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# JRC MONNET – the intense fast-neutron source for fundamental and application-driven research

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Abstract. MONNET is a fast-neutron source based on a 3.5 MV tandem accelerator, located at the Geel (BE) site of the Joint Research Centre. It became operational in 2020. MONNET may deliver intense neutron beams in the energy range from 30 keV to 10.1 MeV and from 12.8 MeV to 24 MeV. Neutrons are generated by means of nuclear reactions in the target material (e.g. protons or deuterons on lithium-7, tritium or deuterium targets). MONNET delivers a neutron flux of up to $10^{10}$ n/sr/s, depending on the producing reaction and the neutron energy. Neutron beams are essentially mono-energetic ( $E_n/E_n < 6\%$ with $E_n > 300$ keV). The accelerator may also be used with proton and deuteron beams. Alpha beams will be offered soon. Photon beams are possible and presently under investigation.
The research program ranges from cross section measurements (e.g. (n, f), (n, p), (n, ) as well as (p, p′), (p, n) and (p, ), nuclear fission research, material studies (e.g. radiation-induced damage), to the investigation of advanced methods in nuclear technologies, safety and security. The MONNET neutron source offers beam-time to external user within the JRC EUFRAT Open Access program. Proposal evaluation by an independent panel is taking place up to two times per year.

## 1 Introduction on the JRC

MONNET is a fast neutron source based on a tandem-accelerator, located at the Geel (BE) site of the Joint Research Centre (JRC). The JRC is the European Commission's science and knowledge service. JRC's mission is to support European Union policies with independent science evidence throughout the whole policy cycle. The JRC is policy neutral as it does not have a policy agenda of its own. The Geel site of the JRC is located in Belgium and it is one of the six sites of the JRC. The other sites are in Ispra (Italy), Petten (Netherlands), Karlsruhe (Germany), Seville (Spain) and Brussels (Belgium). The Geel site hosts several multidisciplinary research facilities and laboratories. Two particle accelerators are present and are mainly dedicated to nuclear physics research: MONNET and GELINA [1].

## 2 The MONNET facility

The MONNET facility was commissioned in 2020. It hosts a tandem accelerator of 3.5 MV in a vertical orientation (fig. 1). Experiments were already performed in the facility with several applications: high social impact activities (e.g. studies of explosives identification in shells, studies of medical isotopes production), nuclear safeguards and security (e.g. detectors characterization), fundamental physics (e.g. fission studies, cross sections, nuclear reactions). Various of these experiments were promoted by the EUFRAT open-access programme of the JRC (see sec. 5 and [2]). There is also a section of the facility dedicated to nuclear fission studies using Frisch-grid ionization chambers in conjunction with the VErsatile Spectroscopy Array (VESPA). This array, consisting of a selection of lanthanide-halide scintillator detectors is used for measuring prompt gamma rays generated in nuclear fission.

## 3 The tandem accelerator and experimental facility

The accelerator at MONNET may deliver intense neutron beams in the energy range from 30 keV to 10.1 MeV and from 12.8 MeV to 24 MeV. Neutron beams are quasi-mono-energetic depending on the desired energy ( $E_n/E_n < 6\%$ with $E_n > 300$ keV). The tandem accelerator (Fig. 1) is equipped with a Toroidal Volume Ion Source (TORVIS) [3] that can produce hydrogen or deuterium beams. There are plans to provide with the same source helium beams in the future. The beams are guided by the beamline (Fig. 2) to a target in which the neutrons are generated by means of nuclear reactions in the target material. Currently used beam-target combinations are: protons or deuterons on lithium-7, tritium or deuterium targets. The target may be air-cooled or liquid-cooled with distilled water, depending on the desired ion-beam power. The water cooling allows higher ion currents on target and, therefore, to generate a higher neutron flux. Depending on

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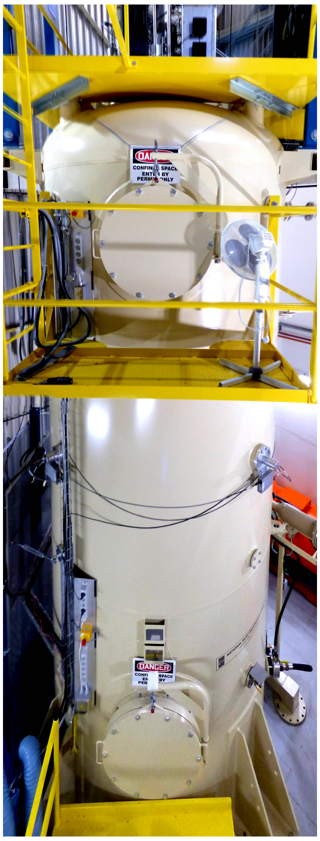

**Figure 1.** Picture of the vertical tank of the tandem accelerator of the MONNET facility.

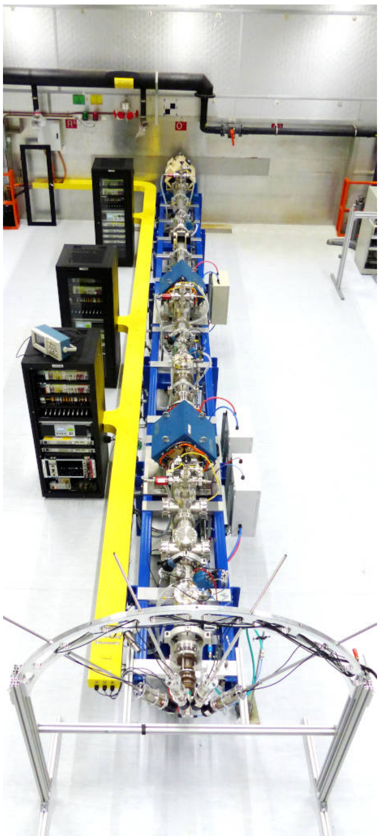

**Figure 2.** Beamline of the MONNET facility. The picture shows the target portion in which the neutrons are generated by means of nuclear reactions in the target material.

the neutron energy, however, the effect of the water layer on the neutron spectrum might need to be taken into account during data analysis. Beams may be pulsed in two regimes of repetition rate: from 100 Hz to 5 kHz (with a selectable duty cycle) or from 600 kHz to 2.5 MHz (with a “buncher” that reduces the bunches' temporal widths to 2 ns). The theoretical achievable neutron fluxes range from $10^6$ n/s/sr to $10^9$ n/s/sr, depending on the beam-target combinations. The target hall (fig. 3) is a relatively empty room to reduce the backscattering of neutrons onto the experiments. It can host set-ups close by the target and up to 7 m away from the target, if the Time-of-Flight (ToF) of neutrons is to be measured. Two high-purity germanium detectors, each located in a lead castle, are available for high resolution gamma ray spectrometry.

## 4 Beam monitoring systems

A beam monitoring system, composed of several detectors, is installed in the target hall (fig. 3). A liquid scintillator (EJ-301) and two CeBr$_3$(Ce) detectors are used to monitor the beam for experiments with the ion beam in the fast pulsing regime. The liquid scintillator provide information about the temporal width of the beam bunches, as well as on the neutron energy by measuring the neutron ToF (Fig. 4). The CeBr detectors are mainly used to obtain information about the bunch width and to monitor the beam-target interaction in the gamma flash region. One CeBr detector is positioned close to the target in a backscattering geometry, in order to reduce the neutron flux on it. A second detector is positioned at about 7 m from the target for high-current experiments.

During the experiment the average neutron flux may be monitored employing Proportional Long Counters (PLC). One movable PLC is normally located at 6 m at an angle of 30 in respect to the beam direction. A second is at a fixed position at 90 with respect to the beam direction. The target is electrically insulated from the beam-line and it is possible to directly measure the beam current on it, also when it is water-cooled. The data from the detectors and the measured beam current are synchronized (Fig. 5) to produce an accurate estimate of the overall integrated charge on the target during irradiations. The beam current information may be synchronized also with the user data, if using the ABCD data acquisition framework [4–7]. ABCD is an open source framework, maintained by the team at MONNET, that may be used with signal digitizers of multiple vendors[1]. External users may use their own detectors and data acquisition systems or may choose to use our equipment and signal digitizers.

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[1] It is available in the official repository on https://github.com/ec-jrc/abcd/

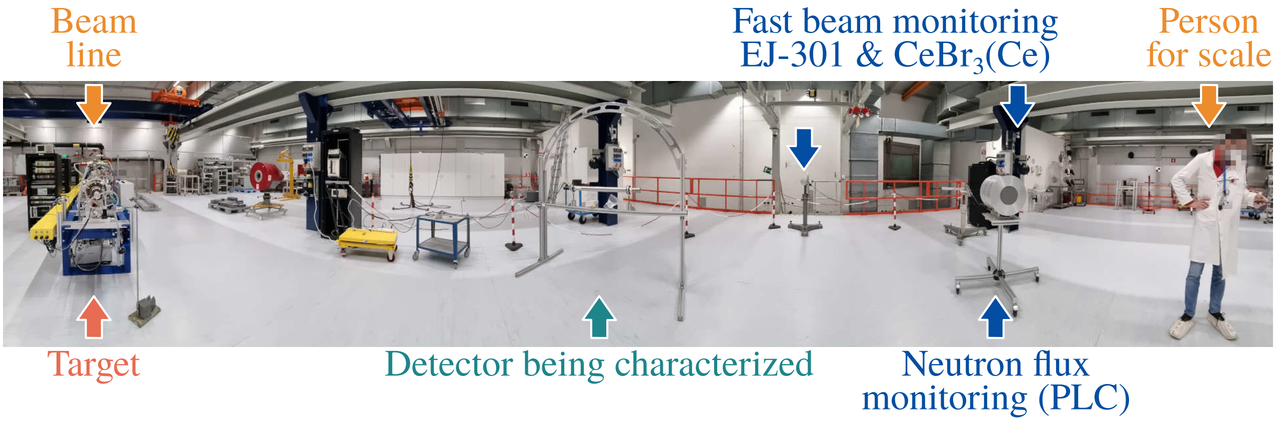

**Figure 3.** 270 panorama view of the target hall of the MONNET facility. The end of the beamline is on the leftmost with a direct view of a water cooled target. A detector being characterized is on the center mounted on an aluminum frame. The detector distance from the target is 6 m and it is at a 30 relative to the beam direction. A set of three detectors is on the right, they are used for the beam monitoring system. A liquid scintillator (4” 1”, EJ-301) is at 7 m from the target and at an angle of 10. Its purpose is to monitor the beam bunches in the fast repetition regime, in order to determine the bunches width and the neutrons energy (fig. 4). A proportional long counter (PLC) is located at 6 m at an angle of 30 from the beam direction. Its purpose is to monitor the neutrons flux during the experiment. Finally a small CeBr$_3$(Ce) scintillator (1” 1”) is located on the black column to monitor the beam bunches in the fast repetition rate. It is applicable in high current experiments. A twin CeBr detector is located close to the target for the same purpose for low current experiments. It can be seen over the yellow cables duct on the left of the target.

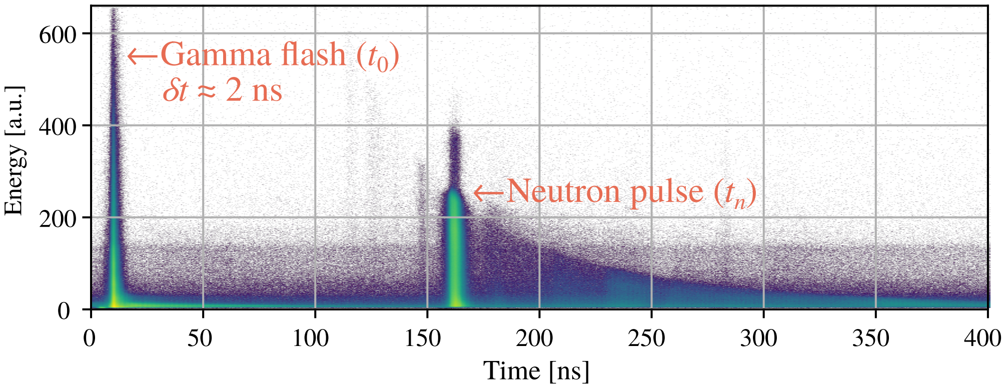

**Figure 4.** Energy vs. Time-of-Flight (ToF) spectrum acquired with an EJ-301 liquid scintillator (Fig. 3) during a fast pulsing regime experiment. Beam bunches were produced with a uniform rate of 2.5 MHz; their temporal width is 2 ns. The gamma flash is evident as a distribution at low values of the ToF. It reaches higher detected energy values compared to the neutron distribution. The neutron distribution is at ToF values around 170 ns. The neutron energy is $E_n$=6.55 MeV. Its energy end-point corresponds to the maximum neutron energy and it matches the expected ToF. Some pile-up is evident above the neutron distribution due to the high-rate of that experiment. On the plot it is evident that there is a tail of neutrons of lower energies.

## 5 EUFRAT, Open Access to the nuclear research infrastructure at JRC-Geel

The JRC invests in unique research infrastructures, which are instrumental in accomplishing the mission to support the policy cycle of the European Union, with independent science evidence. We aim at collaborating with researchers and industry from EU Member States and associated countries. In this framework, since 2005 JRC-Geel offers access to its nuclear facilities to external users[2]. Access scheme of the EUFRAT programme is according to two principal modalities: market-driven access, granted upon payment of a fee (targeted at industry) and relevance-driven access, which depends on scientific and socio-economic relevance at European level (targeted at research). The benefits for users are multiple, access to unique research infrastructures, support in experiment design, contributions to education programs, knowledge dissemination and fostering collaboration at EU level. There is also the possibility of requesting financial support to students for short and long term visits (e.g. for PhD programs). Proposals evaluation by an independent panel is taking place up to two times per year.

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[2] For more information see https://ec.europa.eu/jrc/en/research-facility/open-access

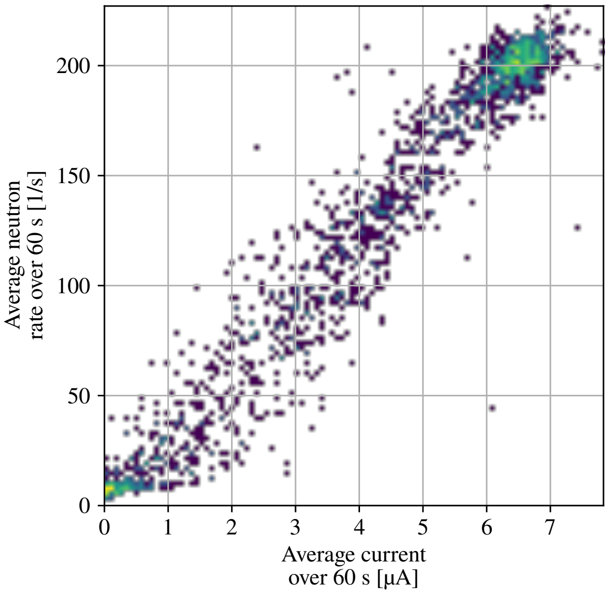

**Figure 5.** Dependency of the measured neutron rate on the measured current on target. The neutron rate is determined with the PLC for beam flux monitoring PLC (fig. 3). The detector data and the beam measurement are synchronized on-line with the ABCD data acquisition framework. They may also be synchronized with the users' detectors data.

## 6 Conclusions

We presented here the recently commissioned JRC MONNET facility. It hosts a 3.5 MV tandem accelerator that is employed to generate intense fast-neutron beams. Neutrons are generated by means of nuclear reactions in suitable target material. Depending on the desired energy, it is possible to have a quasi mono-energetic neutron spectrum ($\Delta E_n/E_n < 6\%$ with $E_n > 300$ keV). Beams may be pulsed in two regimes of repetition rate: from 100 Hz to 5 kHz (with a selectable duty cycle) or from 625 kHz to 2.5 MHz (temporal widths of 2 ns). The target hall can host experiments placed close to the neutron-generating target, as well as experiments up to 7 m far away from the target for time-of-flight measurements of the generated neutrons. The facility is open to external users under the EUFRAT programme, that can provide access and funding for experiments.

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