

NEUTRA 2.0 – Upgrade of a pioneering instrument

P Trtik¹, U Filges², A Bollhalder², A Ivanov³, A Kalt², M Lehmann², T Mühlebach², M Schild², S Thürsam², J Welte², P Boillat^{1,4}, M Busi¹, J Hovind¹, A Kaestner¹, D Mannes¹, E Polatidis¹, M Strobl¹

¹Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

²Laboratory for Neutron and Muon Instrumentation, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

³Accelerator Operations and Development, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

⁴Electrochemistry Laboratory, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

pavel.trtik@psi.ch

Abstract. After more than 25 years of successful operation of the thermal neutron imaging instrument NEUTRA, the NEUTRA 2.0 upgrade project has been approved. This upgrade implies a complete reconstruction of the instrument including a redesign of the shielding bunker. The inner usable area of the bunker will be increased thus creating ample space required in modern neutron imaging instruments for complex set-ups with bulk sample environments. Likewise, full access to an upstream measuring position, MP1, of the beamline will allow utilizing about half an order and one order of magnitude higher flux than at the currently accessible measurement positions MP2 and MP3, respectively. These measures will enable higher temporal resolution neutron imaging investigations and the use of the Neutron Microscope detector at NEUTRA. Together with more available space the higher flexibility of the interior arrangement will enable accommodating components for advanced neutron imaging techniques such as in-situ simultaneous bimodal neutron/x-ray imaging, time-of-flight imaging and thermal neutron grating interferometry. While the upgrade will enable advanced neutron imaging capabilities at NEUTRA 2.0, the instrumentation and techniques that were pioneered at NEUTRA in the past, like the XTRA option for in-line bimodal neutron/X-ray imaging and the NEURAP insert for neutron imaging of highly radioactive samples will be retained in the suite of the available modalities at the beamline.



1. Introduction

NEUTRA, the thermal neutron imaging instrument [1] of the Applied Materials Group (AMG) of the Laboratory of Neutron Scattering and Imaging (LNS) at the Paul Scherrer Institut (PSI), Switzerland, had been built at the end of the previous millennium as one of the day-one instruments of the Swiss neutron spallation source SINQ [2]. NEUTRA as a dedicated neutron imaging instrument with digital detectors became established the state-of-the-art of thermal neutron imaging facilities at the time. Its long-lasting success can be measured, among other criteria, by the high number of publications linked with experiments performed there [3], by the high request and overbooking for allocation of beamtime for academic research and an ever growing demand from industry [4]. Likewise, numerous applications of neutron imaging as well as experimental techniques that are state-of-the-art today at many neutron imaging instruments around the world were pioneered at NEUTRA.

However, despite its successful history, the ageing instrument today requires an upgrade and renewal considering the demands of advanced methods and experiments. As a result, it has been decided that NEUTRA will be upgraded within the framework of a multi-faceted, multi-instrument upgrade project (AM-UP) of the Applied Materials Group (AMG). Led by AMG (formerly known as Neutron Imaging and Activation Group), the project is supported – as can be seen from the broad scope of the co-authorship of this paper – by a large number of other groups and laboratories at the Paul Scherrer Institute (PSI). The AM-UP project is financially supported by the PSI and the Norwegian Center for Neutron Research (IFE) in the frame of a collaboration agreement.

The upgrade is intended to ensure a world-class instrument for more pioneering work in the future and will foster more seminal science to be performed at the upgraded NEUTRA 2.0 instrument. As the project is currently in progress, the purpose of this manuscript is to summarize the aims of the upgrade of NEUTRA and provide the readership with a first glimpse into expected design solutions of the upcoming upgraded instrument.

2. NEUTRA 2.0

The upgrade of the thermal neutron imaging instrument NEUTRA has manifold aims. While the existing installations are aging, many of them requiring replacement, the general layout of the instrument has been reconsidered with the aim to offer more space and installations for state-of-the-art and seminal new applications. Consequently, a significant enlargement of the space available inside the bunker shielding has been a key requirement for the upgrade (Fig. 1).

2.1. Bunker enlargement

With the floorspace in the current NEUTRA bunker being approximately 15 square meters, the space availability and access around the sample positions is suboptimal. While at the most downstream measurement position (MP3) there is sufficient space also for larger samples and environments, the middle position (MP2) is extremely limited in access and space around the sample position, limiting severely possible installations of samples and sample environments, as well as human access. The most upstream position (MP1), providing the highest flux and relaxed collimation conditions is basically not accessible for measurements. NEUTRA has a fixed 20-mm circular pinhole. This condition will remain the same even after the upgrade.

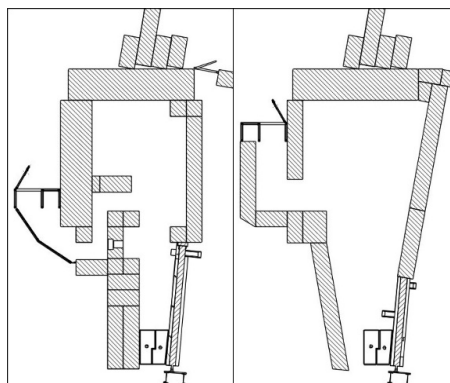


Figure 1. Schematic comparison of the bunker plan of the current (left) versus the upgraded (right) NEUTRA beamline

The available floor space inside the new instrument, NEUTRA 2.0, will be significantly increased to approximately 23 square meters. This is a vast improvement in accessible space for support equipment, sample environments and human interaction for setting up and instrumentation/sample alignment. Figure 1 schematically compares the current and the upgraded versions of the NEUTRA instrument bunker. The bunker area enlargement will be achieved in two ways. First and foremost, thanks to the use of high-density concrete, the thickness of some of the shielding walls will be reduced from 1.0 meter to approximately 0.5 meter. Second, the position of the side walls to both neighboring instruments, the high resolution powder diffractometer HRPT [5] and the materials science pulse overlap diffractometer POLDI [6], will be adjusted. The clearance of the current NEUTRA bunker is 2.5 meters. An increase in bunker space in the third dimension has been considered initially, however, it was found to be beyond achievability within the project and thus the height of the ceiling will remain unchanged. The direct consequence of this is that no permanent crane can be installed inside the NEUTRA 2.0 bunker and, thus, heavy equipment manipulation and insertion still relies on the main crane of the SINQ hall.

Similar to the existing version of the instrument, the access to the bunker will be provided through a chicane-like labyrinth, however, with increased space for passage with equipment. In the very early design stages of the upgrade project, a version with access to the beamline bunker by means of a sliding door (similar e.g. to the one used at ANTARES at FRM2 [7], or at the prospective instrument ODIN at the European Spallation Source (ESS) [8]) has been considered, as it could have enabled an even larger bunker extension and access passage. However, as the beamline is partly positioned on a lid (concrete block) that allows access to the underground part of the SINQ neutron source, this alternative has been dropped.

2.2. Measuring positions and substructures

The NEUTRA 2.0 instrument interior is designed to leverage well proven in-house solutions providing high compatibility with the cold neutron imaging instrument ICON at PSI [9]. Therefore, the substructure is designed using LINOS (X95) profiles that will ensure the same height of the beam centre above the optical bench as at ICON. Similarly, light-weight modular vacuum flight tubes will be utilized at NEUTRA 2.0. Furthermore, the supply with various media (such as gas piping, cooling water, ventilation, etc.) for the different measurement positions will be improved compared to the current version of NEUTRA. The preliminary design of the interior of NEUTRA 2.0 is depicted in Figure 2.

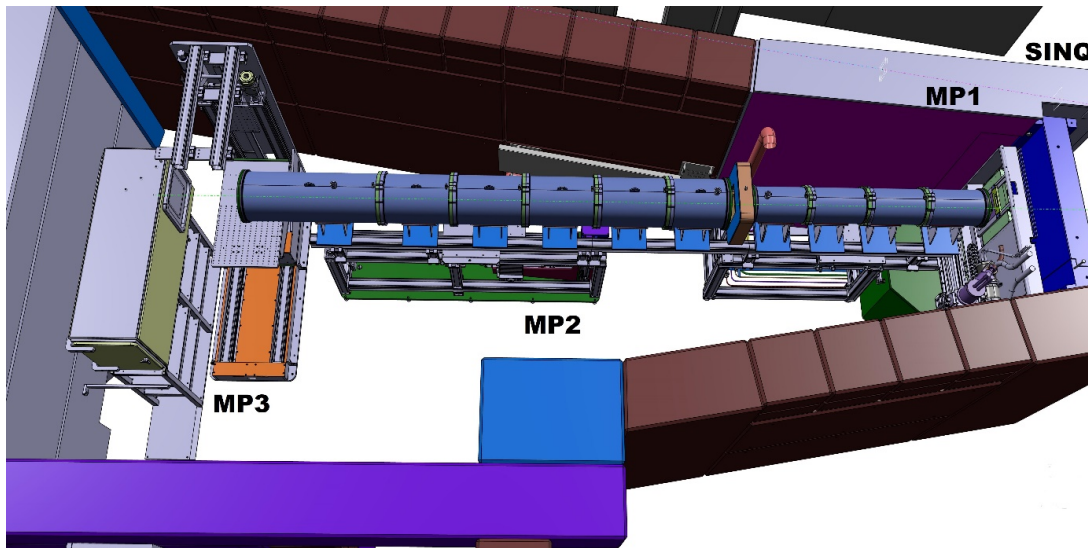


Figure 2. Preliminary design of the shielding walls and the bunker interior of NEUTRA 2.0 beamline. Roof shielding not shown.

Currently, only two positions (MP2 and MP3 at the respective distances of approximately 7.3 meters and 10.5 meters from the beam defining aperture) are routinely utilized for experiments. The upgrade project will allow additional full access to the currently unused front position MP1 at approximately 4.4 metres from the beam-defining aperture. This provides a measurement position with about half an order and one order of magnitude higher flux than at the currently accessible measurement positions MP2 and MP3, respectively, due to the correspondingly lower collimation ratio at this position. High-temporal resolution neutron imaging [10], as well as the optional installations of advanced instrumentation for neutron imaging (see Chapter 2.4) are foreseen at the front position MP1. Enabling access to the position MP1 requires the installation of a permanent additional shielding wall inside the bunker in vicinity of the monolith wall of SINQ (dark blue wall in Figure 2) which will shield fast neutron radiation originating from the adjacent instrument POLDI. The measurement positions MP1 and MP2 will be equipped with redesigned sample stages which will include the option for remote controlled black-body devices for background correction [11][12].

2.3. Retained existing instrumentation

NEUTRA 2.0 will retain the capability of the XTRA option for in-line bimodal neutron and X-ray imaging [13]. It is currently foreseen that the available X-ray source (GE ISOVOLT-Titan 320) will be transferred to NEUTRA 2.0, but will require longer cables between the source itself and its power supply. An upgrade of XTRA with a new X-ray source is being considered for later stages of the upgrade project.

Likewise, the rather unique NEURAP instrumentation [14] dedicated for imaging of highly radioactive samples will be retained as an optional add-on in the upgraded version of the instrument. The position of the NEURAP set-up will be moved approximately 0.4 meters upstream (see Figure 3 - NEURAP positioned upstream of MP2), correspondingly leading to a 12 percent increase in the available flux. The principal difference for the operation of NEURAP in the upgraded instrument will be new safety requirements. While in the existing version of NEUTRA, the dysprosium-based imaging plates are loaded from the chicane-shaped entrance labyrinth via a small window in the shielding block, the loading of the imaging plates into NEURAP will be performed from inside the enlarged bunker in the future.

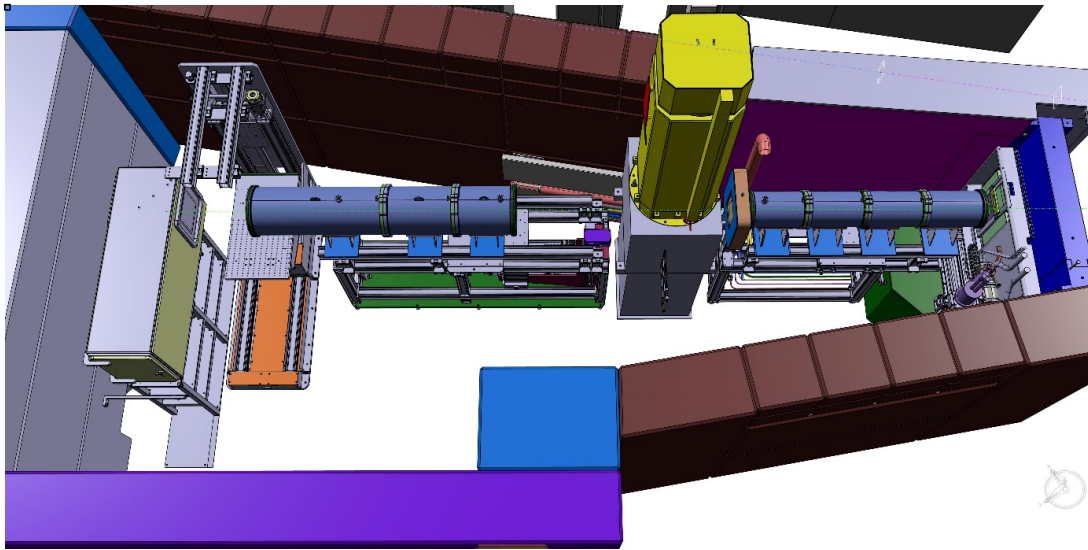


Figure 3. Installation of the NEURAP instrumentation dedicated for imaging of highly radioactive samples at NEUTRA 2.0 beamline. Roof shielding not shown.

2.4. Foreseen novel instrumentation

NEUTRA 2.0 will provide much more flexibility for the installation of various instrumentation than the current instrument.

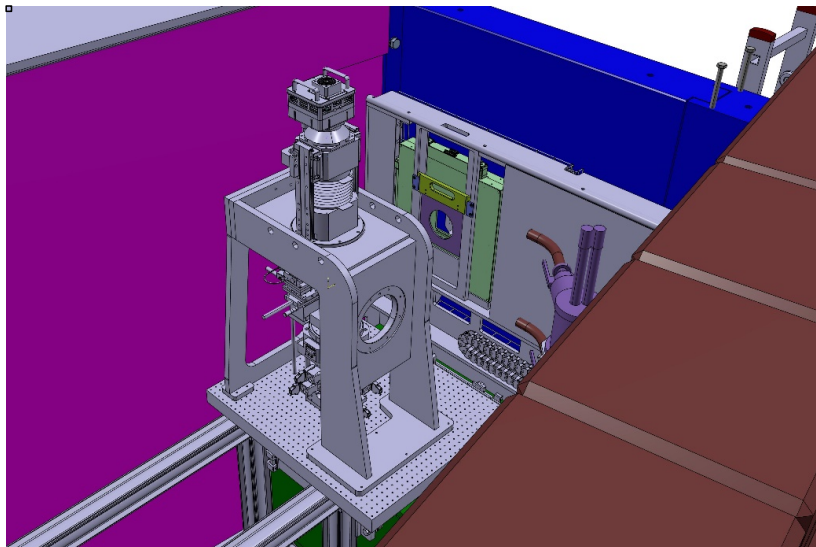


Figure 4. Preliminary design of NEUTRA 2.0 measuring position MP1 equipped with the PSI Neutron Microscope detector.

In particular, providing full access to the position MP1 will allow next to the XTRA option another optional installations including (i) the PSI Neutron Microscope detector [15] at NEUTRA at this high-flux position (see Figure 4) and (ii) a double disc chopper for time-of-flight measurements (see Figure 5) utilizing event-mode detectors [16][17].

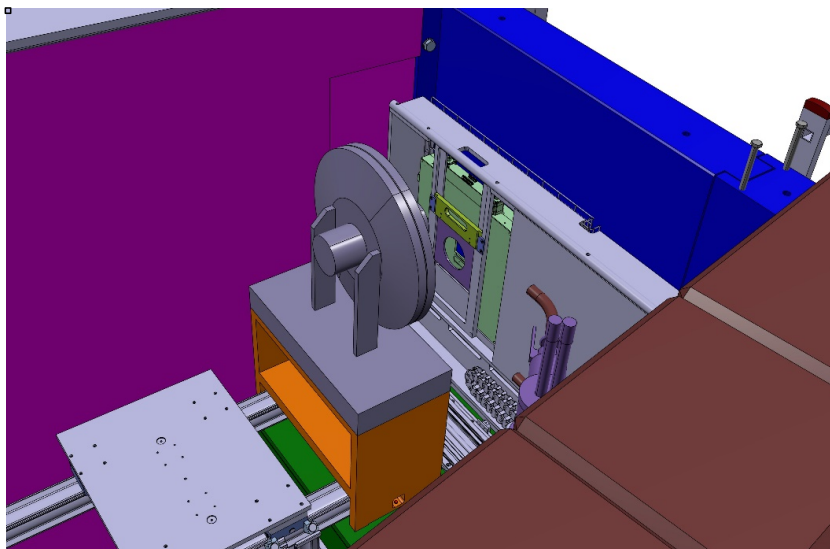


Figure 5. Foreseen preliminary design of NEUTRA 2.0 measuring position MP1 equipped with a chopper for advanced time-of-flight neutron imaging.

The substructure design, i.e. the optical bench, of NEUTRA 2.0 similar to that of the ICON beamline will also allow for a flexible use of the suite of the neutron grating interferometers (nGI) of AMG [18][19][20]. The availability of a high-resolution detector and advanced imaging techniques will open avenues for novel applications of neutron imaging to be pursued at NEUTRA 2.0. In addition, various options of neutron optics are considered as add-ons to NEUTRA 2.0 to improve flux and resolution for specific application requirements.

3. Outlook and conclusions

The works are scheduled to minimise downtime of the instrument and its user operation. Consequently, it is foreseen to start the decommissioning of NEUTRA by the end of a regular yearly user operation cycle and perform the construction as much as possible within the regular yearly shut-down period in the beginning of a calendar year.

In conclusion, this paper presents a first glimpse into the currently ongoing upgrade project of the thermal neutron imaging instrument NEUTRA at PSI. The scientific community will be further informed about the project progress in the future.

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