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DESIGN CALCULATIONS FOR THE SNQ SHIELD

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This paper presents the results of three special activities on SNQ shielding calculations: The neutron flux outside the accelerator tunnel from the view of earth activation, dose rates outside the SNQ target station and activation of air and earth in the surroundings thereof, and the radiation heating of the near target parts of the SNQ shield were calculated.

1. Shielding of the Accelerator

Neutron fluxes in order to determine the production rates of some important nuclides (guide nuclides, Table I) in the earth shield of the SNQ accelerator were calculated using high energy secondary particle cascade theory and group Monte Carlo techniques for low energy neutron transport. The HETC KFA version /1/ together with MORSE /1/ were run for this problems on CRAY-XMP.

The accelerator tunnel was modelled as a channel of virtually infinite length and with the cross section shown in Fig. 1 which is an adequately simplified model of the technical layout given in Fig. 2.

Table I

$^{151}Eu\ (n,\gamma)\ ^{152}Eu$

and the following neutron induced threshold reactions

$^{24}Mg \rightarrow\ ^{22}Na,\ ^{24}Na$
$^{25}Mg \rightarrow\ ^{22}Na,\ ^{24}Na$
$^{26}Mg \rightarrow\ ^{22}Na,\ ^{24}Na$
$^{27}Al \rightarrow\ ^{22}Na,\ ^{24}Na$

For the beam losses, which are the source of radiation in this shielding problem, the following assumptions were made: The lost protons of the beam amount to $3x10^{11}$ per meter and have energies of 1100 MeV each. They will interact with massive parts of the accelerator structure mainly made of steel. This was simulated by assuming a stopping iron target in the beam line.

The neutron fluxes were calculated in different areas (see Fig. 1) in order to obtain the spatial dependence. The area of highest flux is marked in Fig. 1 and the according spectrum is given below in Fig. 3. The broken line denotes the high energy part of the spectrum calculated with HETC, and the low energy spectrum calculated by MORSE is given by the solid curve.

2. Radiation Protection Problems Connected with the SNQ Target Station

The bulk shield calculation that were performed for the SNQ target station do not predict the radiation doses outside the shield and should, therefore, be completed by taking into account the so-called "skyshine" and "groundshine" effects, which are due to the backscattered radiation from the atmosphere and the earth. To study this problem, the neutron yield from an ^{238}U target irradiated by an 1100 MeV proton beam has been considered as a source. Neutron/secondary gamma transport calculations have been performed through the shield and in the neighbourhood up to 1 km from the target station. Unfortunately, the recently performed Monte Carlo hadronic cascade calculations are restricted to the region close to the target assembly and are not able to account for the albedo effects and the phenomenon of neutron spectra transition between different media. Therefore, for the problem with a large spatial range to be solved here the two-dimensional discrete ordinates computation remains the favourable calculational technique.

The procedure of analysis required considering the following three items: (a) the space, energy and angular dependence of the secondary radiation source, produced by the beam interaction with target and other irradiated materials, (b) description of the transport process of the secondary radiation through the shield, ground and atmosphere, and (c) using the response functions relevant to the radiation interaction with elements of environment, human tissue, radiometric counters, etc. The management of the system of applied computing codes and data files is shown in fig. 4. For the source step the KFA version of the INC Monte Carlo code HETC /1/ was run for the three-dimensional model of the ^{238}U target. The spallation events from HETC scored by the SIMPEL code /1/ to the volume-averaged secondary neutron yields versus angle and energy were then input to the GRTUNCL code /2/, calculating analytically the first-collision neutron source. The SNQ facility was modelled in the cylindrical "r-z" geometry, as is shown in fig. 5. The target station consisted of a 5.5 m thick iron shield, surrounded by a 1 m thick concrete layer. The target was considered to be a point source of secondary neutrons from the spallation, with yields equivalent to the thick target, located on the height 1.5 m above the ground level, on the "z" axis. Azimutal symmetry was assumed with the beam direction representing all the azimutal angles. The angular anisotropy was taken into account for the different vertical angles with the "z" axis. There was a graphite moderator of 2 m height and 3 m diameter, placed above the source position. The atmosphere and the ground surface were included up to a distance of 1.5 km away from the SNQ facility and up to 1.5 km above. The LAHI /3/ multigroup neutron cross-section library (KFA combination of the ORNL and LANL libraries) was connected. The highest energy group (700-800 Me) was uniformly extended to the proton source energy of 1100 MeV.

The DOT.4 /2/ two-dimensional discrete ordinates code system was used to solve the neutron and secondary gamma transport equation. The P_3 order Legendre expansion and the S_4-S_8 angular quadrature sets were applied. The results from DOT, the space and energy-dependent neutron and γ fluxes (e.g. Fig. 6) were integrated over energy with several multigroup response functions. The low energy part of the responses (below 17.5 MeV) was collapsed from the MACKLIB-IV library /4/. The high energy parts of the same responses were obtained using the so-called thin target option of the HETC code (Ref. 5). Some radiation protection responses, like the flux-to-dose conversion factors, were appended from the literature /6/. Dose equivalents at various points are given in Table II. The space dependence of the neutron flux, the dose equivalent, the absorbed dose and the induced reactivity are shown by Figs. 7 and 8.

Table II

	low-energy neutrons	high-energy neutrons	gammas	total
below the ground level	4.01×10^{-2}	4.21×10^{-4}	5.69×10^{-3}	5.00×10^{-2}
at the beam level	1.13×10^{-1}	6.03×10^{-3}	1.84×10^{-2}	1.32×10^{-1}
above the roof	3.61	1.91×10^{-3}	5.03×10^{-2}	3.68

3. Radiative Shield Heating

The near target regions of the SNQ shield are intensively exposed to radiation from the target. The layout of the necessary cooling system is strongly dependent on the distribution of the energy deposition which has large gradients and peak values of about 1 W cm^{-3}.

The material in the part of question in the shield is mainly lead shot with some steel structure. As the density of steel is not far away from the density of lead shot, it was, for simplicity reasons, assumed that the whole inner part of the shield was made of lead of density 8.0 g cm^{-3}. Voids and ducts like the beam tubes and the proton channel were considered to be of some importance for the radiative energy transport, and thus taken into the simplified modelling of the SNQ target station. The geometric model was covered by a mesh grid to attain space dependence of the results of the energy distribution calculations. The calculations were also performed using the HETC/MORSE code system for the high and low energy fractions of the energy deposition, respectively. Figs. 9 and 10 show cuts through the target station giving a rough picture of the distribution of energy deposition. The values of the energy deposition in these originally coloured pictures may not be clearly recognized. A more detailed report on the subject of this section is being prepared. The energy depositions in the target, the moderators and the reflector are not considered here, as these components have own cooling circuits.

4. References

/1/ P. Cloth, D. Filges, G. Sterzenbach, T.W. Armstrong, R.L. Colborn
Jul-Spez-196, March 1983

/2/ W.A. Rhoades et al.
ORNL/TM-6529, Oak Ridge National Laboratory (1978)

/3/ H. Schaal
SNQ 3j./BH 120783, KFA Jülich GmbH (1983)

/4/ Radiation Shielding Information Center
RSIC/DLC-60, Oak Ridge National Laboratory (1978)

/5/ J.M. Zazula, P. Cloth, D. Filges
SNQ A1015.1, KFA Jülich GmbH (1985)

/6/ E.A. Belogorlov, V.T. Golowachik, V.N. Lebedev, E.L. Potjamkin
Nucl. Instr.Meth. 199: 563 (1982)

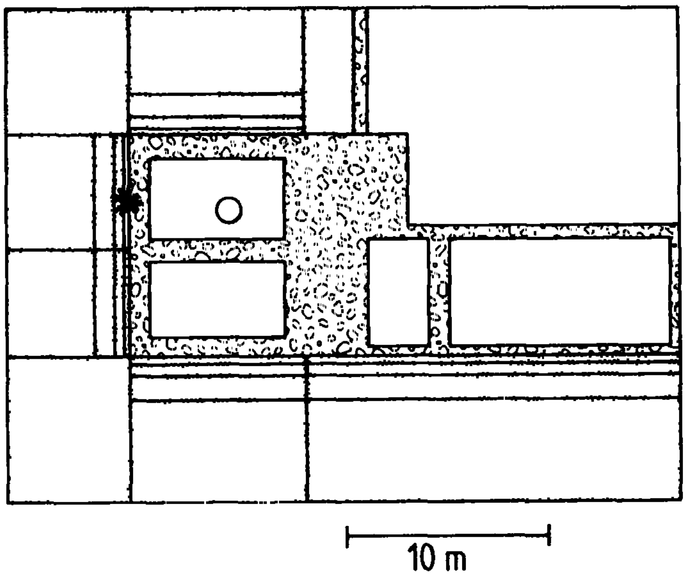


Fig. 1: 3-D computer simulation of accelerator tunnel

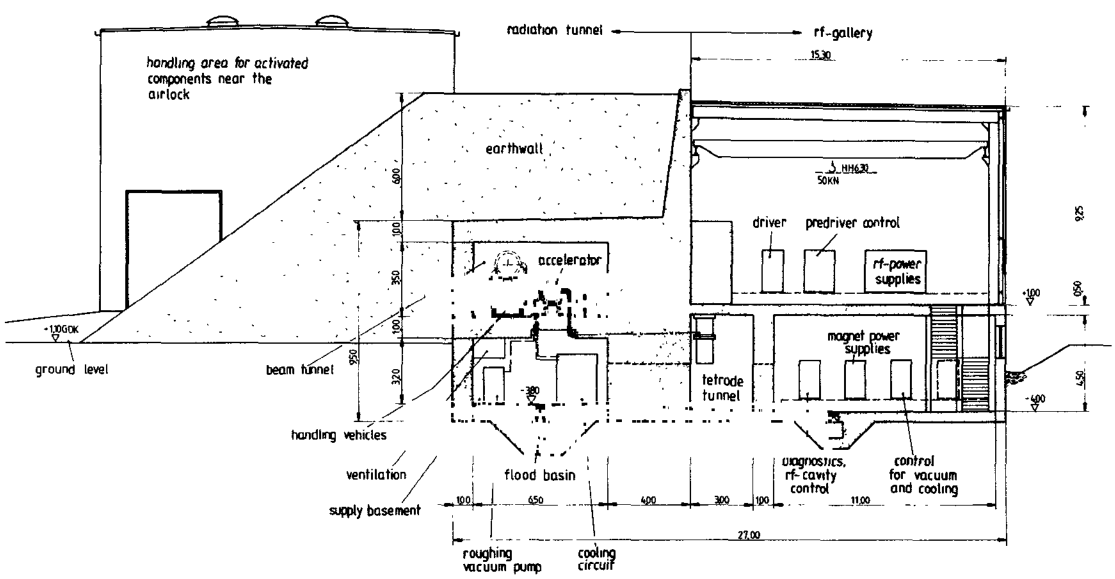


Fig. 2: Technical layout of accelerator tunnel

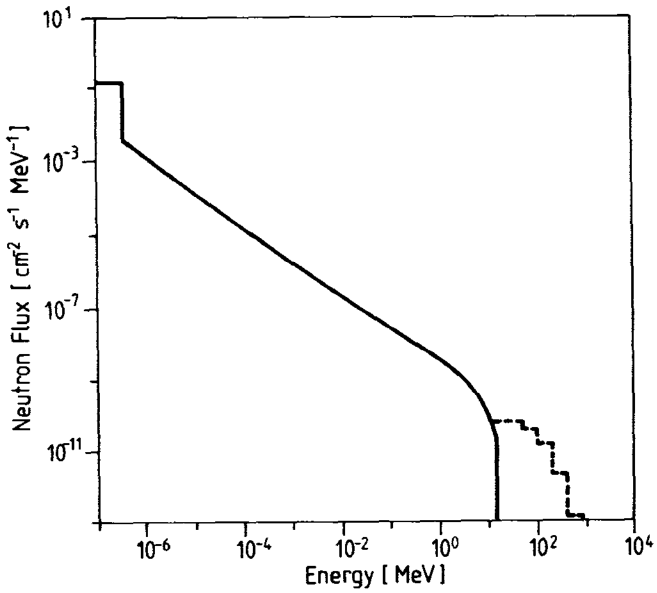


Fig. 3: Typical neutron spectrum in the soil around the accelerator shielding (*marked area in Fig. 1)

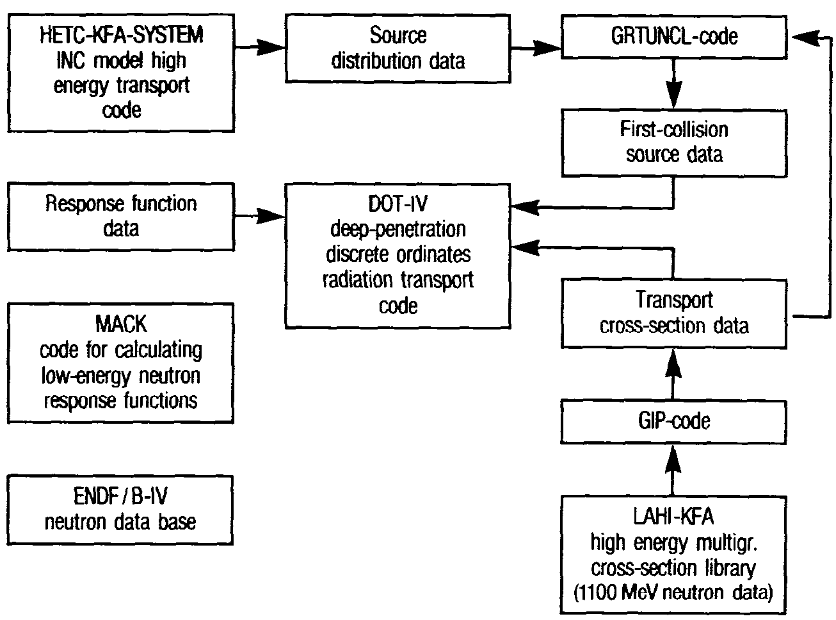


Fig. 4: Management of the computing codes and data bases in the system of Analysis

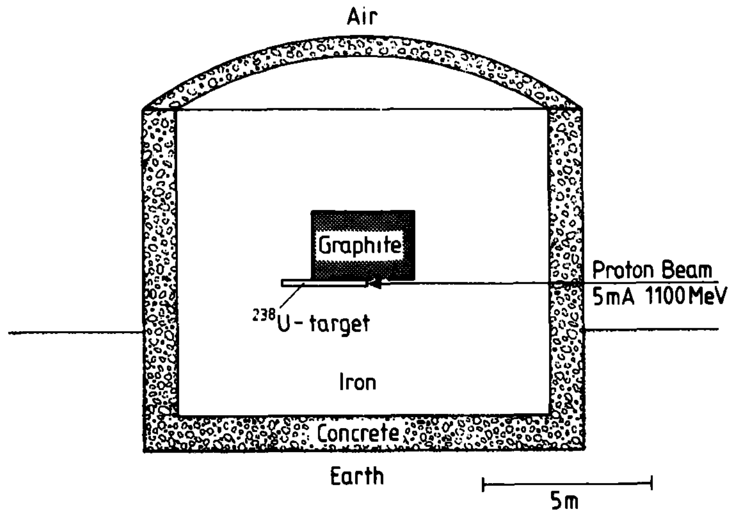


Fig. 5: The geometrical model for 2-D transport calculations (in principle)

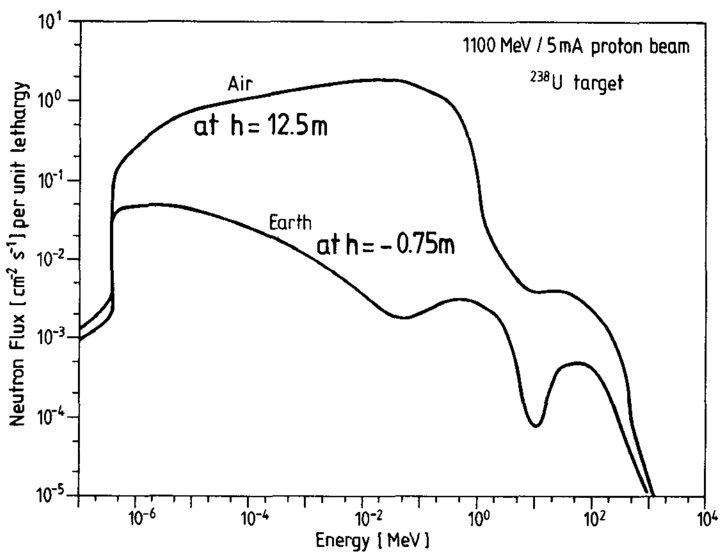
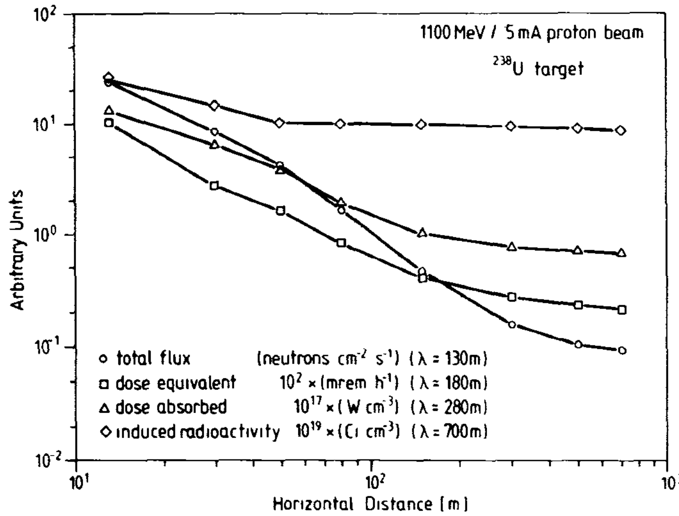


Fig. 6: Comparison of neutron spectra in air and in earth, outside of the shield



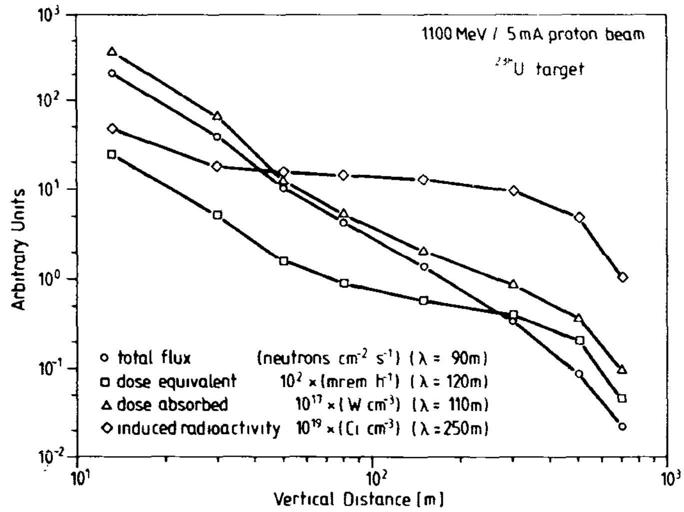


Fig. 7, Fig. 8:

Horizontal and vertical dependence of the total flux, dose equivalent, absorbed dose and induced radioactivity in air, outside of the target station with shield

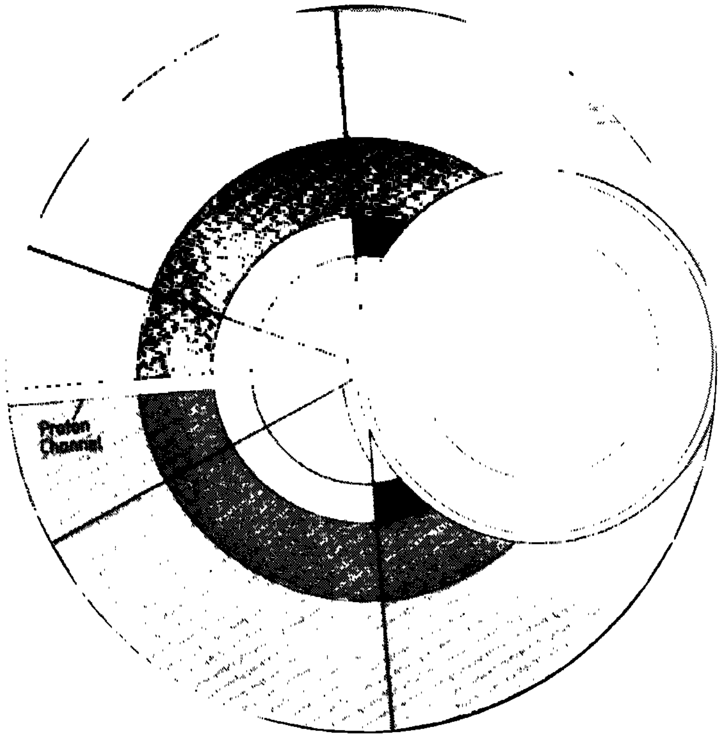


Fig. 9:
Horizontal cut in
target level

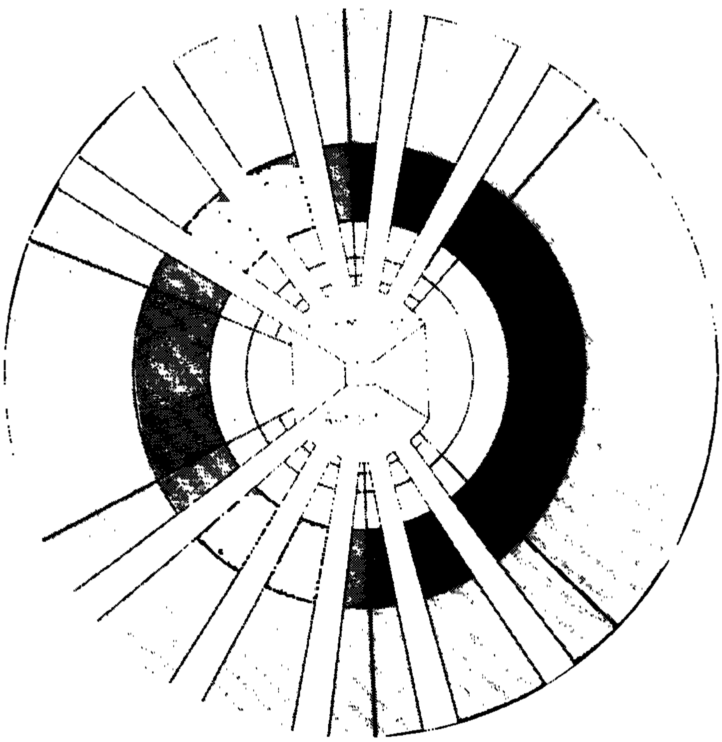


Fig. 10:
Horizontal cut in beam
tube level