

# The intensive DT neutron generator of TU Dresden

Axel Klix, Toralf Döring, Alexander Domula and Kai Zuber

**Abstract**—TU Dresden operates an accelerator-based intensive DT neutron generator. Experimental activities comprise investigation into material activation and decay, neutron and photon transport in matter and R&D work on radiation detectors for harsh environments. The intense DT neutron generator is capable to produce a maximum of  $10^{12}$  n/s. The neutron source is a solid-type water-cooled tritium target based on a titanium matrix on a copper carrier. The neutron yield at a typical deuteron beam current of 1 mA is of the order of  $10^{11}$  n/s in  $4\pi$ . A pneumatic sample transport system is available for short-time irradiations and connected to two high-purity germanium detector spectrometers for the measurement of induced activities. The overall design of the experimental hall with the neutron generator allows a flexible setup of experiments including the possibility of investigating larger structures and cooled samples or samples at high temperatures.

**Index Terms**—DT neutron generator, fusion neutronics, neutron flux detector

## I. INTRODUCTION

TU Dresden (TUD) has been involved in experimental neutronics and nuclear physics research for several decades. A new neutron laboratory replacing the previous one at the branch campus in the city of Pirna Copitz was constructed by the Institute of Nuclear and Particle Physics (IKTP) in the early 2000 and came into full operation in 2005. It is located at the premises of the Helmholtz-Zentrum Dresden-Rossendorf. The main experimental device is an accelerator-based intense DT/DD neutron generator which is used for a broad variety of experimental work ranging from ultra-low background experiments to the development of radiation detectors for harsh environments.

## II. EXPERIMENTAL INFRASTRUCTURE

### A. Neutron generator

The neutron generator is based on a commercial air-insulated accelerator system purchased from HVEE (Amersfoort, Netherlands). The high voltage supply is of Greinacher multiplier (Cockroft-Walton) type and can produce an output voltage from 30 to 300 kV with a maximum current

of 15 mA. The ion source is a type 358 duoplasmatron (HVEE) which can deliver a deuteron beam of several mA (data sheet, literally). The deuterons are typically extracted with a 45 kV voltage and then analyzed by a mass filter magnet and the selected monatomic  $D^+$  ions directed into the vertically arranged acceleration tube. While passing through a second magnet the deuteron beam is bent into the horizontal and focused onto a solid target by a triplet of quadrupole magnets. The general layout of the machine is shown in Fig. 1.

The neutron-generating targets are copper disks coated with a titanium layer. Tritium/deuterium is absorbed into the titanium layer. The tritium targets currently used were manufactured by SODERN and have an active diameter of 6 cm and are loaded with 20 Ci / 740 GBq of tritium with a tritium/titanium ratio  $>1.5$ . The deuterium targets are loaded to a similar tritium/titanium ratio. The targets are water-cooled on the external side of the tritium/deuterium target to dissipate the deuteron beam power (up to 3000 W).

The vacuum system interface for the target assemblies utilizes standard vacuum parts, it is therefore easily possible to use a different target assembly custom-made for a particular experiment for example to achieve a higher neutron flux density in a sample.

The accelerator is capable of providing the deuterium beam in DC mode as well as in pulsed mode. Pulsed mode is available with pulse widths of 10-100  $\mu$ s and repetition frequencies from 1 to 1000 Hz. The accelerator is also prepared for nanosecond pulsed mode with a pulse width of 30 ns and repetition frequencies of 1, 2, and 5 MHz. A buncher is currently not installed in the beam line.

All functions of the accelerator are controlled by a PC via CAN bus interfaces. The PC is connected to the CAN bus controllers in the accelerator via optical fiber.

Primary monitoring of the neutron source is done through counting of the alpha particles associated with the DT reaction in the tritium target and the protons associated with the branch of the DD reaction resulting in  $p + {}^3\text{He}$ . For this purpose, a silicon surface barrier detector is mounted in the beam line which is shielded from scattered accelerator deuterons by a 4  $\mu$ m aluminum foil. The detector is 69.2 cm away from the tritium target and approximately 2 cm above the beam line. It is covered by an aperture with a diameter of 1.55 mm. The deuterium targets are mounted with a slightly different target assembly, in this case the distance between the silicon detector and the deuterium target is 50.0 cm. Additional monitoring is provided by a fission chamber loaded with 85 mg of  ${}^{238}\text{U}$ .

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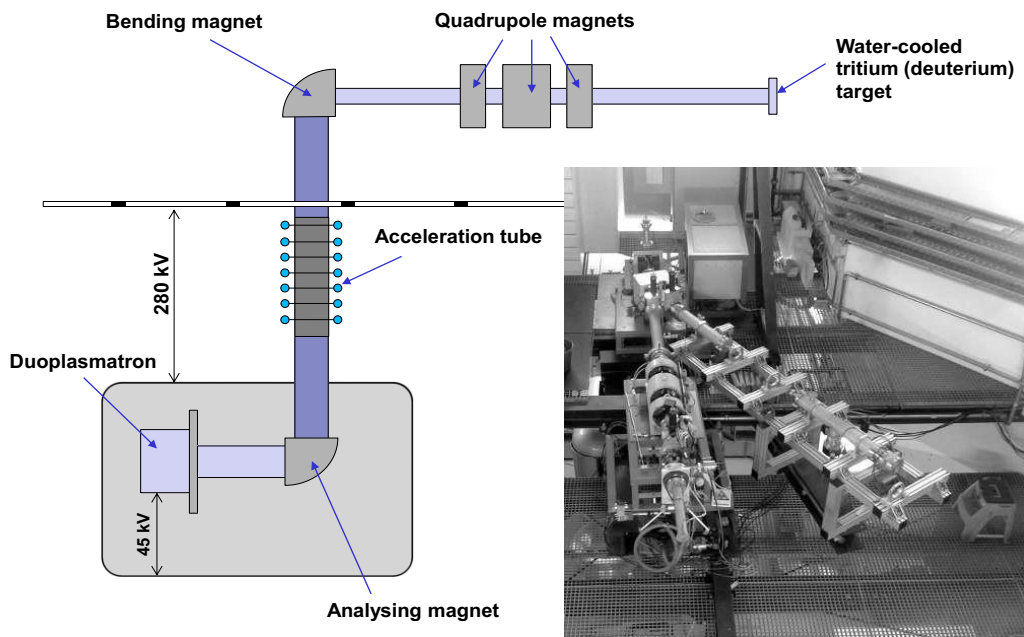


Fig. 1. Layout of the accelerator and photograph of the two beam lines in the second level. The left beam line ends in the wobble target. The right beam line is under construction.

The target of the neutron generator is at a height of 4.40 m above the floor of the experimental room and >4.00 m to the walls. The room has a height of 8.90 m, a length of 10.50 m and a width of 8.00 m. Structures in the room are kept to a minimum to reduce the influence of room-scattered neutrons as much as possible.

**B. Radio nuclide neutron and gamma sources**

Three radio nuclide neutron sources are available for measurements and calibration:

TABLE I  
AVAILABLE RADIO-NUCLIDE BASED NEUTRON SOURCES

Source	Activity <sup>*)</sup> (Bq)	Neutron yield (n/s)
AmBe	$1.71 \times 10^{11}$	$1.25 \times 10^{7**}$
<sup>252</sup> Cf	$1.56 \times 10^5$	$1.81 \times 10^4$
<sup>252</sup> Cf	$4.90 \times 10^7$	$5.70 \times 10^6$

<sup>\*)</sup> activities as of July 2017

<sup>\*\*)</sup> using a standard conversion factor of  $2.7 \times 10^6$  n/Ci

These neutron sources are complemented by a <sup>137</sup>Cs source with an activity of  $1.35 \times 10^7$  Bq and a <sup>60</sup>Co source of  $6.29 \times 10^5$  Bq, both activities as of July 2017. In addition, various gamma sources with several tens of kBq are available for calibration purposes.

**C. Pneumatic sample transport system**

A pneumatic sample changer (PSC) was constructed in collaboration of KIT and TUD with the aim to provide a test bench for the development of a neutron activation system for the European test blanket modules (TBM) for ITER and for the study of short-living induced activities [1].

Up to thirty samples can be prepared and kept ready for irradiation in a storage. The storage can serve also for keeping samples for a certain cooling time. The PSC can transport samples to two high-purity germanium (HPGe) detectors. The irradiation end can be positioned freely to some extent, in particular it can be also used to irradiate samples for example inside a blanket assembly which is important for the development of a neutron activation system for the TBMs or simply to shape the neutron spectrum and enhance the fraction of thermal neutrons.

The PSC is controlled by a programmable logic controller (PLC). The PLC exchanges transport orders and status information with a PC via RS232 connection. Low level control of the PLC is done via a set of orders which are programmed into the PLC. This set of orders is extendable by reprogramming the PLC. High level control of the system is

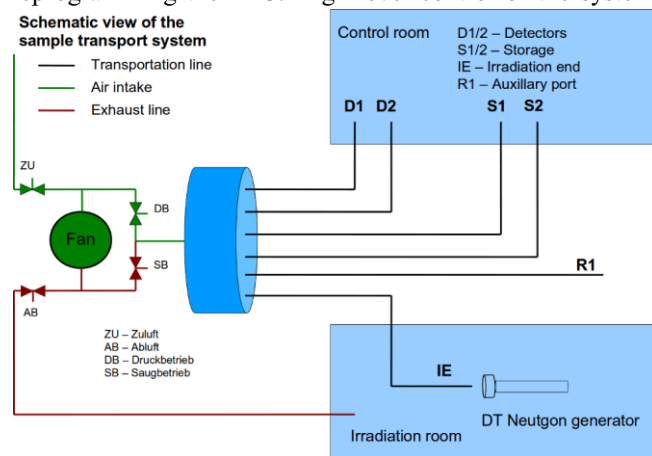


Fig. 2. Schematic view of the pneumatic sample transport system for neutron activation measurements.

provided by a LabView interface and a C# interface which were both written locally. They allow to set up a measurement program to process a set of samples.

The sample containers can hold a cylindrical sample with either 1.0 or 1.8 cm diameter. Their typical transport time from the irradiation end to one of the gamma spectrometers is approximately 11 s. This comparably long time is due to the special design of the distributor of the PSC which must ensure that activated air from the irradiation end cannot be released into occupational areas.

#### D. Detectors for neutrons and photons

Two HPGe detectors with an efficiency of 30% are available on-site, a horizontally oriented DSG NGC-3019 and a vertically oriented ORTEC GEM25P4-76. Several multi-channel analyzer options are available for gamma spectrometry: a) digital signal processor (DSP) Lynx (Canberra), b) DSP DT5780 (CAEN), c) analog processing with a MPA-3 system (multi-parameter acquisition system from FastComtec).

Two NE-213 liquid scintillators are available for neutron/photon spectroscopy in the MeV range. The NE-213 scintillator allows to discriminate photons and neutrons by means of pulse shape analysis. One of the detectors is of cylindrical shape with a diameter of 1.5" and a height of 1.5" and coupled to the photo multiplier unit via a 50 cm long light guide. The second NE-213 detector is also of cylindrical shape but with a diameter of 2" and a height of 2". Both detectors are made available from PTB Braunschweig through a mutual research agreement. The detectors were characterized experimentally at PTB, and response matrices for neutrons and photons are available for unfolding calculations [2]. An analog pulse shape discrimination and pulse height analysis system based on a Canberra PSD and the MPA-3 mentioned above had been used in previous experiments. Recently a DT5720 digitizer with digital pulse shape discrimination capability has been purchased from CAEN.

Two proportional counters LND 281 (LND Inc.) filled with 405.3 kPa hydrogen and a small addition of N for in-situ calibration are available for medium energy neutron spectroscopy.

A  $^3\text{He}$  proportional counter tube 24NH15 (Canberra), several  $\text{BF}_3$  counter and Li glas scintillators are available for online thermal neutron detection.

### III. EXPERIMENTAL PROGRAM

The activity induced by fast neutrons is of concern for many application areas. IKTP plays a leading role in several ultra-low background experiments in search for the double-beta decay. Detector material activation by cosmogenic neutrons needs to be understood and supporting experiments with TUD-NG are ongoing to study for example nuclear level schemes and decay chains [3]. Similar experiments are performed to check evaluated nuclear data files utilized in shut-down dose rate calculations for fusion reactors [4].

The understanding of the neutron and photon transport in materials and structures is of importance for radiation

shielding applications in areas ranging from medical to energy production but also for the design and operation of fusion reactor breeding blankets. A series of experiments with simple mock-ups of European fusion reactor tritium breeding blankets were performed with the aim to measure neutron and photon flux spectra under DT neutron irradiation inside the mock-ups and compare the measurements with simulations [5,6].

In the last years a program to develop radiation detectors for harsh environments was undertaken in collaboration with several European universities and research institutions. The work aims in particular at qualifying nuclear instrumentation for the European ITER TBM. Among others, the PSC is used to test activation probes for a neutron activation system [7], silicon carbide fast neutron detectors have been successfully tested at operating temperatures up to 500 OC under DT neutron irradiation, and self-powered neutron/photon detectors are investigated in a similar way.

Other applications of the neutron generator cover such fields as single event upset tests in microprocessors, cross section measurements of neutron reactions relevant for astrophysics and geology and others.

#### REFERENCES

- [1] A. Klix, A. Domula, U. Fischer, D. Gehre, P. Pereslavtsev, I. Rovni, "Test Facility for a neutron flux spectrometer system based on the foils activation technique for neutronics experiments with the ITER TBM," *Fus. Eng. Des.* 86 (2011) 2322.
- [2] M. Guldbakke, H. Klein, A. Meister, U. Scheler, S. Unholzer, J. Pulpan, M. Tichy, "Response Matrices of NE213 Scintillation Detectors for Neutrons," *Proc. of the Eighth ASTM-EURATOM Symposium on Reactor Dosimetry*, 29 Aug.-3 Sept 1993.
- [3] A. Domula
- [4] A. Klix, A. Domula, R. Forrest, K. Zuber, "Measurement and Analysis of Activation Induced in Titanium with Fusion Peak Neutrons," *J. Nucl. Mat.* 417 (2011) 688.
- [5] K. Seidel, P. Batistoni, U. Fischer, H. Freiesleben, A. Klix, D. Leichtle, E. Poenitz, S. Unholzer, R. Villari, "Measurement and analysis of neutron and gamma-ray flux spectra in a neutronics mock-up of the HCPB Test Blanket Module," *Fus. Eng. Des.* 82 (2007) 2212.
- [6] A. Klix, P. Batistoni, R. Böttger, D. Lebrun-Grandie, U. Fischer, J. Henniger, D. Leichtle, R. Villari, "Measurement and Analysis of Neutron Flux Spectra in a Neutronics Mock-up of the HCLL Test Blanket Module," *Fus. Eng. Des.* 85 (2010) 1803.
- [7] A. Klix, A. Domula, U. Fischer, D. Gehre, G. Kleizer, I. Rovni, "Preliminary experimental test of activation foil materials with short half-lives for neutron spectrum measurements in the ITER TBM," *Fus. Sci. Techn.* 64 (2013) 604
- [8] D. Szalkai, R. Ferone, F. Issa, A. Klix, M. Lazar, A. Lyoussi, L. Ottaviani, P. Tüttő, and V. Vervisch, "Fast Neutron Detection With 4H-SiC Based Diode Detector up to 500 °C Ambient Temperature," *IEEE Trans. Nucl. Sci.* 63(3) (2016) 1491
- [9] Spnd Prasoon P. Raj, A. Klix, M. Angelone, U. Fischer, "Self-Powered Detectors for ITER Test Blanket Modules," *IEEE Nuclear Science Symposium*, Strasbourg, France, November 3, 2016