ICANS-XIV
14th Meeting of the International Collaboration on
Advanced Neutron Sources
June 14-19, 1998
Starved Rock Lodge Utica, Illinois U.S.A.

RADIATION PHYSICS EXPERIMENTS TO DEVELOP THE TARGET-MODERATOR-REFLECTOR SYSTEM FOR ESS (EUROPEAN SPALLATION NEUTRON SOURCE)

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ABSTRACT

To develop high power spallation targets the calculational methods have to be applied to demonstrate feasibility, to optimize the design configuration and to support the engineering layout. The requirements of the calculational methods in spallation technology are the predictions for the following interesting questions, which have to be answered for all high current accelerators and their target stations: - neutron, gamma and charged particle production and fluxes; - energy deposition and heating; - radioactivity and after heat; - materials damage by radiation; - high energy source shielding.

The ability to predict, on a theoretical or computational basis, all aspects of radiation physics is crucial for the performance optimization of the whole system by advising engineers in their decisions with respect to the effect on the source characteristics. While the standard of computational models for neutronics and nucleonics calculations is generally quite high, there are still some areas where more research is urgently needed.

Manifold experiments have been performed to proof and validate the physical models of secondary particle production and transport of particles through matter applied in Monte Carlo simulations. Several basic nuclear experiments are underway to validate important parameters for the ESS target station design and will be discussed.

1. Introduction

In the ESS study report[1] we identified several areas where further spallation physics research and code validation is urgently needed: Neutron and charged particle production and multiplicities above one GeV incident protons, energy deposition and heating, material damage parameters, radioactivity and after heat, and high energy source shielding. All simulation calculations will be done using the Jülich HERMES code system[2]. For this purpose and the various aspects four collaborations were organized: NESSI (Neutron Scintillator Silicon Detector), ASTE (AGS Spallation Target Experiment), JESSICA (Jülich Experimental Spallation Target Setup in COSY Area) and RECOIL.

The NESSI Experiment[3]

Within the NESSI collaboration at COSY-Jülich (Cooler Synchrotron) neutron and charged particles multiplicities are measured up to 2.5 GeV incident proton energy for "thin"and "thick" targets for various structure and target materials from Al to Pb (and U). For thin targets (only one nuclear interaction in the target) the number of evaporative neutrons is a good measure of the distribution of the thermal excitation energy induced in the nucleus. In this sense the neutron multiplicity distribution is a sensitive test of the primary spallation process, i.e., the intranuclear cascade part of the theoretical model. At high excitation energies above about 2-3 MeV/nucleon in heavy nuclei additional information on light charged particles (evaporative protons and He) improves the excitation energy resolution by about a factor 2-3. For thick targets (multiple reactions) the alteration of the neutron multiplicity distribution reflects the production of additional neutrons produced in secondary reactions and thus it is a sensitive test to both the intra- and internuclear cascade part of theoretical models.

In summary, one can show the advantage of measuring the whole neutron multiplicity distributions instead of single average values. This brings much more constraint to the INCE (intra nuclear cascade evaporation) model. Also the measurements in both thin and thick targets appear quite complementary since, in thick targets, compensation effects between the first reaction and secondary reactions can mask deficiencies in reproducing the primary reaction by the INCE model. The thick target measurement brings an additional, although indirect, test of the thin target measurement insofar as it allows one to follow the fate of the products of the primary interaction in generating extra neutrons.

The experimental equipment consists of two 4π-detectors, namely the large spherical neutron tank (BNB) with 1500 litres of scintillating liquid and 24 photomultipliers on the surface, and, inside the tank and around the target, the silicon detector (BSIB). BNB uses the old principle of slowing down the neutrons and detecting them by their capture in Gadolinium. BSIB is a spherical shell of 20 cm diameter, assembled in a selfsupporting way from 162 silicon detectors, 12 pentagons and the "magic" number of 150 hexagons. They all have the same size (7.5 cm^2) and thickness (500 μm). BSIB detects and to some degree identifies all charged nuclear particles by energy, or energy loss, and time-of-flight over the 10 cm from the target.

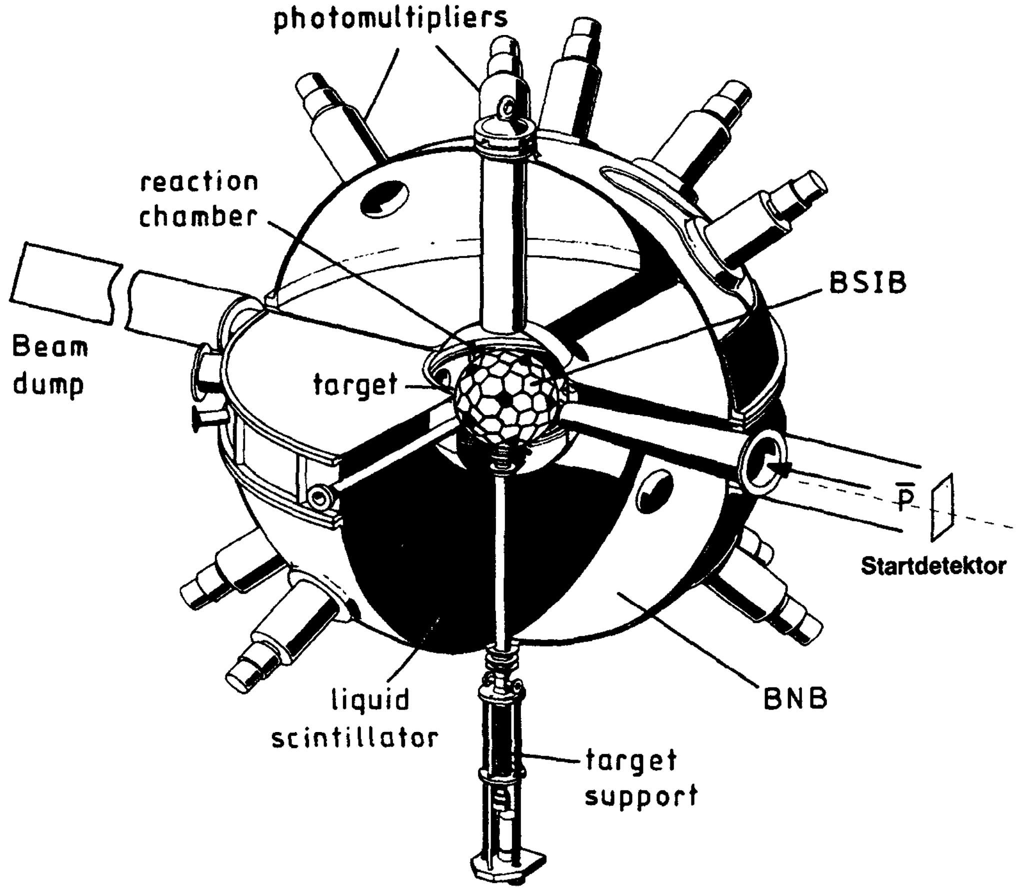

Fig. 1: The NESSI detector

During the first experiment at COSY in April 1997 we measured the neutron multiplicity of a thin Hg target (5 mm thick, diameter 20 mm, stainless steel 0,3 mm container). This is very important because mercury is the favourite target material for ESS (European Spallation Source) and there exist no experimentally estimated cross sections.

For comparison with the experiment the simulated result of the neutron multiplicity of the thin mercury target setup is shown in figure 2.

Measured and simulated neutron multiplicities are distributed very differently. Whereas the experimental multiplicity shows its maximum at 15 neutrons the simulation shows the maximum at 23 neutrons. The detector system has an energy dependent detection efficiency which has to be taken into account . If we fold the simulated neutrons with this energy depend detector efficiency we receive a simulated neutron multiplicity distribution which should be comparable to the measured distribution. In fact we find a simulated distribution which tends to have a higher multiplicity by 1 neutron at both sides of the maximum. It is not possible to evaluate the real neutron multiplicity by experiment only, even not with the knowledge of the energy dependent detector efficiency. Therefore, the simulation is absolutely necessary for the interpretation of the experiment.

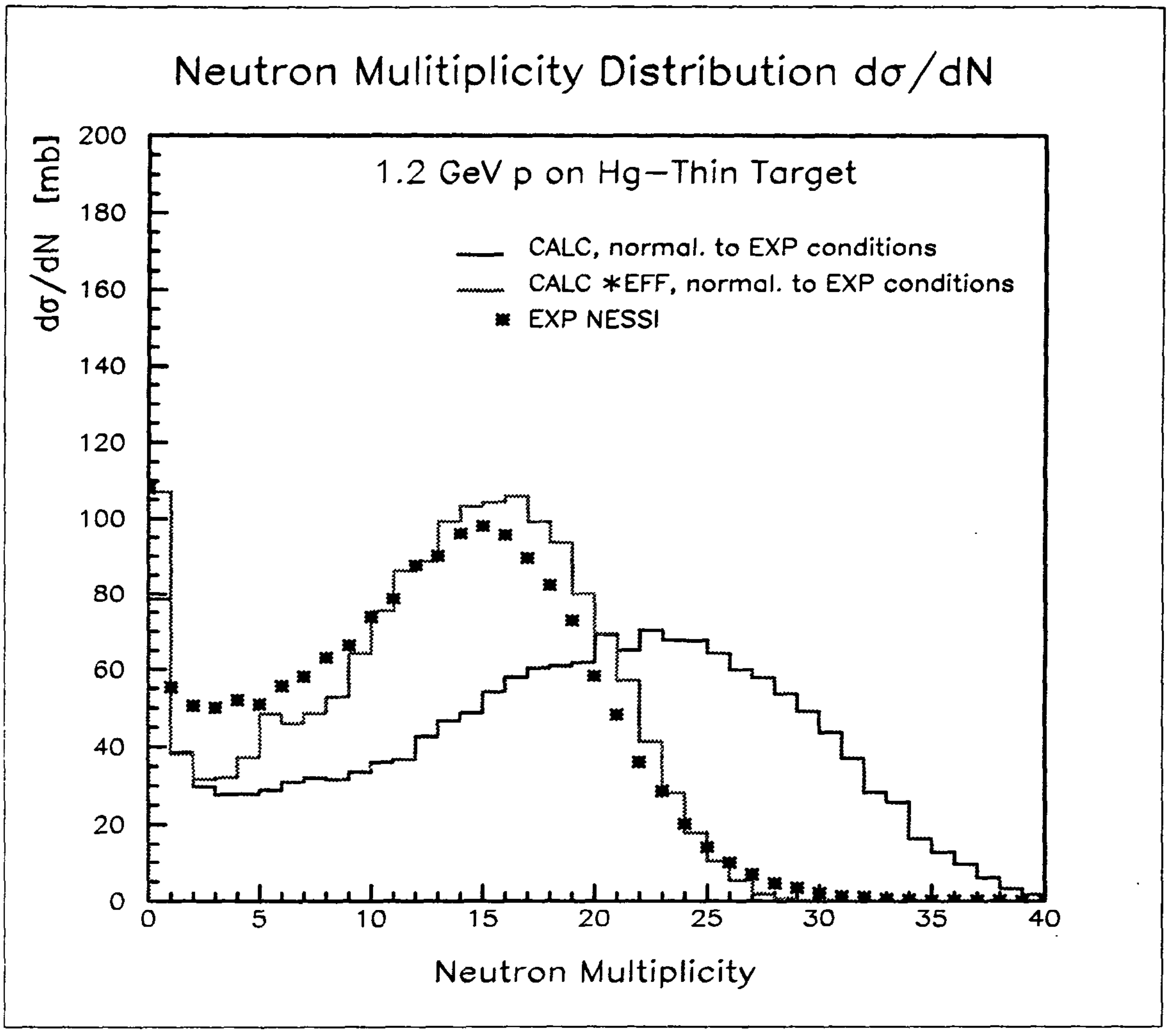

Fig. 2: Measured and simulated neutron multiplicity for 1.2 GeV protons on a thin mercury target.

For thick targets (multiple reactions) the alteration of the neutron multiplicity distribution reflects the production of additional neutrons produced in secondary reactions and thus it is a sensitive test to both the intra- and internuclear cascade part of theoretical models. We have prepared target blocks (15 cm in diameter and 40 cm length) from three materials, tungsten, mercury and lead, which are all suited for spallation neutron sources, with Hg beeing favoured for the European Spallation Source. These blocks are highly segmented in length and diameter, so that the neutron production at some selected proton energies can be simultaneously studied as a function of target geometry, thereby adding constraints also to the transport part of the models. The idea is to provide bench-mark data for the high energy transport codes.

In figure 3 a comparison of INCE and low energy neutron transport calculations with first experimental results for thick mercury targets are given. The open circles represent the calculated values. The stars represent the efficiency corrected values, which can be compared with experimental ones.

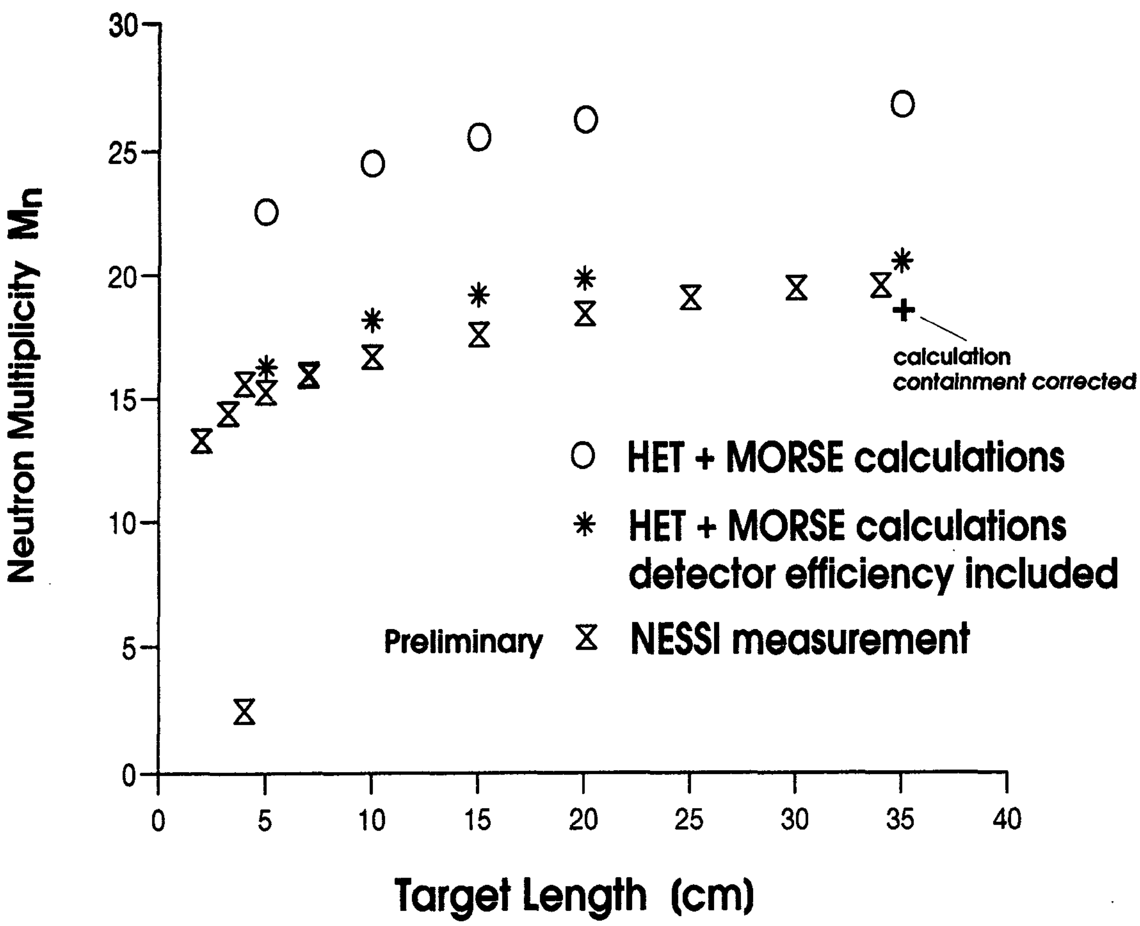

Fig. 3: Mean neutron multiplicity for 1.2 GeV incident protons on thick mercury targets of 15 cm diameter

The ASTE Experiment

The purpose of the ASTE-Collaboration is to perform experiments to verify experimentally a number of predictions from theoretical calculations on the neutronic and thermo-mechanical behaviour of spallation targets designed for pulsed operation in the megawatt power regime. The experiments started in 1997 with a first test run with a bare cylindrical (diameter 20 cm, length = 130 cm) mercury target and will continue with reflected target systems.

The main goals of the experiment are to verify experimentally a number of theoretical predictions:

distribution of neutron leckage reaction rates, energy deposition distribution from 1.5 to 24 GeV incident proton beam energy, pressure waves in mercury, stress wave monitoring of the target container, spallation product measurements, reaction rate distributions in reflected target systems and neutron spectra time of flight measurements.

Of major interest of the experiment is the estimation of energy deposition distribution in the target. A pulse with all protons of the AGS in two bunches, i.e. $2x4.0x10^{12}$ protons of 24 GeV in less than ~ 30 ms introduced a maximum temperature jump of 3.4 K in the target. A comparison of the axial distribution of measured and simulated temperature jump is given in fig. 4. The calculation was performed using the measured incident proton beam density profile.

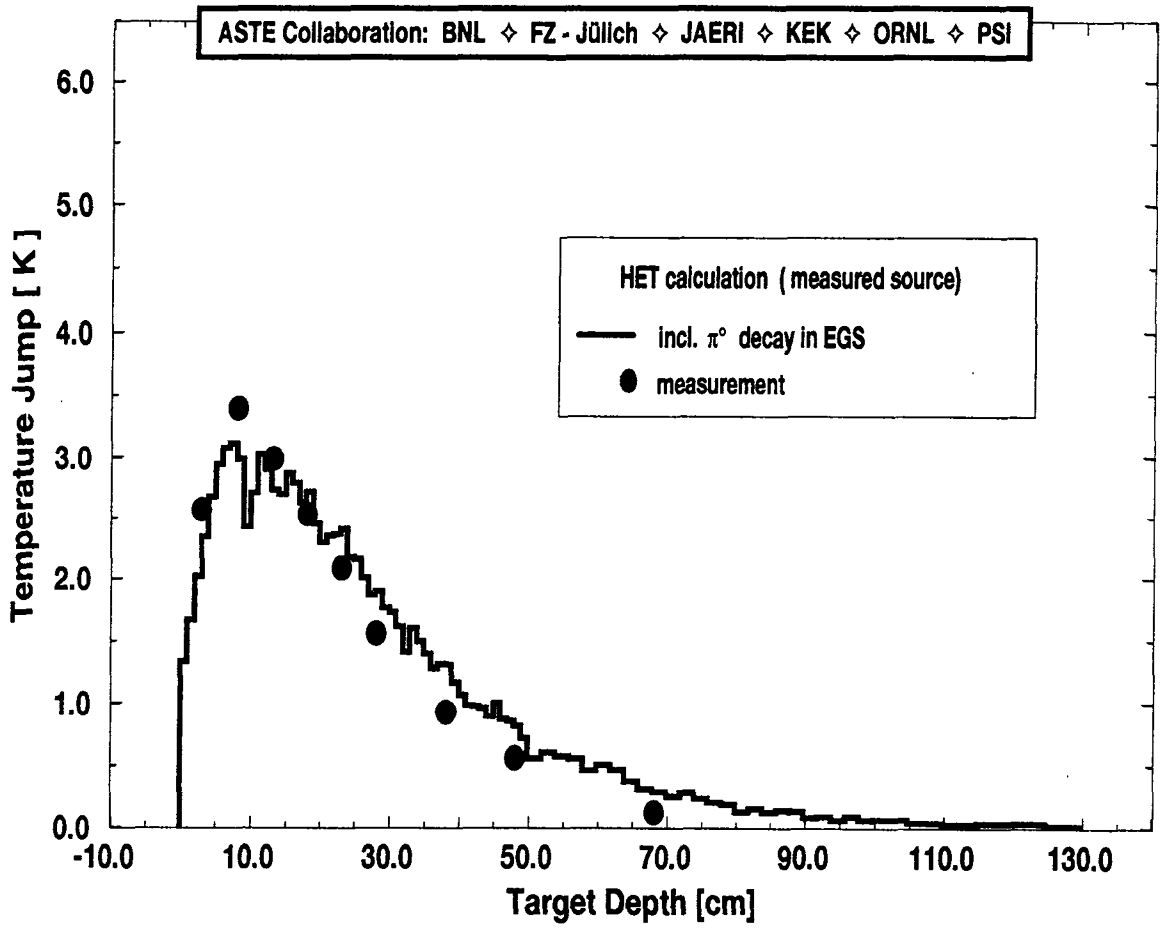

Fig. 4: Measured and calculated temperature jump in the mercury target during a 30 kJ incident proton pulse

A first comparison of calculated and measured temperature jump distribution indicates that the calculations are in good agreement with the measurements.

Two further experiments are in preparation at COSY-Jülich:

- JESSICA

JESSICA is planned as a ESS Target-Moderator-Reflector station mockup with in axial direction movable ESS mercury target. The experiments will be performed with bare and reflected target systems including beam tubes, cooling systems for reflector and moderators. Reflector and moderator materials and geometries can be changed easily for comparable measurements. This mockup will be an advanced cold moderator test facility for ESS.

- RECOIL

The recently found RECOIL collaboration will study the various aspects of proton induced reactions with nuclei by spallation physics experiments. The main part of the experimental installation is the large magnetic spectrometer THETYS from CERN with field strength of 1.2 Tesla and wide gap of 1.0x1.0x0.4 m^3 with a very homogeneous electromagnetic field. The planned experimental program consists of the measurement of spallation cross sections of recoiling nuclei over a proton energy range of 0.1-2.5 GeV on different target materials; inclusive and exclusive high energy charged particle spectra from 50 MeV to beam energy. The energy spectra of the recoiling nuclei are important to evaluate damage energy cross sections. The high energy charged particle spectra are important to validate the distribution of the excitation energy E^*, which is the transition energy from the intranuclear cascade to the evaporation phase of the de-exciting residual nucleus.

References

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