An upgrade of the SCANDAL facility for neutron scattering measurements at 175 MeV

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Abstract

The experimental setup SCANDAL (SCAttered Nucleon Detection AssembLy) at the The Svedberg Laboratory (TSL), previously used for measurements of the differential cross section of elastic and inelastic neutron scattering in the 50 – 130 MeV range, has recently been upgraded with new Na doped CsI scintillating detectors for measurements at 175 MeV. The performance of the new setup is described and illustrated by the early steps in the analysis of the first experimental campaign, carried out in January and February 2009.

1. Introduction

The SCANDAL setup at TSL has been used for cross section measurements of elastic and inelastic neutron scattering since 1999. Since then, the differential cross sections for a series of nuclei have been measured at the incident neutron energy 96 MeV, see [1], [2], [3], [4]. Recently the setup was upgraded with new thicker CsI scintillating detectors, and measurements have been carried out at the neutron energy 175 MeV.

Collecting nuclear data of this kind is motivated both by various applications and an improved understanding of fundamental physics. There is a shortage of neutron-induced experimental data today in the 20 - 200 MeV region. Filling this gap will help improve the theoretical models of nuclear reactions. In particular the optical model potential (OMP) [5] would benefit from elastic scattering data. The OMP is a key ingredient in nuclear reaction codes, widely used in many applications. We find three major fields of applications involving neutrons at these energies. In radiation treatment of cancer tumors, neutron therapy [6] has proven to be a good alternative in some cases where conventional radiation treatment, using photons or electrons, has failed. Neutron data is therefore needed to improve our understanding of the dose delivery to the human body.

In electronic devices, especially at high altitudes, e.g. in airplanes, cosmic-ray neutrons can induce a nuclear reaction in the silicon substrate, and thereby cause a random change of the memory content. This is obviously unwanted and the problem is referred to as single event effects [7]. Nuclear data on elastic neutron scattering is very useful in this field of research, since the elastic scattering cross section makes up the larger part of the total neutron cross section [8]. Electronics testing related to this phenomenon is routinely carried out at the neutron beam facility at TSL [9].

The third, and maybe the most obvious, field of application for this type of nuclear data is nuclear technology for energy purposes – nuclear power. Nuclear reactors of today produce radioactive waste, which is difficult to handle. Future reactor concepts, e.g. accelerator driven systems (ADS), may be a solution to this problem.

The results from previous cross section measurements of elastic neutron scattering on H, D, C, O, Fe, Y and Pb, at 96 MeV, using the experimental setup SCANDAL, show good agreement with theoretical predictions, see e.g. [1], [2]. From some of these data sets, information on inelastic scattering has also been extracted, and a publication with data for C, Fe, Y and Pb is currently in preparation [10]. The new detectors on SCANDAL are designed for measurements of elastic, and possibly inelastic, scattering at 175 MeV, which is the maximum neutron energy available at TSL [11]. This paper reports on the performance of the new CsI scintillating detectors, and other changes of the SCANDAL setup.

2. SCANDAL

2.1 Overview

A brief overview of the SCANDAL setup is given here, since it has previously been described in great detail, e.g. [12]. A schematic picture of the setup can be seen in figure 1. The scattering target is placed on a table in front of the two identical SCANDAL arms. Each arm can be swung into the desired

angle, together typically covering angles between 10° and 70° in the lab system. The arms are usually put in such a way that their angular range have a slight overlap, to get a cross check of systematical errors between the two arms. It is also desirable to put one of the arms as close to the beam as possible, to measure at small angles. This is important for normalization of the measured cross section, since elastic scattering peaks at forward angles. The data is normalized to the well known total cross section. The limiting factor of how close to the beam we can get is the housing of the detectors, since any material in the beam will cause an unwanted background of scattered particles. The SCANDAL arms are flexible enough to be turned all the way around for measurements beyond 90°.

When a neutron has been scattered in the target, it passes through the veto scintillator, which is a 2 mm thick plastic scintillator, 60 cm wide and 30 cm high. Its chemical composition is $C_1 H_{1.1}$. The scintillator serves to reject charged particles produced in the target, by acting as a fast veto on the trigger signal for the data acquisition system. The second detector is the active converter, where the neutron is converted into a proton in the reaction H (n, p). It is a 20 mm thick plastic scintillator, 60 cm wide and 30 cm high, and measures the energy loss of the recoil proton in the converter material. Since the energy loss can be compensated for when using an active converter, it is possible to use a thicker converter without impairing the energy resolution.

The angle of the outgoing particle may change relative to the incoming particle in the conversion. Therefore two drift chambers [13] record the path of the outgoing proton. The proton path determines the conversion point, and the scattering angle of the original neutron can be calculated. However, conversion on carbon might also occur in the plastic of the converter scintillator. But as this reaction has a Q-value of - 12.6 MeV, protons scattered on H at angles smaller than 15° can be identified on the basis of their energy. Protons scattered on H at larger angles than 15° on the other hand, will lose more than 12.6 MeV due to kinematics, and cannot be distinguished from protons produced on carbon. In the analysis, the drift chamber information can be used to discard all events with a conversion angle above 15°.

A 2 mm thick plastic scintillator, 60 cm wide and 30 cm high, is placed in front of the drift chambers, and a 2 mm thick plastic scintillator, 75 cm wide and 30 cm high, is placed behind them. Coincident signals from these two define a trigger criterion for the data acquisition. The very last detector at the back of the SCANDAL arms is an array of CsI crystals. They measure the full energy of the protons, which is necessary for distinguishing between protons originating from elastically scattered neutrons, and protons originating from inelastically scattered neutrons. The energy losses in the plastic scintillators are recorded, and the total energy can be corrected for these losses event by event. SCANDAL can be operated in both neutron mode and proton mode. If the signal from the veto scintillator is used as a veto in the data acquisition trigger, only neutrons will be recorded. If we instead require a triple coincidence between the veto, trigger one and trigger two scintillators, then only charged particles will be recorded. Protons can be distinguished from other charged particles in the off-line analysis using ΔE-E techniques, see section 5.1. Proton mode is used for energy calibration of the detectors, see section 4.2.

An optional feature of SCANDAL is the multi-target box, which sits upstream of the position of the scattering target, see figure 1. It is mainly used for calibration purposes, but can, if left empty, also be used for rejection of charged particles in the neutron beam during cross section measurements. The rejection of charged particles is then done in the off-line analysis. Seven different scattering targets can be placed in the multi-target box at the same time. The target planes are separated by multi-wire proportional counters, which means that for (n, p) reactions the scattering plane for each event can be identified. A more detailed description is given in ref. [14].

The detection efficiency of SCANDAL varies with the neutron beam energy because of varying reaction cross sections. Typically, cross sections are smaller for higher energies, which gives a lower detection efficiency. The neutron detection efficiency consists of two parts: the conversion efficiency and the proton detection efficiency. The conversion efficiency depends on the (n, p) cross section for hydrogen, the converter thickness and the accepted conversion angle. For 175 MeV neutrons, 20 mm thick converter and an accepted conversion angle of 15°, it is $6.1 \cdot 10^{-4}$. The proton detection efficiency consists of many parts: the efficiency of the drift chamber planes, correct drift chamber wire selection in the analysis in case of double hits and the CsI response. The efficiency of the drift chamber planes is assumed to be the same at 175 MeV as at 96 MeV. It has been estimated to be 0.93 for each drift chamber plane [12]. The total contribution from the four planes is thus 0.75. The

analysis of the data will show how common double hits are, but previous experience shows that the contribution to the detection efficiency is about 0.93 from the wire selection process.

The CsI full energy deposition efficiency is estimated to be 0.83 at 175 MeV. This is based on an investigation of CsI(Tl) detectors, previously carried out at the same beam line at TSL [15]. This points towards a proton detection efficiency of about 0.6 at 175 MeV. For estimation of the count rate in the experiment, the dead time of the data acquisition system and neutron reaction losses in the target have to be taken into account as well. The reaction losses in the Fe target are estimated to be about 20 %.

The angular resolution achieved in SCANDAL depends on the size of the scattering target and the beam diameter. It will be worse at higher energies, because we have to use larger targets and beam size, once again because of smaller cross sections at higher energies. Using a target of about 11 cm in diameter, as in the latest measurements, and a beam diameter of 8.2 cm, the angular resolution is about 2.3° (rms).
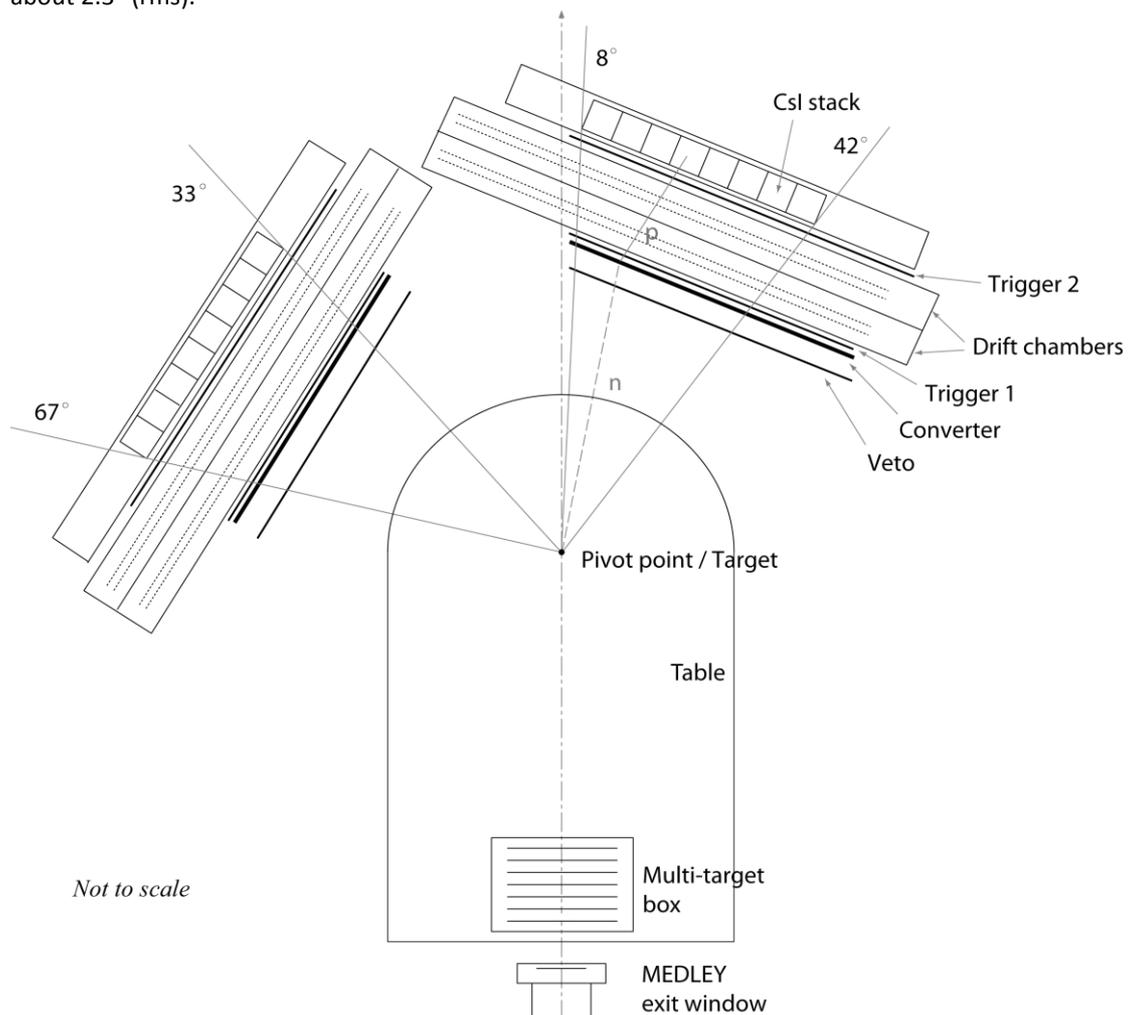

Figure 1: *A schematic figure of the SCANDAL setup. The neutron beam leaves the Medley setup, at the bottom of the picture, and passes through the multi-target box and the scattering target on the table. It continues through parts of the right SCANDAL arm, which have been designed to allow measurements at small angles close to the beam, but with as little material as possible in the beam. The scattered neutrons are detected by conversion to protons. A typical event is illustrated by a neutron and a proton path.*

The old SCANDAL setup had an energy resolution of 3.7 MeV, to which the CsI detectors contributed 3.0 MeV [12]. There are four contributions to the energy resolution: the width of the full energy peak in the neutron beam, straggling in the plastic scintillators, straggling in other materials and the resolution of the CsI detectors. The first three of these contributions are 2.5 MeV, 1.9 MeV and 1.1 MeV respectively in the new SCANDAL. The estimations of the contributions from straggling in different materials are based on calculations of stopping ranges calculated using the SRIM software

[16]. It is reasonable to expect the energy resolution in the CsI detectors to be roughly proportional to the square root of the energy. Assuming that the new CsI detectors behave in a similar way to the old ones, a resolution of 4.1 MeV can be expected for the new detectors at 175 MeV. This would mean a total resolution of 5.3 MeV for the new setup.

As a worst-case scenario, if the energy dependence of the resolution is linear, the energy resolution of the CsI detectors can be closer to 5.5 MeV. For the new setup this would result in an energy resolution of 6.4 MeV at 175 MeV. The actual measured energy resolution is discussed in section 5.3.

2.2 Upgrades of SCANDAL

2.2.1 CsI crystals and PM-tubes

The CsI crystals of the old SCANDAL setup were not deep enough to cover the top end of the energy range of the neutron beam at TSL. Protons of 175 MeV would have been able to pass through the detectors without depositing their total energy in the CsI crystal. SCANDAL has therefore been upgraded with larger, and more suitably shaped, Na-doped CsI crystals and PM-tubes.

A detector depth of about 8 cm is required to fully stop 175 MeV protons in the detector material [16]. The new SCANDAL is equipped with 16 CsI scintillating detectors, eight on each arm, with an individual surface area of 8 cm × 22 cm and a depth of 9 cm, see figure 2. Together they cover a solid angle of approximately 0.4 sr (0.2 sr for each arm). Each CsI crystal is fitted with a PM-tube, collecting the light via a 5 mm thick silica light guide. The light guide is attached to the crystal with optical glue. The crystals are wrapped in white Teflon tape, about 500 μm thick, to improve the reflectivity of the walls. But because of the hygroscopic properties of Na-doped CsI, they are also wrapped in 15 μm thick aluminum foil to keep any humidity out.

The CsI detectors are placed alongside each other on an aluminum beam inside the housing on the SCANDAL arms, with the PM-tubes pointing up. They are held in place by two carefully fitted aluminum beams, which also serve as a connection point for grounding of the PM-tubes. The back of the housing is an aluminum sheet with feed-throughs for the high voltage and the signal cables. The detectors themselves are not completely light tight, why the housing must be carefully sealed with black electrical tape. The front of the house is a similar aluminum sheet, but with a window the same size as the eight CsI crystals on each arm. This window is covered with a thin black plastic sheet, originally meant for storing of light sensitive photographic film.
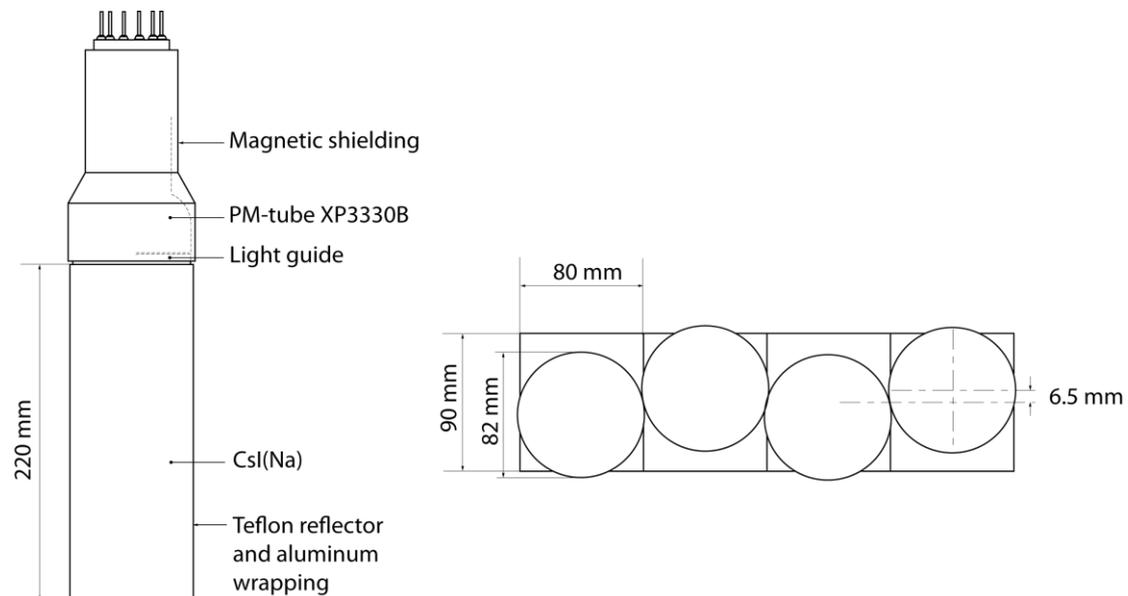

Figure 2: *The dimensions of the CsI detectors. The left figure shows an individual CsI crystal with a PM-tube. The diameter of the PM-tubes is 2 mm wider than the width of the crystal, and they are therefore glued on to the crystals slightly off center. The right figure, a view from above, shows how they are fitted together in the setup by alternating the direction of the off set.*

2.2.2 Changes of the SCANDAL frame

The frame and the housing of the CsI detectors were also changed, in order to get closer to the neutron beam. The amount of material in the beam must be minimized, to avoid a background of particles scattered elsewhere than in the target material. Therefore some of the frame material has been redesigned to create a free passage for the beam. The differences between the old and new SCANDAL can be seen in figure 3.
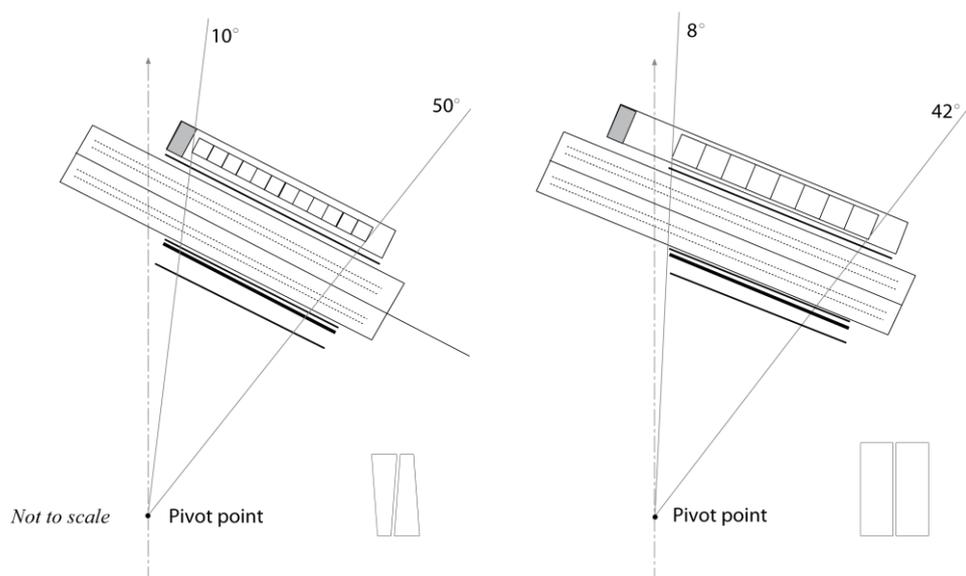

Figure 3: *The differences between the old and the new SCANDAL. The left panel shows how the smallest measuring angle was limited by an iron beam (highlighted in grey) in the old SCANDAL. In the new SCANDAL, seen in the right panel, the CsI housing has been extended to create a passage for the neutron beam. In the new SCANDAL, the CsI detectors are bigger, but fewer. The shape of the crystals, and how they sit together, is indicated in the bottom right corner of each panel.*

2.2.3 Consequences of the upgrades

SCANDAL can now measure neutron scattering at energies up to 175 MeV. As mentioned in section 2.1, the angular resolution depends on the size of the target and the beam rather than the setup itself. But it will be worse at higher energies, because we have to use larger targets and beam size. The detection efficiency also varies with the neutron beam energy because of varying reaction cross sections. The right angles of the CsI crystal walls in the new detector design mean that any corrections, concerning hit position within the crystal, which might have to be applied in the data analysis, will be simpler. The new design also gives a better geometrical acceptance of events, since each crystal is bigger and covers a larger solid angle. Together they do however cover a smaller solid angle than the old ones, because they are fewer. But the angular overlap between the two arms can be decreased to maintain the total angular range covered by them.

The smallest scattering angles are of greatest importance for normalization of neutron data. The elastic neutron scattering falls off quickly between 0˚ and 10˚, meaning that even the tiniest improvement of how close to 0˚ we can measure will be important. The combined effect of measurements at smaller angles and the larger CsI detectors, allowing a better geometrical acceptance, will lead to a smaller uncertainty in the normalization.

A 2 cm thick converter scintillator was chosen for the experiments at 175 MeV. A thick converter is made possible by the fact that the energy loss per unit path length in the material will be lower at higher energies. This is very welcome since the (n, p) cross section on H is roughly 30 % lower at 175 MeV than at 96 MeV [17], where previous measurements were done. A thick converter is needed to maintain a decent count rate in the experiment.

3. The TSL neutron beam facility

3.1 Overview

The neutron beam facility at TSL can be seen in figure 4. It is described in detail in ref. [11]. Protons from the cyclotron hit a lithium target and produce a quasi mono-energetic neutron beam. The reaction employed is $^7Li(p,n)^7Be$. A Li target thickness of 23.5 mm is used for SCANDAL experiments, but thinner ones are available, down to 2 mm. TSL can deliver a neutron beam in the energy range 1 - 175 MeV. After the lithium target, the protons in the beam are deflected by a magnet into a well shielded proton beam dump 10 meters away. The neutron beam continues through a 2 m long set of iron collimators into the experimental hall, which is on the other side of an iron wall. SCANDAL experiments are often run in parallel with the experimental setup Medley [18] that measures light ion production. In these cases, Medley is positioned upstream of SCANDAL. The Medley vacuum is terminated by a 0.1 mm thin stainless steel window, and the targets used are typical less than 0.5 mm thick.

The pivot point of SCANDAL is 727 cm downstream from the lithium target. About 9 meters further down the line is the neutron beam dump. For monitoring of the neutron flux there is a thin film breakdown counter [19] and an ionization chamber monitor in the neutron beam and a Faraday cup at the proton beam dump.

The energy spectrum for the quasi mono-energetic neutron beam has a full energy peak, containing about 40 % of the neutrons, and a low energy tail [11]. In the data analysis, the low energy neutrons can be suppressed using time-of-flight techniques, where the radio frequency from the cyclotron serves as a time reference.

The user at TSL can chose between different collimator sets. There are a number of collimator openings available in the 2 – 30 cm range. For SCANDAL and Medley runs, conical collimators, following a cylindrical part with a defining diameter of 2 cm, are usually used, which gives a beam diameter of 8.2 cm at the SCANDAL target.
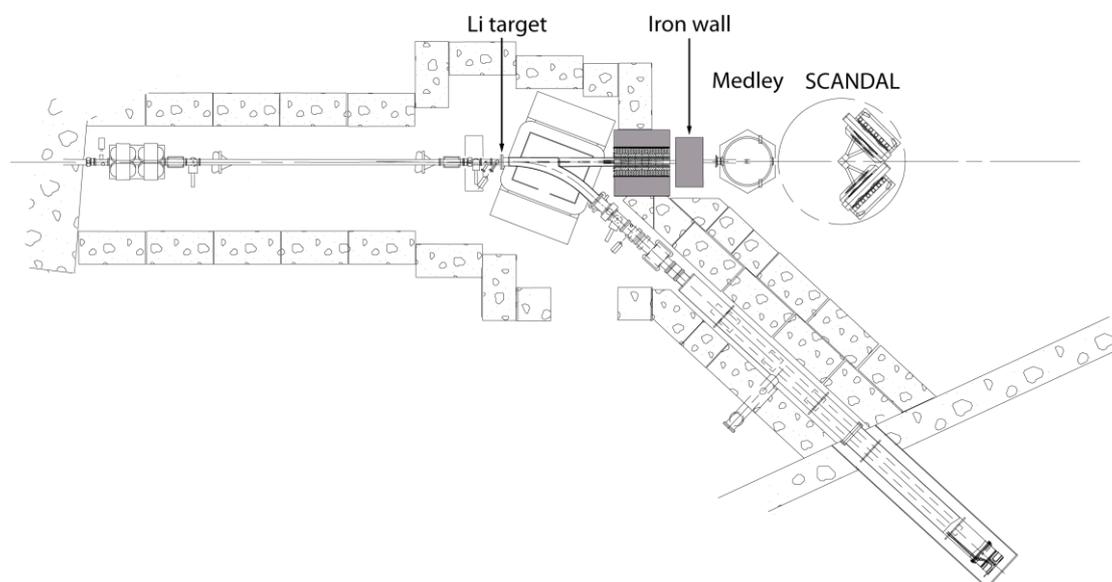

Figure 4: *A schematic view of the neutron beam facility at TSL. The experimental setups Medley and SCANDAL can be seen in the experimental area. The installation of the iron wall has forced SCANDAL 87 cm farther downstream, and the pivot point is now at 727 cm from the lithium target.*

3.2 Recent changes at TSL

A new neutron beam facility was built at TSL in 2004, with emphasis on high neutron beam intensity [11]. For this purpose the distance between the Li target and the experimental area was shortened. The neutron flux was thereby increased by about an order of magnitude. The experimental area now extends from 3 to 15 m downstream from the Li target.

Since 2008, an iron wall can be erected between the lithium target and the user area for additional shielding. It can be seen in figure 4. When the iron wall was installed in the experimental hall, SCANDAL was forced 87 cm downstream to its present position 727 cm from the Li target.

4. Experimental procedure

4.1 Data acquisition

The signals from the SCANDAL detectors are sent to the counting room at TSL, where they are handled using standard CAMAC and VME electronics. For a full description of the data acquisition system, see ref. [4]. The data is recorded on an event-by-event basis using SVEDAQ, a data acquisition system employed at TSL, and is written to disc.
The same data acquisition system as before the changes of SCANDAL is used for the new SCANDAL. Some of the CsI signal input channels are therefore left empty, since the detectors have decreased in number.

4.2 Calibration and energy resolution measurements

The first experiment with the new SCANDAL was carried out during three weeks in January and February in 2009. During the first days of the campaign a few runs in proton mode were devoted to calibration.
The (n, p) reaction on H is used for calibration of the setup, but pure H targets are very impractical. Instead hydrogen rich plastic is used. The multi-target box is filled with five thin plastic targets of thicknesses 1 mm, 1 mm, 0.95 mm, 0.95 mm and 0.95 mm respectively, and two thin carbon targets of a thickness of 1 mm each. The design of the multi-target box makes it possible to identify in which plane the (n, p) reaction took place. After normalization, with regards to the carbon content in the plastic, the carbon spectra can be subtracted from the plastic spectra, leaving a pure hydrogen spectrum. Since each plane can be analyzed individually, the geometry is very well defined and the calibration energy can be calculated to a high precision.
Using a series of thin targets, rather than one thick target, improves the energy resolution without loss of statistics, and the beam time can be kept short. A total of 6 hours of beam time was spent on calibration. Four CsI detectors were calibrated at a time, by placing them at the most forward angles possible, where the full energy peaks are most clearly visible.

4.3 Experimental program

The idea of SCANDAL is to measure cross sections on a series of relevant nuclei. The obvious nuclei to study, for theoretical reasons, are the magical or semi-magical nuclei, ^{12}C, ^{16}O, ^{40}Ca, ^{90}Zr and ^{208}Pb. Other elements common in various applications, such as Fe, U and Si are also interesting. Already, three data sets have been recorded, but not yet analyzed. For the first experimental run, iron and bismuth were chosen as target nuclei. The beam time, in total 120 hours of data collection, was shared between the two targets and background measurements. Natural Fe was chosen because it is a very common construction material in almost all nuclear technology applications. ^{56}Fe is also the most tightly bound nuclei and therefore theoretically interesting. Natural iron is almost mono-isotopic, which gives pure targets. Because ^{209}Bi is very close to ^{208}Pb in mass number, it is of great relevance to the development of theoretical models for nuclear reactions. Luckily it is also mono-isotopic by nature and quite easy to handle as a target material. But ^{209}Bi was also chosen because it is of highest interest for future bismuth/lead cooled reactor concepts.
For the second experimental run, carried out in June in 2009, the scattering cross section for silicon was measured. Data on Si is important for the understanding of radiation damage to electronic devices. Together with Fe and Bi, it also contributes to cover a wide range of mass numbers. Just like iron, silicon is close to mono-isotopic in nature.
SCANDAL is a versatile instrument, since it can be run in both proton mode and neutron mode. An attempt has been made to measure the proton content in ANITA [20], the white neutron beam at TSL, by putting one of the SCANDAL arms in the beam. The results from this test will be reported later.

5. Analysis and results

5.1 Data reduction

The CsI detectors record the energy of the incoming protons. In the spectrum from the calibration run we expect to see a full energy peak of recoil protons from hydrogen in the plastic targets in the multi-target box. We also expect to see a peak of protons created on carbon, in both the carbon targets and the plastic targets, separated from the H-peak by 12.6 MeV. At lower energies we expect a continuum of protons and other charged particles from reactions on carbon. A raw CsI energy spectrum can be seen in figure 5. The hydrogen peak is visible, but the carbon peak is not. The pedestal at zero energy consists of events detected in other CsI detectors.

The SCANDAL data is analyzed using the ROOT software from CERN laboratories [21]. A major part of the background events can be removed from the spectra by particle identification. When plotting the energy loss in one of the plastic scintillators against the energy measured in the CsI for each event, the protons form a band in the plot, as seen in figure 6. These events can be chosen for analysis. Occasional deuterons form a band above the protons, as suggested in the figure. The zero energy depositions in the CsI detectors have been removed by applying a cut at 20 MeV. What remains in the CsI spectra after particle identification can be seen in figure 7.
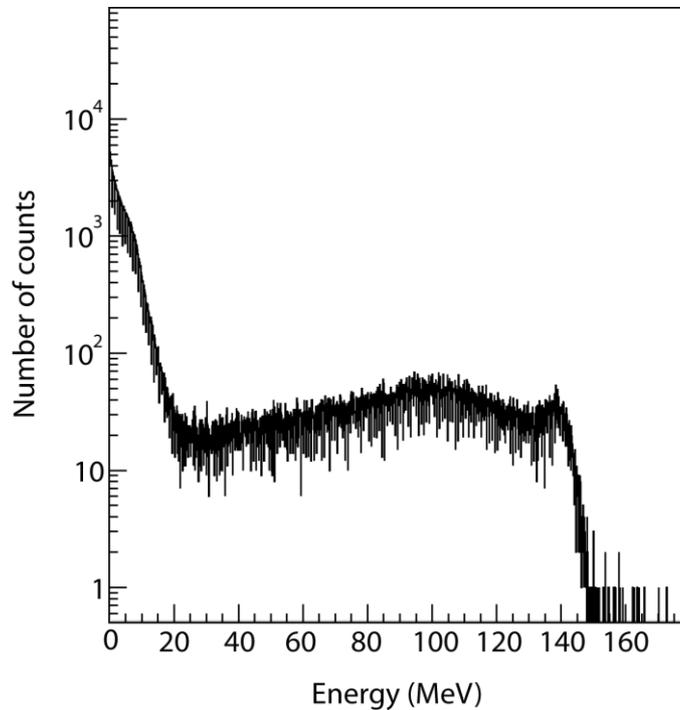

Figure 5: *CsI energy spectrum from the calibration run. This spectrum shows the energy deposited in CsI 4, at about 30˚ in the lab system, during a calibration run where SCANDAL is run in proton mode and there are both plastic and carbon targets in the multi-target box. The full energy peak, consisting of protons from hydrogen in the plastic targets, can be identified. But the expected carbon peak is not visible. The pedestal at zero energy is due to events detected in other CsI detectors. This figure can be compared to figure 10, which is a simulation of the same setup, but at a smaller scattering angle, hence the higher energy in the H-peak.*
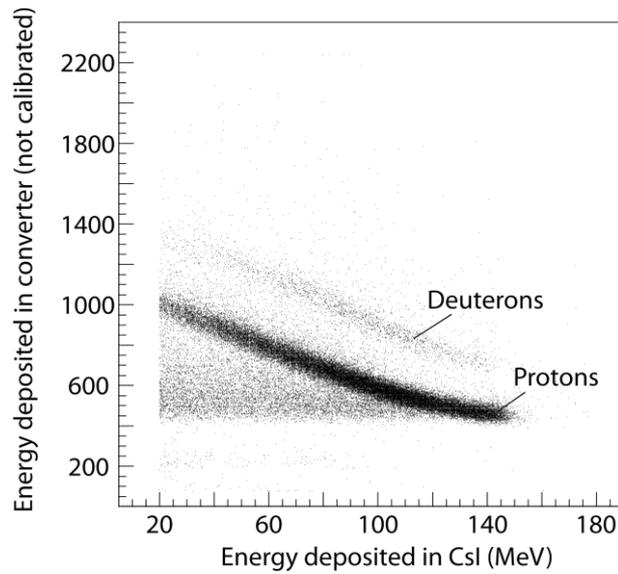
Figure 6: *Particle identification. By plotting the energy loss in one of the plastic scintillators against the full energy measured in the CsI, different particles can be identified. Protons form a distinct band and these events can be chosen in the analysis, and the rest are discarded.*
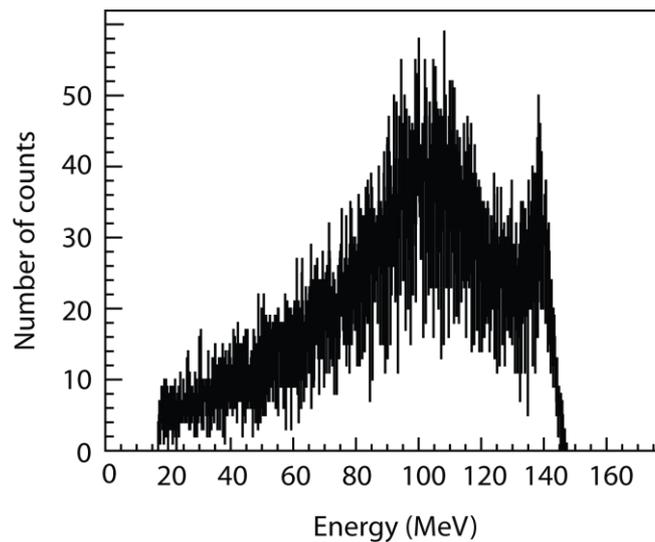

Figure 7: *A CsI spectrum after particle identification. This figure shows an energy spectrum from CsI 4 after particle identification. Zero energy depositions have also been removed.*

5.2 Calibration

The energy calibration of the new CsI detectors is done by identifying the channel numbers for two known features in the pulse height spectra of protons in the calibration runs: the pedestal channel due to events detected in other CsI crystals, corresponding to zero energy, and the full energy peak from (n, p) scattering. A linear relationship between pulse height and deposited energy is assumed. This assumption is valid for a short energy interval only, but it is good enough for the purposes of this analysis. The pedestal channel is easily found by looking at the raw spectra. Fitting a Gaussian to the full energy peak identifies the center channel number. An example of this is shown in figure 8. The energy for this channel number is obtained by calculating the energy of the scattered proton at this particular angle, and the loss of energy between the scattering target and the CsI, taking into account that the path length within the materials varies with the angle. A calibrated spectrum is shown in figure 5.

The pulse height for a certain energy varied with hit position in the CsI crystals in the old SCANDAL

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setup, because of the irregular shape of the crystals. No such correspondence was found in the new SCANDAL. This simplifies the analysis, and no corrections need to be made.
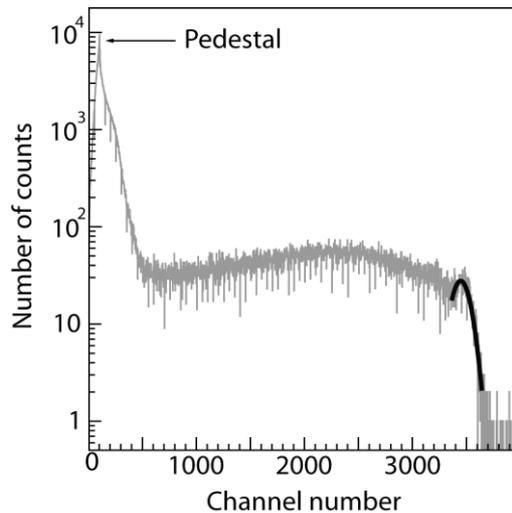

Figure 8: *Energy calibration of the CsI detectors. The pedestal channel, corresponding to zero energy depositions, is easily identified as shown in the figure. The center of the full energy peak is found by fitting a Gaussian to the peak. The calibrated spectrum is shown in figure 5.*

5.3 Energy resolution

When the calibration of the CsI detectors is done, their energy resolution of the setup can be determined. The energy resolution of the CsI detectors was found by fitting Gaussians to the full energy peak and to the background close to the peak, as shown in figure 9, using predefined tools in ROOT. An example is shown in figure 9. The full width at half maximum (FWHM) of the fitted Gaussian defines the resolution. The resolution was found to be on average 5.8 MeV, ranging from 4 to 8 MeV in the different CsI detectors.
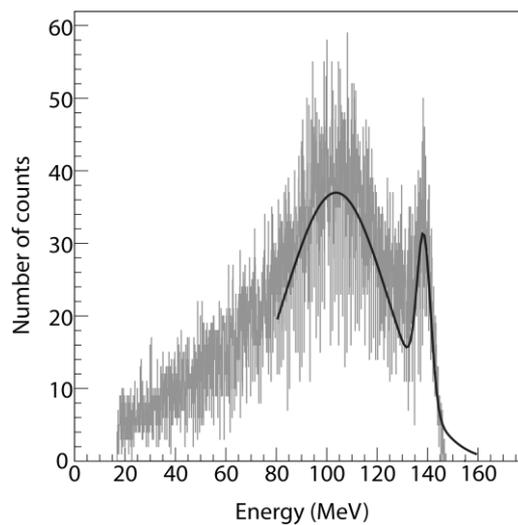

Figure 9: *The energy resolution of the CsI detectors is found by fitting a Gaussian to the full energy peak. The full with at half maximum of the fitted curve defines the resolution.*

Using a Gussian to describe the background is not necessarily the correct choice. At the time of writing, finding the resolution is work in progress. In figure 9 we can se that the fitted curve extends beyond the maximum energy, which indicates that the background would be better described by

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some other shape. For the purpose of finding an upper limit of the energy resolution, this is still a helpful tool.

Performing the same procedure on the data before and after particle identification showed that no improvement of the resolution was to be found this way. Nor does the resolution improve from other cuts that can be applied, because of the great loss of statistics that they cause.

5.4 Simulations

The new SCANDAL setup has been simulated [22], using the software MCNPX [23]. The aim is to provide supportive calculations regarding the efficiency of the plastic scintillators, especially the converter. The geometrical acceptance of events in the new detectors is also investigated. Figure 10 shows a simulated CsI spectrum, corresponding to a calibration spectrum in SCANDAL at small angles. The two peaks, separated by about 12 MeV, are protons produced on carbon and hydrogen respectively in the simulated multi-target box. It can be compared to figure 5, showing experimental SCANDAL data, where only the hydrogen peak resolved. The measured resolution of 5.8 MeV implies that the peaks should be resolvable at small angles. It seems that the experimental data is clouded by a background of something that we do not fully understand.
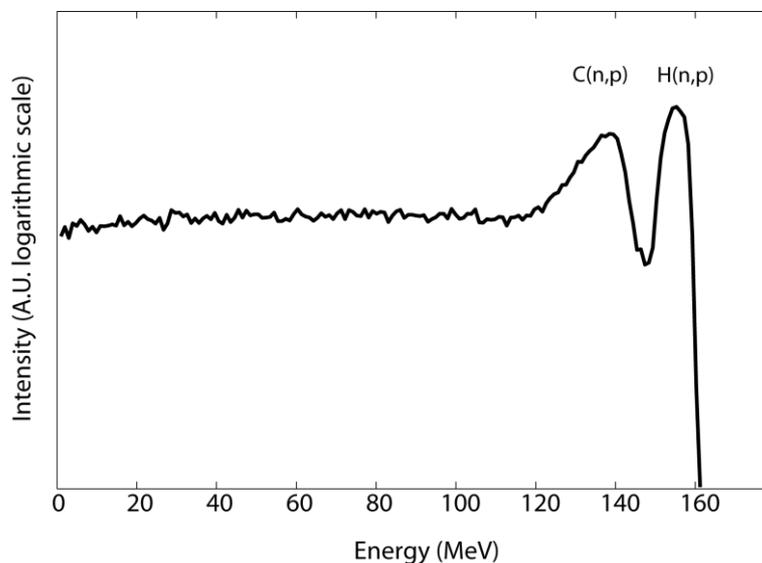
Figure 10: *Simulated data. A simulation of a SCANDAL calibration run, with plastic and carbon targets in the multi-target box, shows that the hydrogen and carbon peaks are clearly separated. This spectrum can be compared to figure 5, which shows the corresponding experimental data, but at a larger angle, hence the difference in energy.*

6. Conclusions and outlook

The conclusion that we can draw so far is that the new CsI scintillators and PM-tubes have been successfully installed on the SCANDAL setup.

The analysis of the acquired data shows that particle identification and calibration can be done successfully with the new setup, as shown in the previous sections. The energy resolution is on average at least 5.8 MeV for the new detectors.

It seems that a major part of the recorded data consists of a background that we do not fully understand. Possibly this contribution can be reduced by optimizing the off-line sorting routines and adjust them to the new situation with higher energy neutrons and different detectors. This work has already started.

Acknowledgements

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