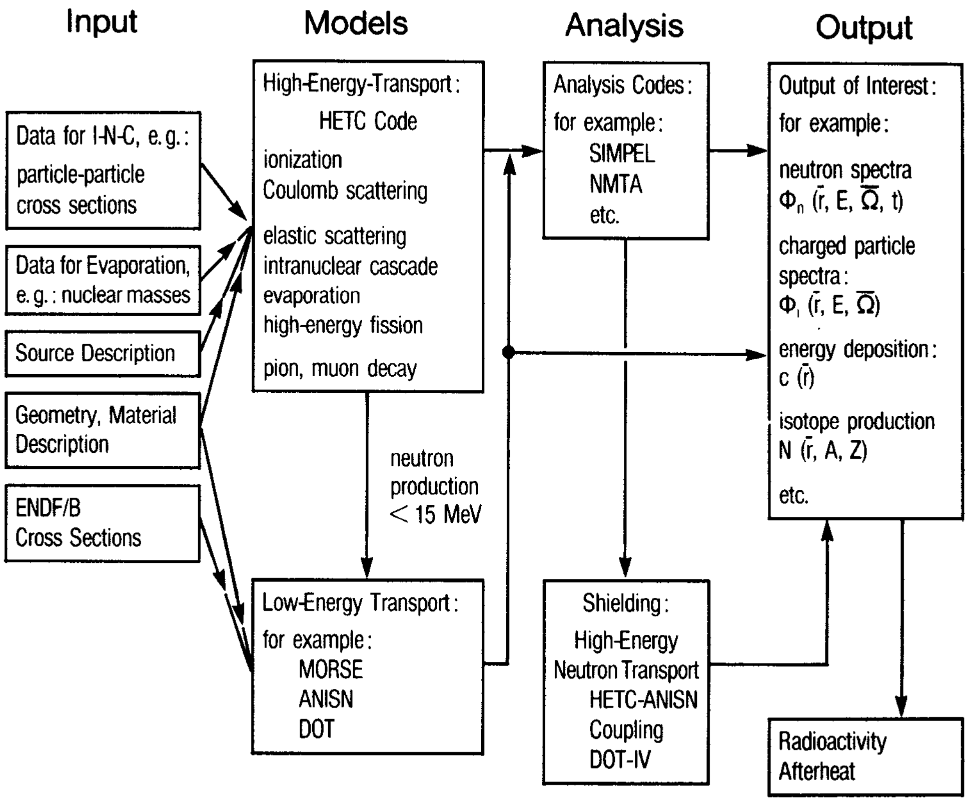


Fig. 1: Scheme of performance of radiation transport codes

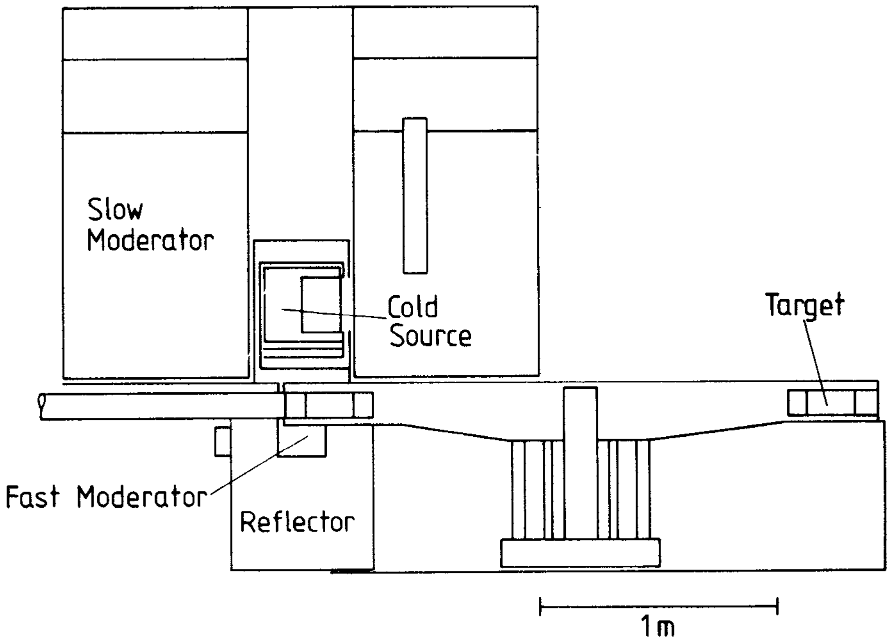
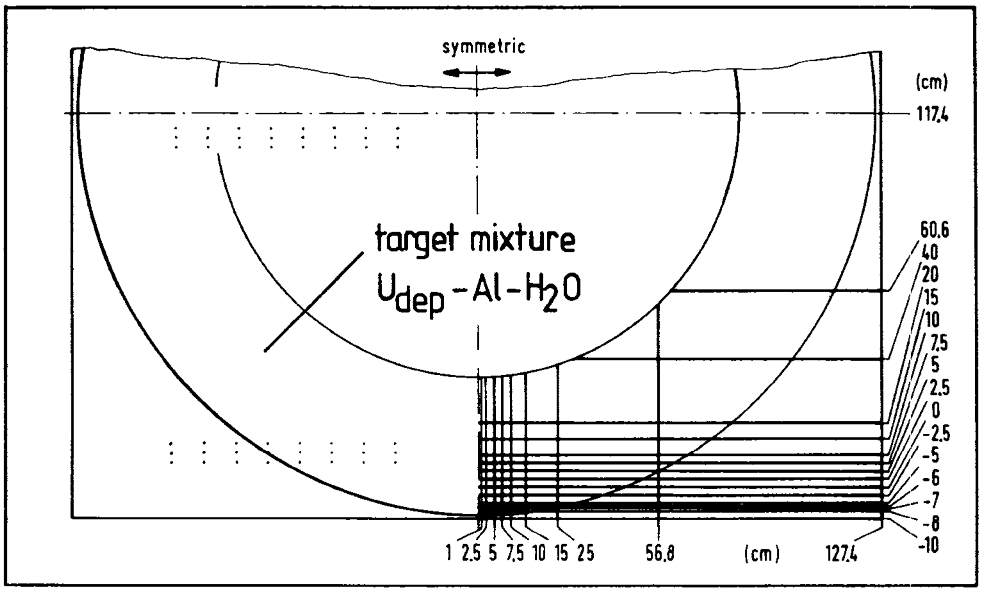
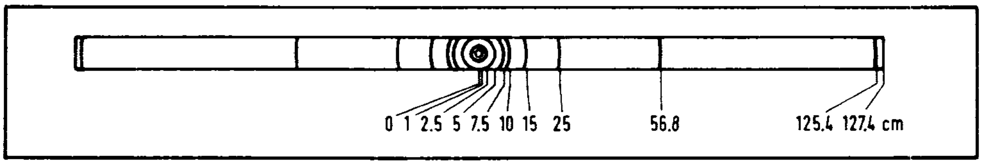


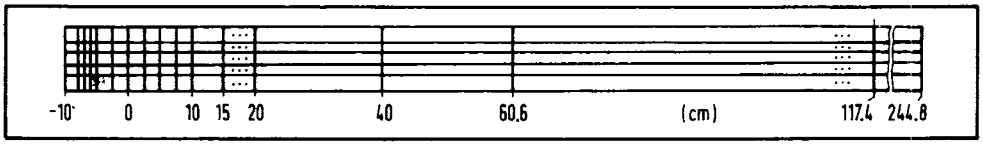
Fig. 2: Vertical cut of target-moderator-reflector-system



Horizontal cut



Vertical cut perpendicular to proton beam



Vertical cut in beam direction

Fig. 3: Mesh grid of the target for spatial energy deposition calculations

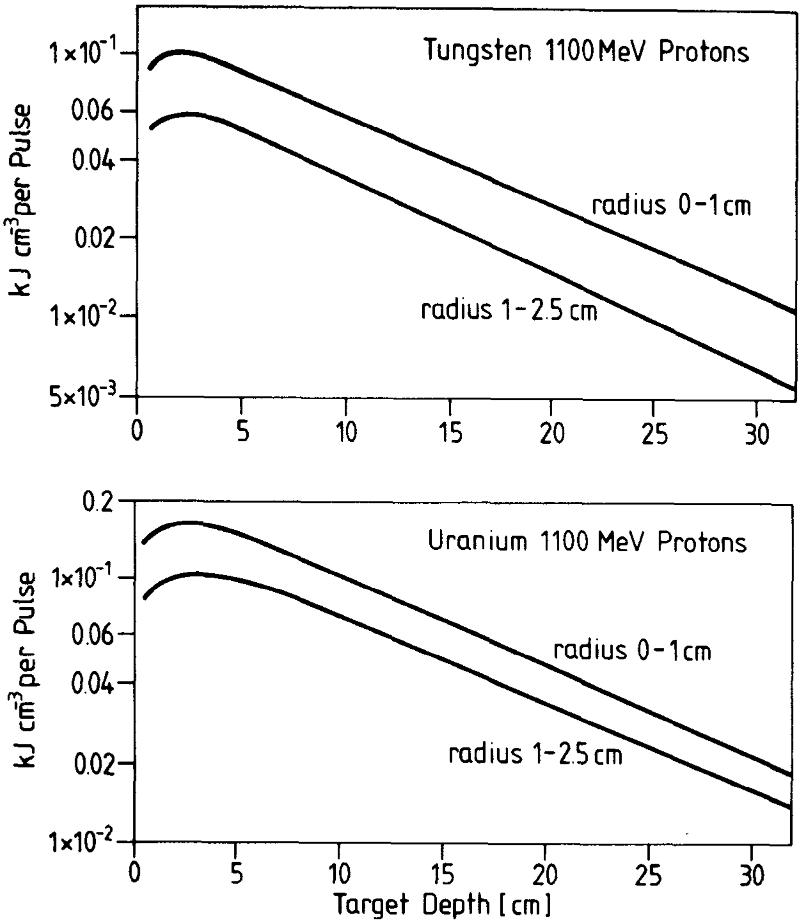


Fig. 4: Depth dependent energy deposition inside target wheel for two radial intervalls about proton beam axis

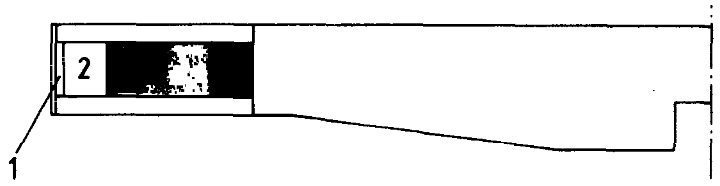


Fig. 5: Three zone model of target wheel with active zone 1-4

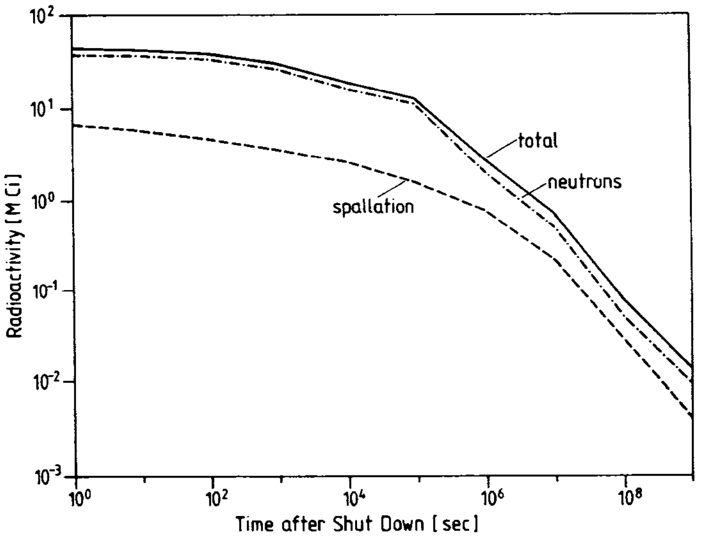


Fig. 6: Time behaviour of activity in uranium after 12000 hours irradiation

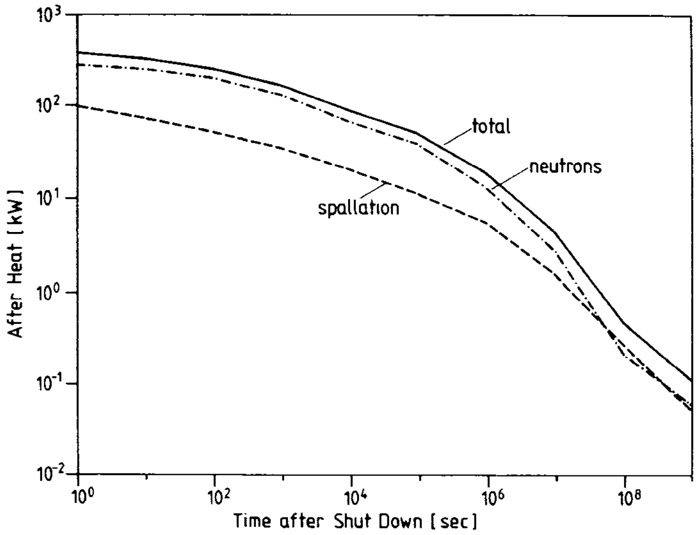


Fig. 7: Time behaviour of thermal power in uranium after 12000 hours irradiation

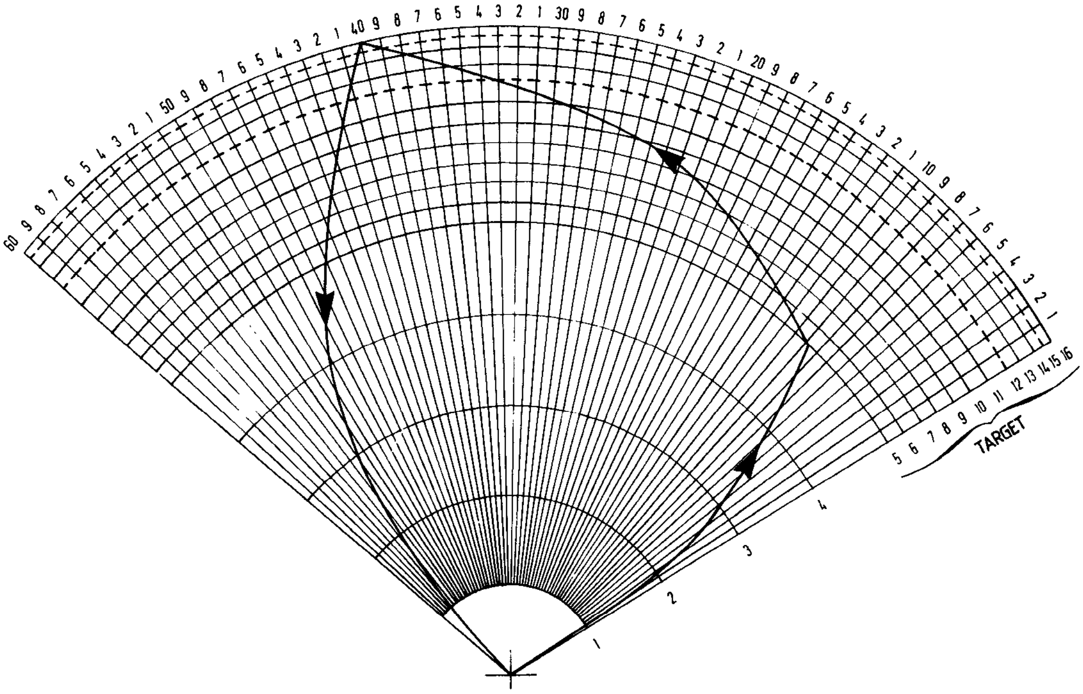


Fig. 8: Water flow path through mesh grid

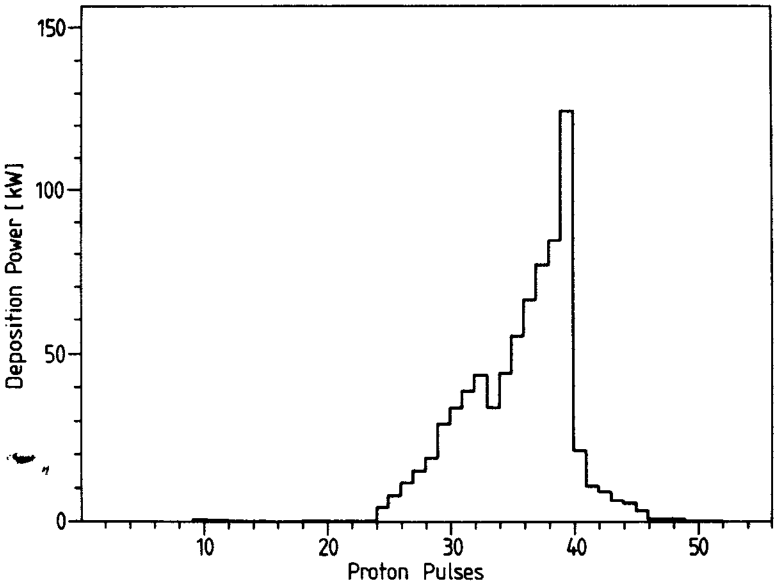


Fig. 9: Energy deposition power of neutrons (energy group 1.35-15.0 MeV) in sectors 156-165

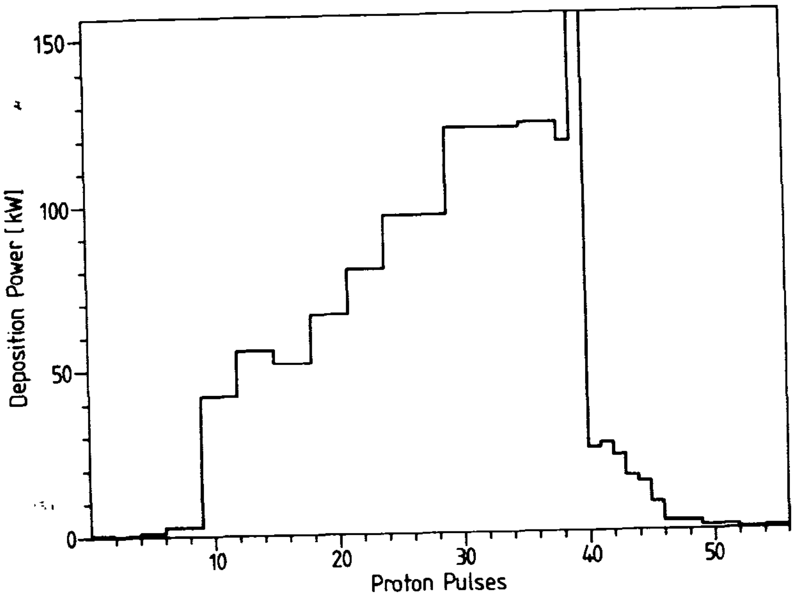


Fig. 10: Averaged deposition power of neutrons (energy group 1.35-15.0 MeV) over all sectors

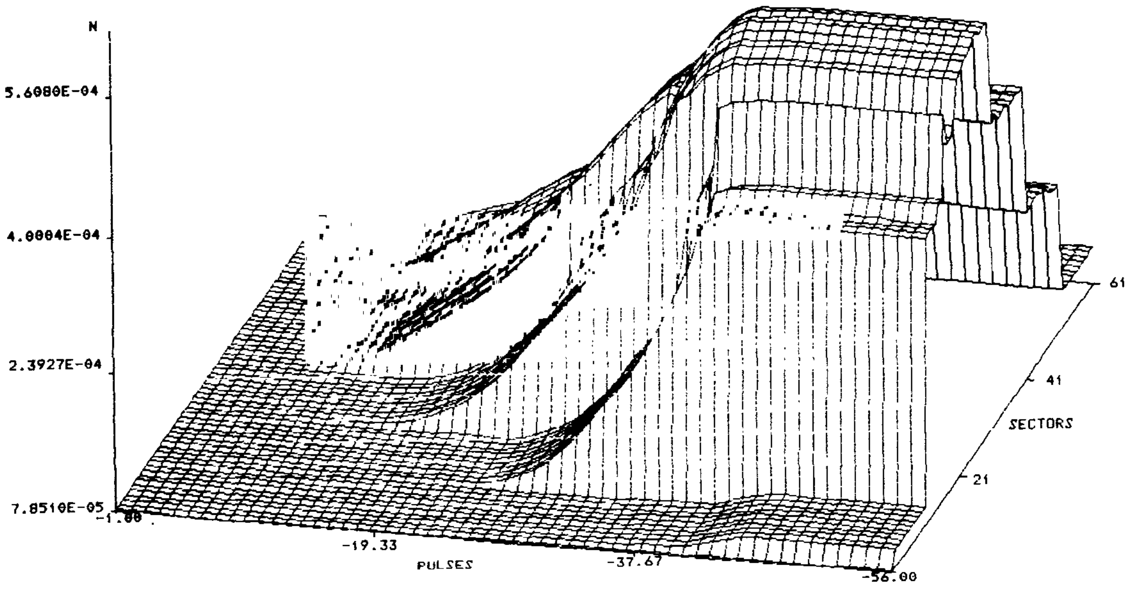


Fig. 11: H_2 concentration in mol per litre/sector/time