Appendix A
Existing Conceptual Design and Design Criteria for the PGAA Irradiation Chamber and Sample Holder

Figure A1 presents a schematic of the assembly of the PGAA component in operation.

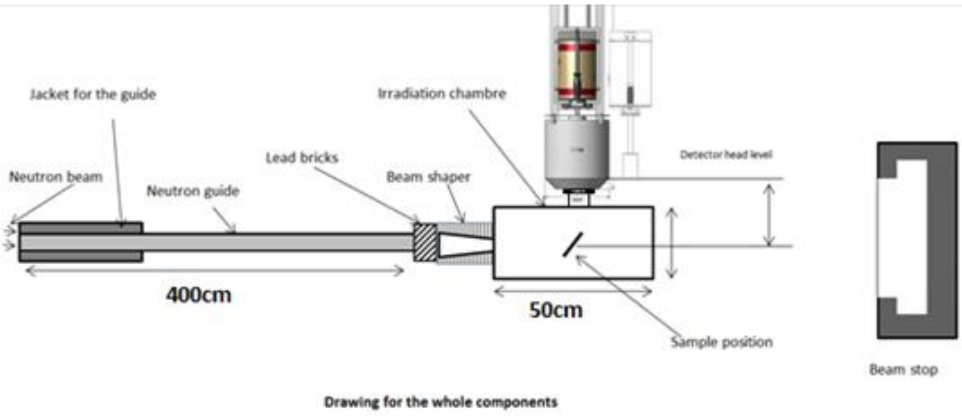


Figure A1: Assembled Design Concept for PGAA

Please see Appendix B for the layout of the beam optics and shared design of the NRAD and PGAA instruments. A low-efficiency neutron monitor is required for the operation of PGAA that should be placed at the end of the guide, downstream of the fast shutter, on a removable stand (Figure B1).

Jacket for the neutron guide

A 4-m long, $3\theta_c$ neutron guide is used for guiding neutrons onto the irradiation chamber when in PGAA mode. The guide's cross section is 2.5 x 10 cm, which differs from the 6.8 cm diameter aperture of the shutter (Figure A2). The intensity of the neutron beam at the exit of the beam shutter is described in Table A1. A jacket is required at the incident side of neutron guide (Figure A2) to reduce the background of scattered neutrons generated by a mismatch between the primary shutter's aperture and the internal cross section of the guide. Further guide dimensions are in Appendix F.

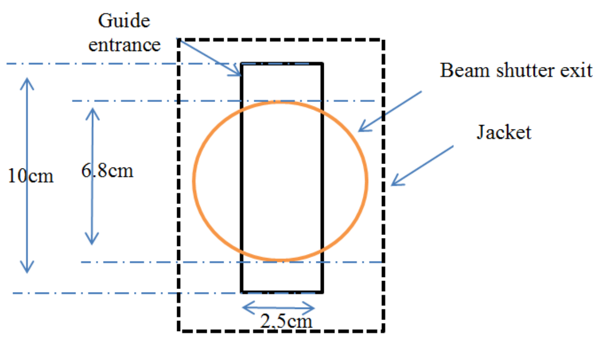


Figure A2: Shape difference between the shutter exit (orange circle) and the neutron guide inlet

1. Design criteria for the jacket:
   1.1. long enough to provide shielding for the full divergence of the neutron beam (the calculated divergence is about 2.1°).
   1.2. cover and fit the neutron guide's external frame (defined in Appendix F);
   1.3. consist of neutron and gamma absorbing material to reduce the background coming from the diverging beam, so that on the surface of the jacket, the neutron and gamma doses shall under no circumstances exceed 100 microSv/h. These field will be further reduced by the biological shielding to be installed by the End-User.
   1.4. Be mechanically self-supporting, as no additional weight can be placed on the guide or its supports.

   Solutions that can reduce direct irradiation or possible rapid aging of the mirrors are desirable.

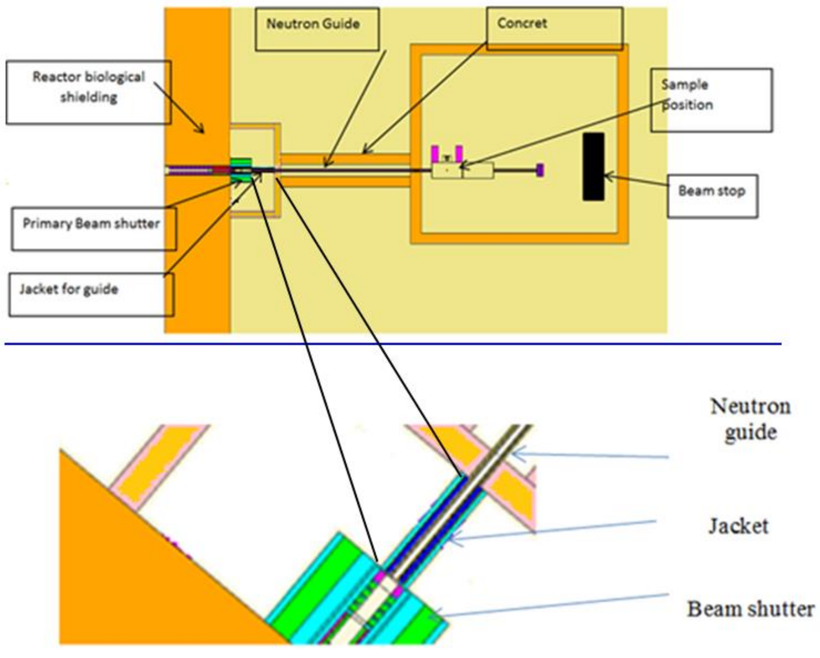


Figure A3: PGAA facility design showing the position of the jacket

Beam shaper

The beam shaper reduces the cross section of the neutron beam for final delivery to the sample. It is placed between the neutron guide and the irradiation chamber (Fig A1, A3) to adjust for the mismatch between the neutron beam exiting from the guide (cross section 2.5 x 10 cm) (Fig A2) and the desirable square cross sections at the sample position.
Proposed design criteria for this component include:

   1.5. a minimum gamma background at the irradiation chamber side to be achieved by suitable choice of materials and dimensions;

1.6. an acceptance aperture with dimensions at least as large as the internal cross section of the neutron guide (2.5 x 10 cm);
1.7. square apertures of 2.5 x 2.5 cm, 2 x 2 cm and 1 x 1 cm for neutron beams to allow for different sample sizes without changing the overall length of the beam shaper. We suggest the following removable extension slides with the same total thickness: if this concept is followed, we would require two copies of Item a; one copy of Item b; one copy of Item c; one copy of Item d, where these items are defined schematically in Figure A4.

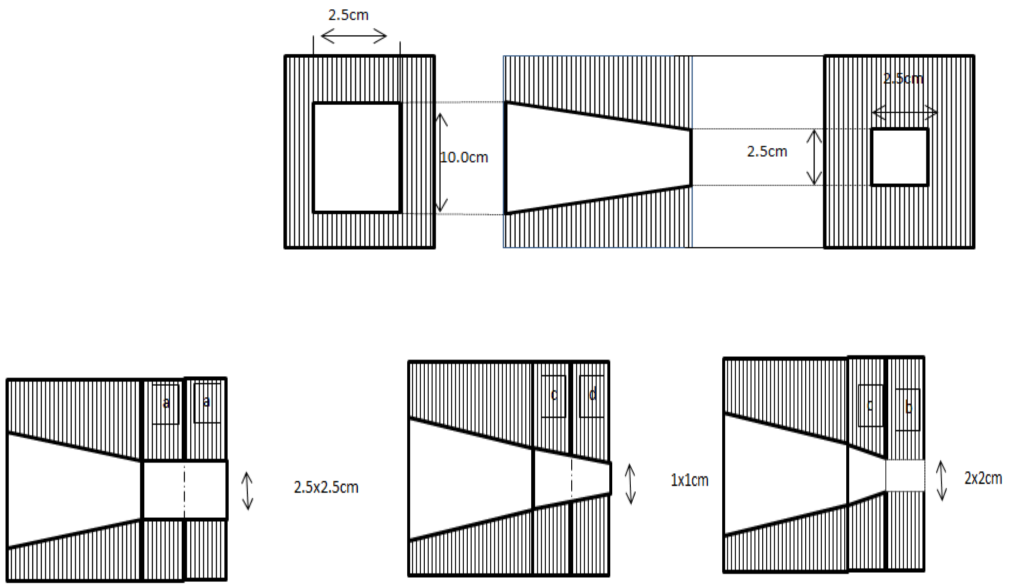


Figure A4 : Drawing of the internal structure of the suggested beam shaper showing the definitions of the removable slides defined as items a, b, c and d

Irradiation Chamber

An irradiation chamber is required to hold the sample under vacuum for investigation by PGAA. It must allow the passage of neutrons through it with minimum interaction with its structure and allow prompt gamma rays emitted from the sample through to a gamma spectrometer with which it must integrate.

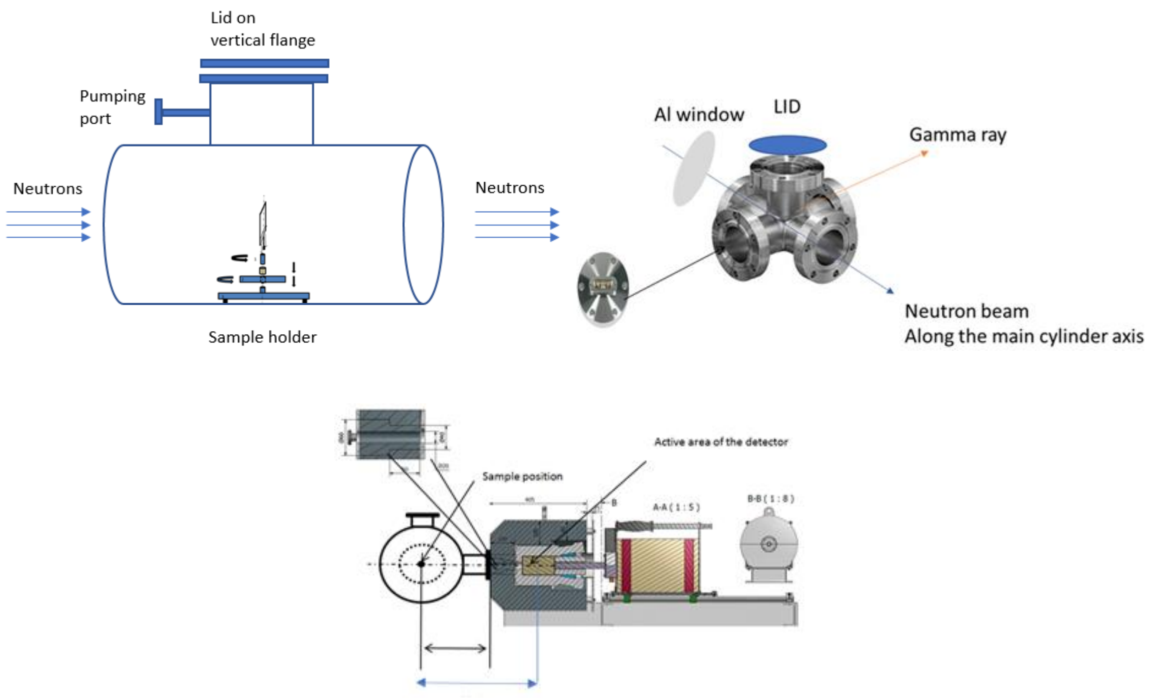


Figure A5: Irradiation chamber drawing. *Top Left:* schematic showing the main cylinder axis, and vertical flange. *Top Right:* a schematic showing the main cylinder axis (not to scale) for the neutron beam, the vertical flange for the lid and vacuum port, a horizontal flange to allow the gamma beam to the spectrometer. The second horizontal flange is one option that could be considered to place a vacuum-compatible electrical feedthrough to the irradiation chamber. *Lower centre:* Schematic showing view down the axis of the neutron beam and the interface of the irradiation chamber with the gamma spectrometer via the proposed gamma window.

Proposed design criteria for this component include that it:

1.8. be constructed of a grade of aluminium with sufficient mechanical strength to support the vacuum, its weight and any external force from the vacuum lines, but with low probability of neutron activation;

1.9. be in the form of a horizontal cylinder of suitable diameter that the beam not strike the edges. (Fig. A5);

1.10. have a vertical flange attached to the cylinder with an opening large enough that a sample holder can be easily placed and removed from the chamber and any required electrical connections readily made (Figs. A5 and A6): we suggest at least 150 mm diameter. It is suggested that a suitable lid can make a vacuum seal with this flange. This vertical flange or lid may provide a pumping port access for a vacuum pump (suggested KF-16);

1.11. provide vertical adjustment of the irradiation chamber by ±2.5cm (e.g. with adjustable legs);

1.12. be bolted to a supporting platform;

1.13. have on both ends of the horizontal cylinder, replaceable aluminium alloy vacuum windows with seals to allow the neutron beam to pass through the experimental sample from the exit of the neutron guide to the beam stop. The thickness of the windows shall be sufficient to hold the vacuum, but be as thin as possible to minimize interaction with the neutron beam. Two spare windows would be requested;

1.14. have a horizontal flange at 90 degrees to the horizontal cylinder with a thin replaceable aluminium alloy window at its end to allow prompt gamma radiation to reach the gamma detector. The thickness of the windows shall be sufficient to hold the vacuum but be as thin as possible to minimize interaction with the prompt gamma radiation. The dimensions of this window shall be large enough to totally illuminate the detector in the gamma spectrometer from the largest sample (2.5 cm x 2.5 cm). One spare window would be requested;

1.15. be provided with flexible neutron-absorbing shielding material of low gamma emission: these materials should not be placed either in front of the incident or exiting neutron beam or between the gamma detector and the sample but shall cover all other internal surfaces of the irradiation chamber. We suggest 2 mm of enriched Li-6-enriched (70% or greater content) shielding.

1.16. be provided with a vacuum compatible electrical feedthrough with enough pins to allow power and signals for two stepper motors and encoders (for eventual expansion). The wires from these feedthroughs would be fed to the area of the sample stage and should not be illuminated by the neutron beam or obscure the window to the gamma detector.

A sample mount to hold a typical sample holder is required inside the irradiation chamber. We suggest that:

1.17. the sample mount be fixed to the bottom of the irradiation chamber. (Figure A6);

1.18. the sample mount and holder must hold the sample at the centre of the neutron beam when placed in the irradiation chamber;

1.19. the sample holder (Fig. A7) be fixed on a mechanism allowing rotation (item “2”, Fig. A6) to adjust the angle of the sample to the neutron beam. Item “2” could be fixed to item 3 (Fig A6) once the adjustment is performed. Item 3 would be permanently fixed to the irradiation chamber;

1.20. It come with at least two sample holders. A suggested design is in Fig A7.

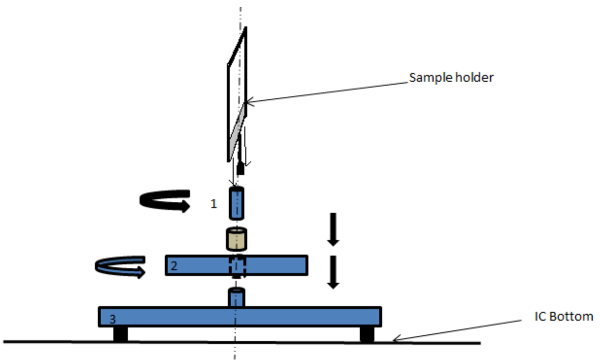


Figure A6: Suggested sample mount

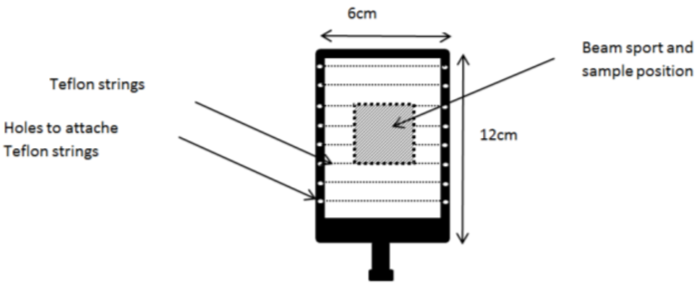


Figure A7: Suggested sample holder. The concept calls for two rows of Teflon strings. The samples themselves will be in the form of small Teflon bags. It is expected that the sample sizes could be between 2.5 x 2.5 cm^2 and 1 x 1 cm^2 to match the beam shaper.

Table A1: Maximum calculated flux at the hot spot of the beam at the shutter exit position, filtered by 10 cm sapphire filter and 10cm bismuth (cooled to 90K)

Neutron Energy (MeV)	Flux at the exit of the shutter ($n.cm^{-2}.s^{-1}$)	Neutron Energy (MeV)	Flux at the exit of the shutter ($n.cm^{-2}.s^{-1}$)
1,00E-09	1,15E+04	2,62E-04	5,79E+04
2,00E-09	1,27E+05	5,24E-04	7,46E+04
4,00E-09	6,93E+05	1,05E-03	3,22E+04
8,00E-09	5,05E+06	2,10E-03	4,29E+04
1,60E-08	1,40E+07	4,19E-03	1,07E+05
3,20E-08	3,45E+07	8,39E-03	1,07E+05
6,40E-08	4,30E+07	1,68E-02	8,02E+04
1,28E-07	1,61E+07	3,36E-02	3,81E+04
2,56E-07	2,16E+06	6,71E-02	1,16E+05
5,12E-07	3,80E+05	1,34E-01	1,04E+05
1,02E-06	1,38E+05	2,68E-01	1,21E+05
2,05E-06	1,75E+05	5,37E-01	5,01E+04
4,10E-06	1,47E+05	1,07E+00	2,23E+05
8,19E-06	1,38E+05	2,15E+00	7,37E+05
1,64E-05	5,97E+04	4,30E+00	2,70E+05
3,28E-05	5,62E+04	8,59E+00	8,95E+04
6,55E-05	7,94E+04	1,72E+01	3,22E+02
1,31E-04	6,30E+04	**Total**	1,19E+08

Appendix B

Existing Conceptual Design and Design Criteria for the NRAD instrument

The System when in NRAD imaging mode will be designed as shown in Figure B1 below. This system shall allow for neutron radiography and tomography. The neutron optical components immediately downstream of the primary shutter are placed on a neutron optics exchanger. This could be either horizontal or vertical, but a vertical design is suggested for reasons of space. The exchanger would switch between (1) the guide for PGAA and (2) the primary flight tube and the L/D exchanger for NRAD. It is shown in Figure B1 as a vertical translator actuating the first three supporting legs. The current concept places the neutron monitor (not shown) immediately after the fast shutter.

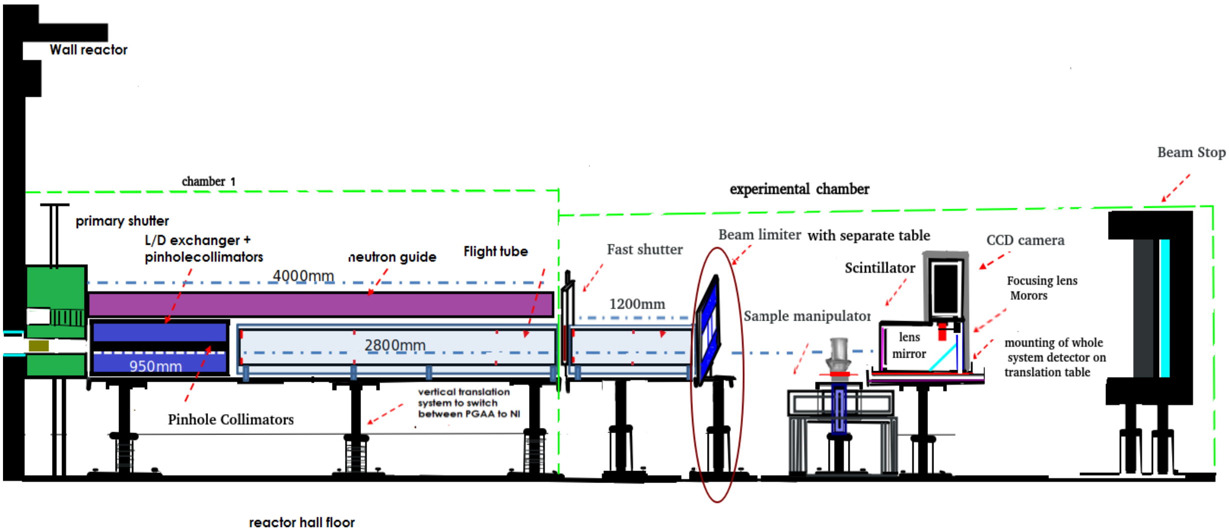


Figure B1: The System in the NRAD setup showing the placement of the components within the two chambers (dashed green lines) of the bunker (Appendix C, Figure C3).

1. **Convergent–divergent pinhole collimators and the L/D exchanger**.

   A critical parameter for the design of a neutron imaging system is the L/D collimator ratio, where L is the length of the collimator and D is the diameter of the entrance aperture. In order to allow for variation in the resolution of the images, the ability to change this ratio by interchanging different collimators is required.

   The following design criteria are suggested:

1.1. A four-position automated system (hereinafter the “L/D exchanger”) with positive location confirmation is required to position convergent-divergent collimators in the centre of the beam. We suggest an accuracy and bidirectional repeatability of ±0.1 mm; this mechanical selector must be mechanically well balanced (Figure B2);

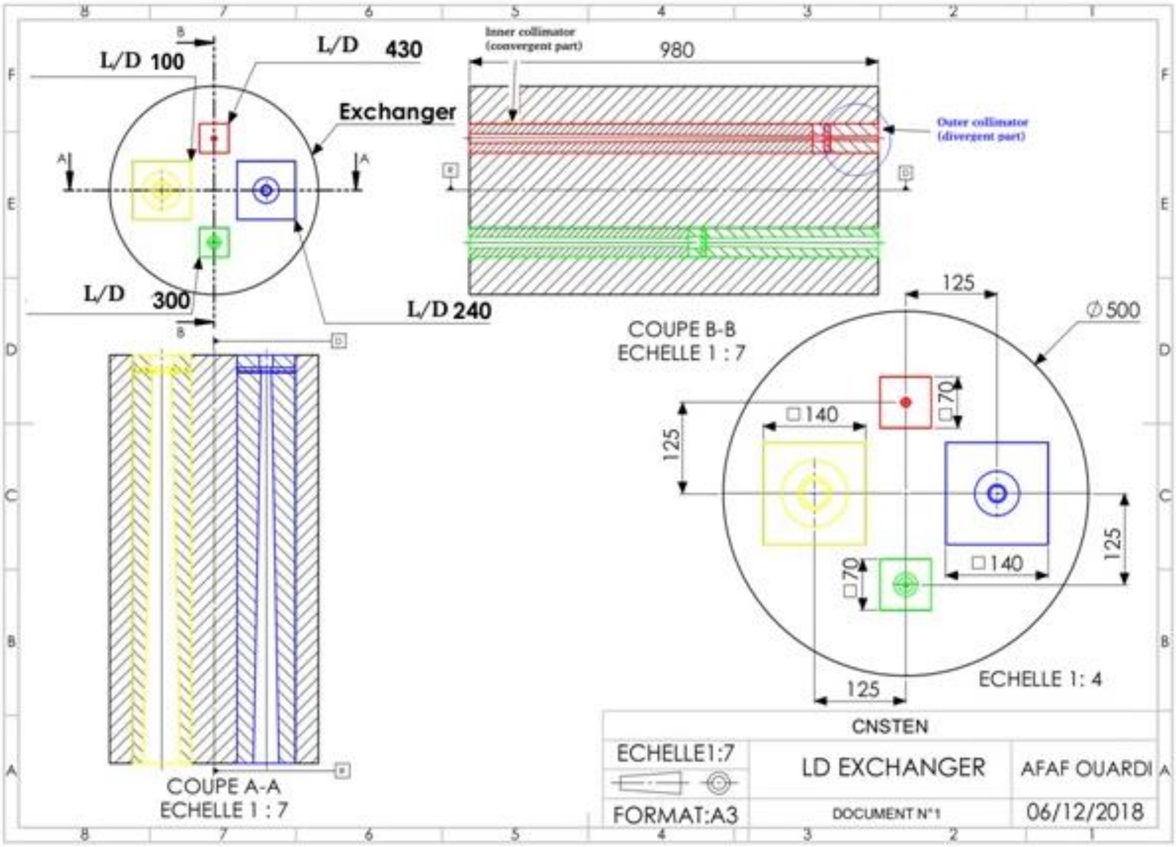


Figure B2: Suggested technical specifications of L/D exchanger device housing the convergent–divergent pinhole collimators

1.2. The L/D exchanger is requested to have 4 selectable collimation settings: 3 convergent–divergent collimators with pinhole dimensions as defined in Table B-1. The fourth position (L/D = 100) consists of an open channel without an aperture, corresponding to the divergence of the beam emerging from the NB-1 beam tube.

Table B-1: The convergences and divergences and apertures for each collimator

Collimator L/D	100	240	300	430
Convergent angle (α)	4°	0,37°	0,34°	0,40°
Divergent angle(β)	4°	1,12°	0,80°	0,61°
Radius of Gd aperture (mm)	open	25	20	10

1.3. Each inner (upstream) collimator accepts neutrons within the convergent angle (α as defined in Table B-1) to travel to the aperture. Itsuppresses undesired radiation components coming from the primary collimator within the NB-1 tangential beam tube (see Appendix D) and the shutter. Borated steel is suggested as the primary construction material (Figure B3).

1.4. Each aperture is made of a pair of 2-mm thick Cd and 0.1-mm thick Gd sheets. The hole in the Cd sheet has a diameter 1 mm greater than the Gd sheet so that the Gd edge is fully exposed to avoid forming an extended cylindrical hole (Figure

B3). The tolerance of the circular “apertures” within the convergent–divergent collimator is suggested to be ±0.1 mm. These are to be placed in the centre of the convergent–divergent collimator.

1.5. The outer collimator lies downstream of the aperture (Figure B3) and permits the divergence of the beam from the aperture (β, as defined in Table B-1). Borated steel is suggested as the construction material.

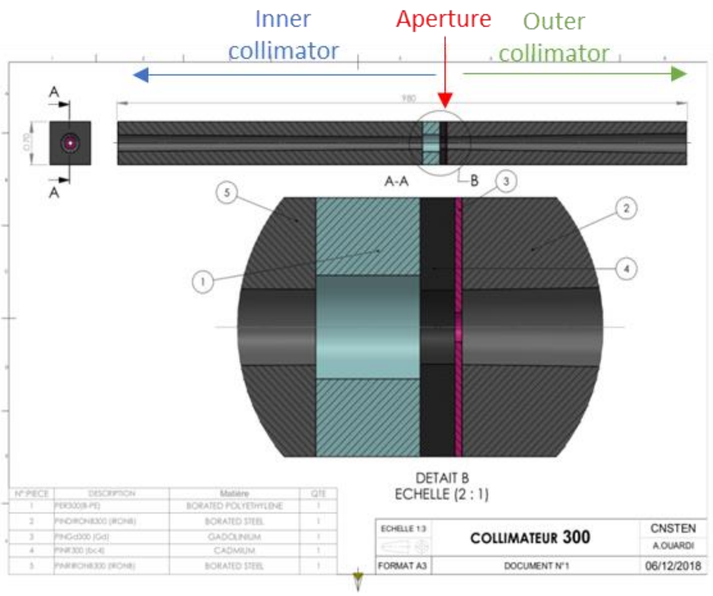


Figure B3: Pinhole collimator technical description. The shaded dark grey material is borated steel, turquoise borated polyethylene, solid black Cd, and red Gd)

1.6. It is suggested that flat springs be used to mount each collimator inside the channels of the L/D exchanger.

1.7. The L/D exchanger should position each collimator such that the apertures of the selected collimator lie in the centre of the neutron beam;

1.8. The outer frame of each collimator will possess a means of fixing it to its channel in the L/D exchanger.

Flight Tubes (primary and secondary)

Two flight tubes are requested as shown in light blue in Figure B1. The design concept for the flight tubes has the following criteria:

1.9. The primary flight tube is the longer, upstream component (shown with a suggested dimension of 2800 mm) and must be fixed to the neutron optic exchanger; the secondary flight tube (shown as 1200 mm in Figure B1) should be on an independent platform and readily removable from the System when in PGAA mode or when not required in NRAD mode.

1.10. Flight tubes are composed of a grade of aluminium of sufficient strength to hold the vacuum safely and of low neutron activation probability;

1.11. Flight tubes are of suitable internal dimensions that neutrons cannot strike the sides: it is suggested that the flight tube include several blinds (blinds defined as an assembly of 1cm iron, 2cm casing with B_4C powder and 3mm Cadmium lining with circular cross section) that are designed to limit divergent neutrons, with a suggested minimum internal dimension of 40 mm (Figure B4).

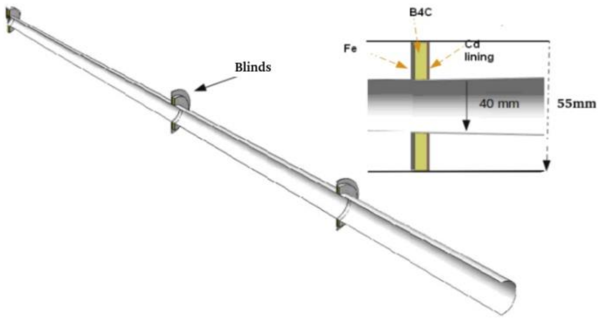


Figure B4: Suggested structure of the blinds of the flight tube with circular section

1.12. The Contractor may decide to specify flight tubes that are either evacuated or filled with an overpressure of He gas.
1.12.1. If a vacuum design is chosen, a standard vacuum flange must be provided to evacuate the flight tubes, together with a “dry” (oil free) pump. Flight tubes are provided with vacuum-safe “windows” on both ends that are of high neutron transparency and low probability of long-term neutron activation.
1.12.2. If a He-filled design is chosen, suitable inlet valves for He gas, a purge valve, and “bleed” valves to maintain an overpressure would be required. The windows on the ends of the flight tubes high neutron transparency and low probability of long-term neutron activation.

3-axis translation + 2-axis rotation sample stage

1.13. The NRAD instrument shall provide a sample stage with 3-axis translation and 2-axis rotation on an independent platform such that the manipulator;
1.14. provides movement of 80 cm (i.e. ±40 cm) along the neutron beam direction and ±50cm in the horizontal normal to the neutron beam; we suggest a positioning accuracy and bidirectional repeatability of 0.1 mm under load;
1.15. provides movement of 50 cm (i.e. ±25 cm) vertically; we suggest a positioning accuracy and bidirectional repeatability of 0.1 mm under load;
1.16. provides 360° rotation about the vertical and a tilt of ±15° in the horizontal, normal to the incident neutron beam under maximum design load; We suggest both an accuracy and bidirectional repeatability of 0.01°. In the case of the rotation axis about the vertical axis, no mechanical stops or limit switches are required;
1.17. can hold and manipulate without interference with the camera or other components of the System a sample of size 80 cm x 100 cm x 50 cm and a mass of up to 200 kg) (Figure B5);
1.18. The platform supporting the manipulator must be movable (upstream by 1m when the secondary flight tube is not in place) and completely removable for when the PGAA modality is used.

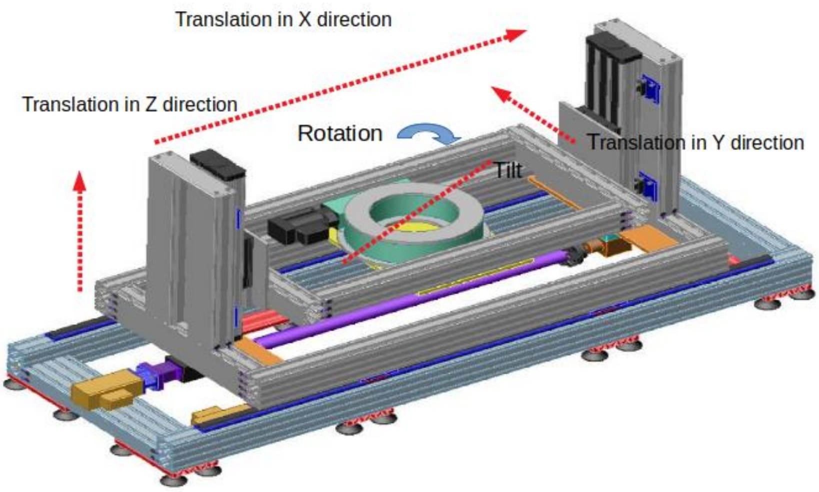


Figure B5: schematic of possible sample stage design

Fast shutter

1.19. The fast shutter is principally used to protect the detector and to shut off the thermal beam between exposures in order to minimize activation of the sample. In order to be able to absorb the thermal neutron beam a sandwich structure is considered for the shutter plate: 5 mm B_4C plastic and up to 10 mm Pb. It will be mounted after the primary flight tube and neutron guide (see Figures B1 and B6) just inside the experimental chamber of the bunker (Figure C3). The dimensions of this shutter plate must cover the whole cross-section of the flight tube.

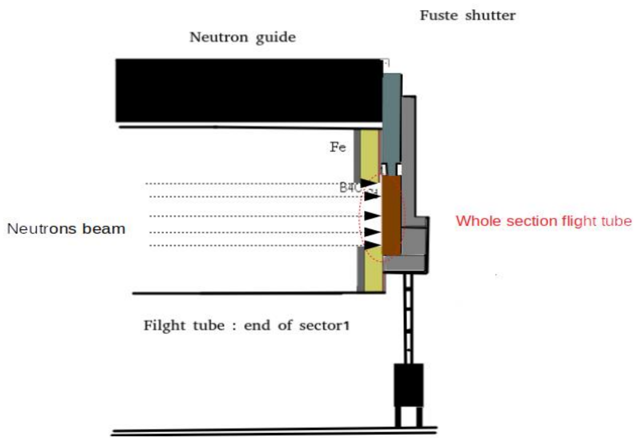


Figure B6: Schematic of a fast shutter

Beam limiter

1.20. In the beam direction, a neutron beam limiter (Figure B7) will be placed at the end of the secondary flight tube on a separate table in the experimental chamber of the bunker (Figure C3). Our concept consists of four boral (borated aluminum) plates (each of thickness 6 mm) that can be driven independently with respect to the neutron beam. It must be supported on its own table (Figure B1) in the centre of the beam and be capable of totally closing and opening up a beam of 25 cm by 25 cm. We suggest that the all four boral plates (e,g, +X and -X, +Z and -Z) be driven independently and positions recorded with encoders. The beam limiter and its table will be removed when the System is in PGAA mode.

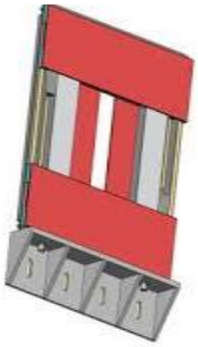


Figure B7: Beam limiter

Camera platform

The NRAD instrument's detection system is based around scintillators, mirrors, lenses and an ANDOR CCD, whose dimensions, masses, and mounting points are defined in Appendix H. The CCD, lenses and scintillators require a shielded, light tight box around them. This box must be supported by a platform to hold the centre of the scintillator in the centre of the beam. This platform must be removable when the System moves to PGAA mode.

1.21. The distance between the primary shutter and the irradiation plane (on the scintillator) is between 5 m and 6 m. For this reason, there are two flight tubes, described below. The Contractor shall be responsible to ensure the following requirements:

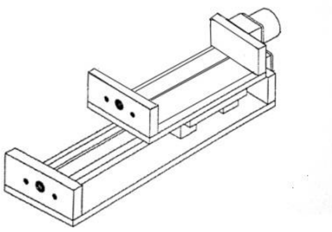
1.22. The camera (Appendix H) shall be at a distance (relative to the spatial resolution with a minimum of 200 µm).

The camera box shall be manufactured according to the specifications cited below:

- Light-tight aluminium alloy construction;
- L-shaped design for an indirect optical path via a mirror to protect the CCD from direct radiation;
- Low activation materials with aluminium alloy screws;
- Sturdily constructed with mounting bolt holes on the back and light-tight trap door for access to the lens;
- The CCD must be mounted on the outside of the box by the End-User, to allow for cooling;
- The vertical section shall be a minimum 350 mm high, with a horizontal section 150 mm long for a total of 500 mm for a 200×200 mm FOV with the 50 mm lens. With the 105 mm lens, a 50 mm front section shall give a FOV of 80×80 mm and with a 200 mm front section a FOV of 120×120 mm;

- The minimum focus distance shall be 500 mm for the Nikkor 50mm f/1.2 lens, and 410 mm for the Nikkor 105 mm f/2.8 lens.
- Flexible design, including:
  - Easy replacement of a broken mirror;
  - Scintillators mounted on light-tight frames for easy exchange in 25mm square frame;
  - Possibility to change the CCD unit, which is simply mounted on the exterior of the camera box;
  - With feedthroughs to allow USB and power for focussing motor on the lens.

1.23. For projection ratios from infinity to 1:1 the distance from lens to the CCD camera has to be varied. As the End-User has lenses with manual focus and of different fixed focal length, in order to change the field of view, the working distance from the lens to the object needs to be varied. Therefore, remote focussing provided by a motorised drive is required, controlled either by a remote manual control box or via a USB computer connection (see Figure B8-right). A translation table will be used to translate the whole shielded camera assembly towards or away from the sample in direction of the beam, keeping the sample–scintillator distance as small as possible (see Figure B8-left). Camera and lens should be connected with each other via a light-tight optical bellows. A second bellows should isolate the light path from the lens to the camera box wall.



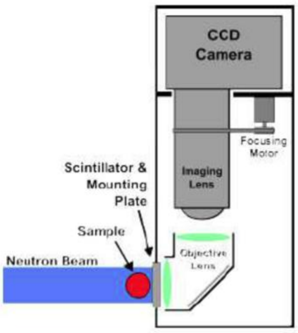


Figure B8: Left: the translation system for the whole detection system; **Right:** the imaging lens that can adjusted using the focusing motor.

Shielding for body camera CCD

1.24. Shielding of the camera box (containing the scintillation screen, CCD camera and associated optics) is required. We suggest an additional 5 cm of lead and 5 mm of flexible, 80% B4C-loaded shielding close to all sides of the CCD camera box (Appendix H) except the front. Figure B9 shows a shielded camera assembly.

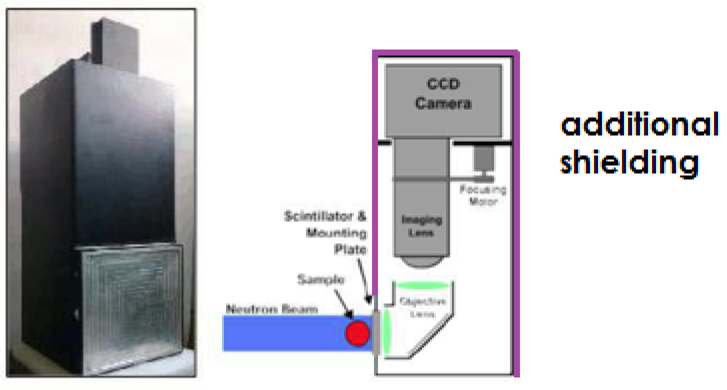


Figure B9: an example of a shielded camera body (c.f. Figure H1).

Beam stop

The Contractor is to provide a beam stop to achieve fields less than 10 microSv/h (gamma + neutron) behind it based on MCNP calculations given in Table D2 gives the flux distribution at the beam stop position. The beam should be expected to be (with penumbra) up to 70 cm in diameter. The design should reduce “back-scatter” as much as possible towards the detectors.

Appendix C
Overview of the reactor hall

The core of the 2 MW TRIGA Mark II Reactor of CNESTEN is located near the bottom of a water-filled aluminum tank which is 2.5 m in diameter and approximately 8.2 m deep. Fig C1 depicts the reactor hall and the crane access within. A detailed plan of the reactor main hall will be provided to the Contractor.

The centre of the NB-1 beamline lies 85.5±1 cm above the main floor of the reactor

The floor loading limit in the reactor hall is everywhere 5000 kg/m^2.

RESTRICTIONS ON SPACE:
1. The Basement Access on the right-hand side shall not be impeded.
2. Access to the thermal column via the removable plug at the top of the figure should be avoided if possible.

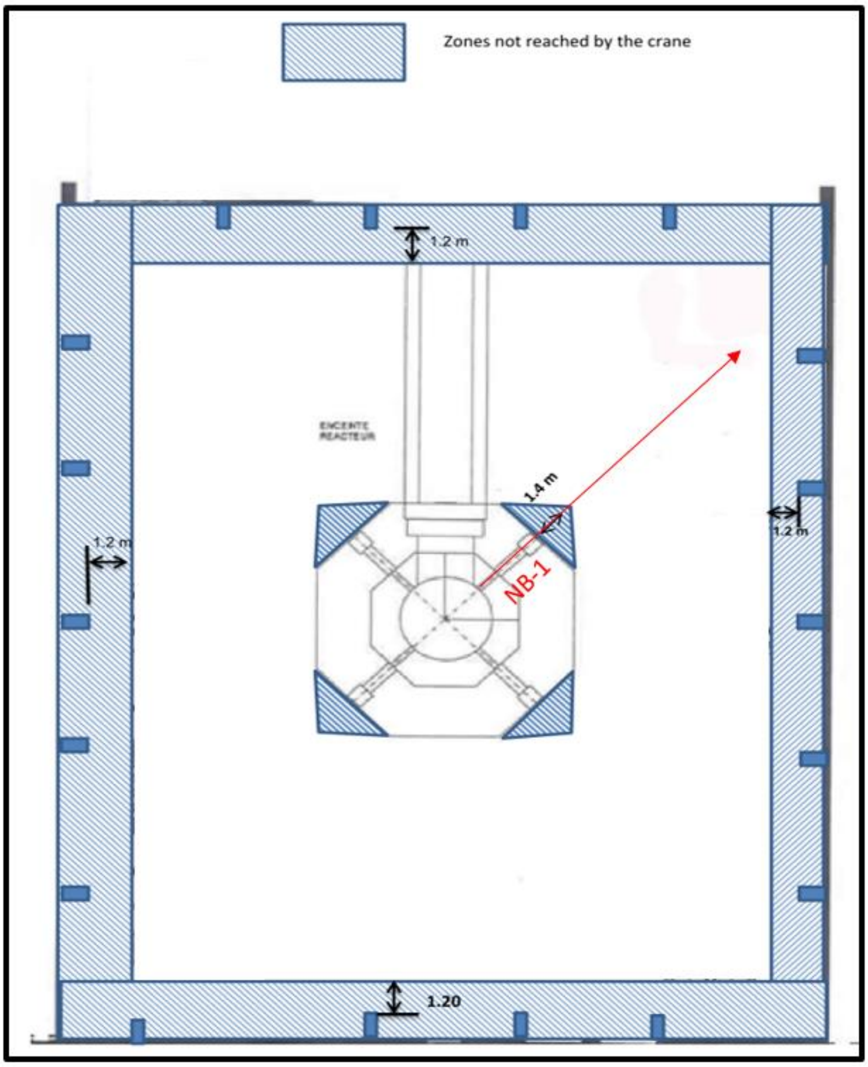


Figure C1: Crane Access for both 6t and 3t cranes. Shaded areas show where the cranes cannot reach.

The bunker design

The shielded bunker will be designed by the End-User for the combined instruments NRAD and PGAA. The design will be finalized with input from the Contractor taking into account the interfacing issues which include the following:

- Final design dimensions and placement of all components;
- Services (electrical, water etc.) required to be fed into the bunker;
- Any constraints the beam stop may place if it is to be integrated into the bunker wall;
- The safety PLC

The major acceptance criteria for the shielding design are: (i) dose rate less than 8 μSv/h at external surfaces of the instrument's experimental area, (ii) floor load limit < 5 tonnes/m^2, (iii) low cost, and (iv) for maintenance purposes "easy access" to components of the instruments.

The bunker is shielded with walls and a roof of heavy and regular concrete elements. The structures will be designed to resist to the seismic forces and the critical nonstructural components will be provided with seismic restraint. The bunker will be designed to use the minimum number possible of different block designs and the minimum number of blocks. It is designed such that during an earthquake it will not shift or overturn on to the critical structures or components, nor endanger personnel safety.

The shielding

2D transport calculations to determine the shielding composition, and three-dimensional Monte Carlo calculations to determine the detailed dimension of individual components were performed. The structural characteristics in the vertical direction are as follows:

(i) A roof is to be installed over the bunker made of baryte concrete with a thickness of 20cm;

(ii) The walls will be made of baryte concrete blocks;

(iii) The base (Orange color) of the shielding is widened by 20 cm in both height and width (Fig C2).

Internal structure of the bunker

The bunker is defined by two chambers. Each chamber has independent access. The first, the beam optics chamber, is accessed by a dedicated shielded door. The experimental chamber has a labyrinth and relatively simple interlocked door (see Fig. C3).

The **beam optics chamber** will be entered only for maintenance and will house:

- the primary shutter,
- L/D exchanger (with collimators)
- the neutron guide
- the primary flight tube

The dimension of this chamber is: 1.5m x 1.5m x 1.8m (working height).

The larger, experimental chamber contains the other equipment for NRAD and PGAA. The dimension of this experimental chamber is defined so as to be able to receive large samples and to have reserved areas to store equipment; e.g. PGAA equipment can be stored while NRAD is running.

The dimension of this experimental chamber is: 4.5 x 5 m and an open roof.

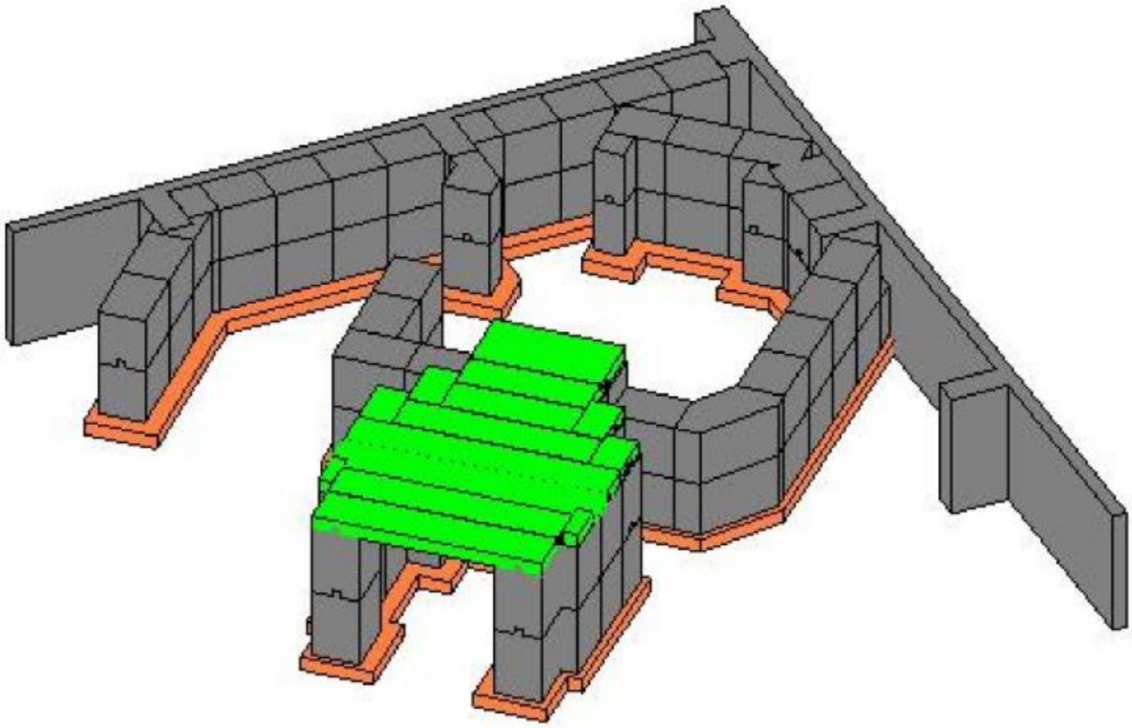


Figure C2: 3D presentation of the current conception of the biological shielding.

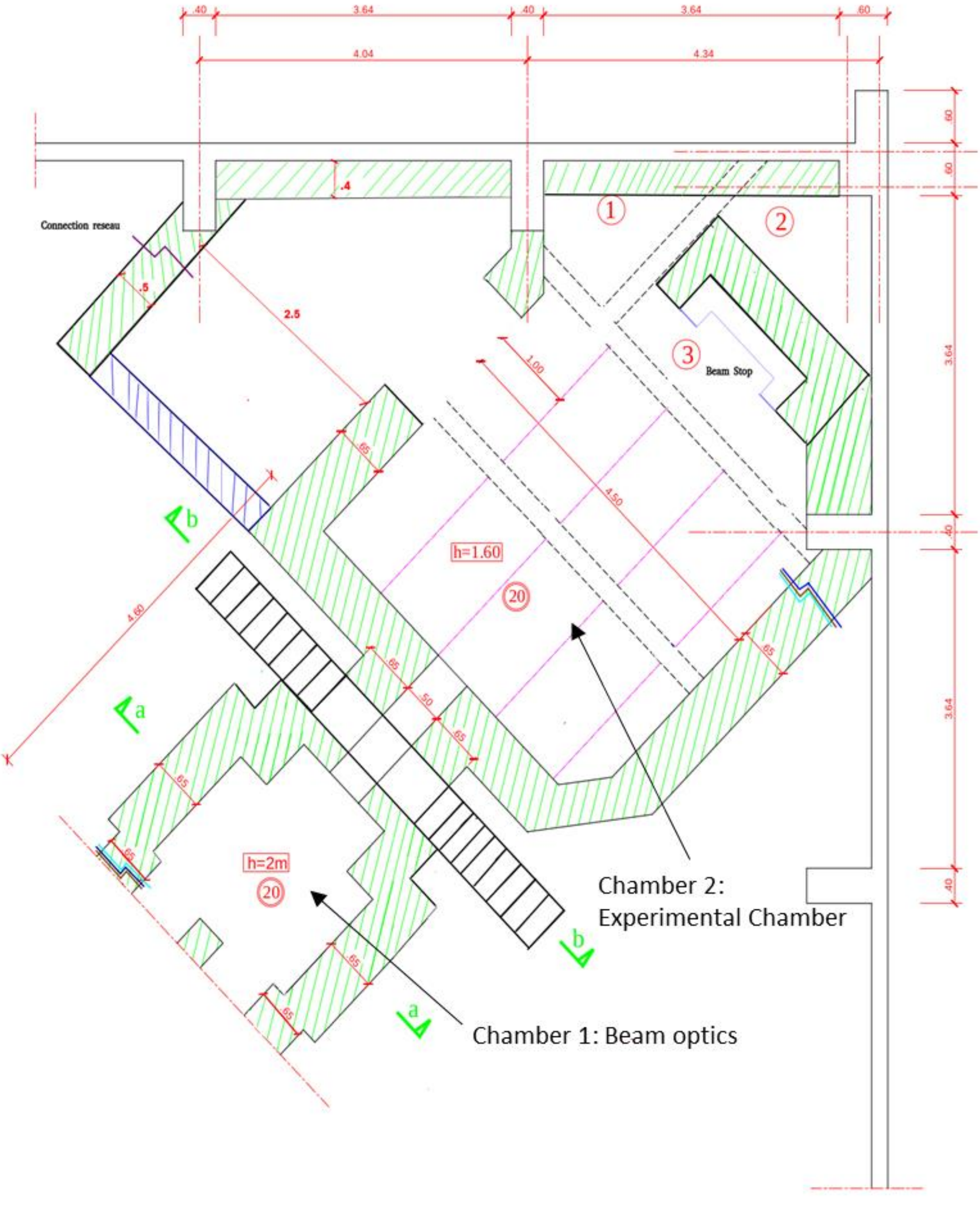


Figure C3: the design of the current conception of the biological shielding showing available space of PGAA and NRAD instruments.

Appendix D
Fluxes, Filters, and Beam Sizes

Figure D1 lists four sets of unfiltered neutron fluxes in four energy bins assuming a full reactor operating power of 2 MW. The vertical axis is in units of n/cm^2/s.

- *Surface 2041* represents the results of an MCNP calculation in June 2016 by CNESTEN Reactor Physics at the same location.
- *Activation foil* measurements were performed at the back of the NB-1 beam tube near the core vessel; values are from the report of Ladislav Viererbl of November 2014.

The good agreement of the two above datasets gives confidence in the MCNP model

- *Surface 2043* is an MCNP calculation extended to the exit of the NB-1 tube near the edge of the biological shielding for an open beam tube (no collimator).
- *Collimator* is an MCNP calculation that shows the effect of the in-pile collimator on the NB-1 channel; it reduces the fluxes by about 0.5. This is the best estimate of the unfiltered fluxes at the exit of NB-1.

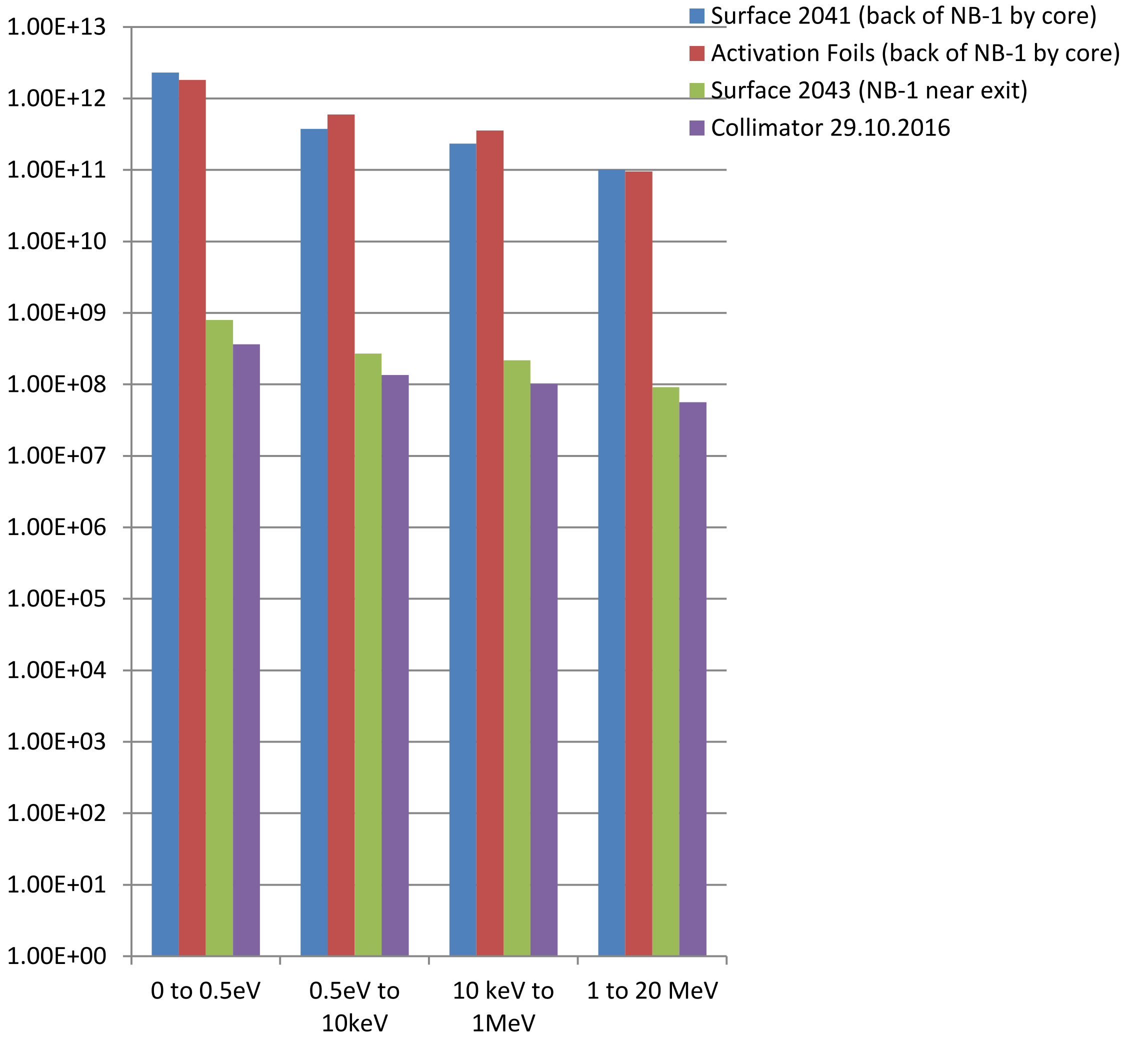


Figure D1: Neutron fluxes as a function of energy

The in-pile collimator and filters described below are already the property of the End-User. They are presented for information purposes.

Beam Size and Primary Collimation

The neutron beam is collimated by an in-pile collimator composed principally of steel rings and boronated-polyethylene. It provides a circular aperture of 55 mm diameter in which the 50-mm diameter sapphire filter is placed (Table D1). The length of the collimator aperture is 1400 mm. This defines the beam shape and is the primary collimating element of the neutron beam leaving the NB-1 channel.

Neutron and Gamma Filtration

Neutron: The neutron fluxes given above shall be modified by a sapphire filter (Table D1) placed inside the beam collimator. It is expected that the neutron fluxes (Fig. D1) for energies greater than thermal will be reduced to a few % of those given in Table D1.

Gamma: The gamma flux was calculated by MCNP at *Surface 2043* (Fig. D1, NB-1 near exit, without collimator) as 9.89×10^{8} photons.cm^{-2}s^{-1}. A liquid-nitrogen-cooled 10-cm long Bi filter will be placed inside the primary shutter on the incident side to reduce this (Table D1).

Table D1: Description of the beam filters

Neutron Filter	
Material	Sapphire (alumina) Al_2O_3
Orientation	*c*-plane
Diameter	50.00 mm
Length	100.00mm
Purity	99.99%
Grade	Optical, category 3
Tolerance	±0.1mm
Gamma Filter	
Material	Bismuth Bi
Orientation	(111)
Diameter	45.00 mm
Length	100.00 mm
Purity	99.999%

The End-User suggests the beam stop be located at 9.5 m along the neutron beam path. At this point, the Contractor may assume the neutron flux distribution shown in Table D2

Table D2: Maximum calculated filtered flux vs. neutron energy around the hot spot of the beam at the proposed beam stop position with flight tube in place

(9.5m from the exit of the beam tube)

Energy (MeV)	Flux ($n.cm^{-2}.s^{-1}$)	Energy (MeV)	Flux ($n.cm^{-2}.s^{-1}$)
1,00E-09	9,20E+01	2,62E-04	1,85E+02
2,00E-09	1,29E+03	5,24E-04	6,27E+02
4,00E-09	6,75E+03	1,05E-03	1,05E+02
8,00E-09	5,72E+04	2,10E-03	1,04E+02
1,60E-08	1,52E+05	4,19E-03	1,38E+03
3,20E-08	3,80E+05	8,39E-03	1,31E+03
6,40E-08	4,62E+05	1,68E-02	2,49E+03
1,28E-07	1,63E+05	3,36E-02	1,68E+03
2,56E-07	1,85E+04	6,71E-02	1,48E+03
5,12E-07	3,79E+03	1,34E-01	1,14E+03
1,02E-06	1,71E+03	2,68E-01	2,23E+03
2,05E-06	2,74E+03	5,37E-01	1,20E+03
4,10E-06	2,36E+03	1,07E+00	3,32E+03
8,19E-06	1,81E+03	2,15E+00	8,60E+03
1,64E-05	8,48E+02	4,30E+00	3,61E+03
3,28E-05	1,07E+03	8,59E+00	1,15E+03
6,55E-05	9,69E+02	1,72E+01	1,20E-01
1,31E-04	9,87E+02	**Total**	1,29E+06

Appendix E

The Primary Shutter

The following describes equipment that is already property of the End-User. The shutter is controlled via a PLC system. It can only be opened from the control room, but can be locally closed by beamline staff. Further information can be supplied.

DIMENSIONS OF BASE PLATE: The base plate extends laterally (parallel to the reactor wall at the NB-1 exit) and is approximately 1150 mm wide and extends to ca. 500mm out from the reactor wall.

SPACE and WEIGHT RESTRICTION: Some local shielding may be in place around this shutter by the End-User Therefore, the Contractor shall not build a structure closer than 500mm to the reactor wall.

DIMENSIONS OF SHUTTER: The shutter's dimensions are given in Figure E1.

Neutrons exit the in-pile collimator as a beam of circular cross-section delivered by the Primary Shutter to the beamline via a circular aperture of diameter 68 mm centred at a height of 855mm over the floor level.

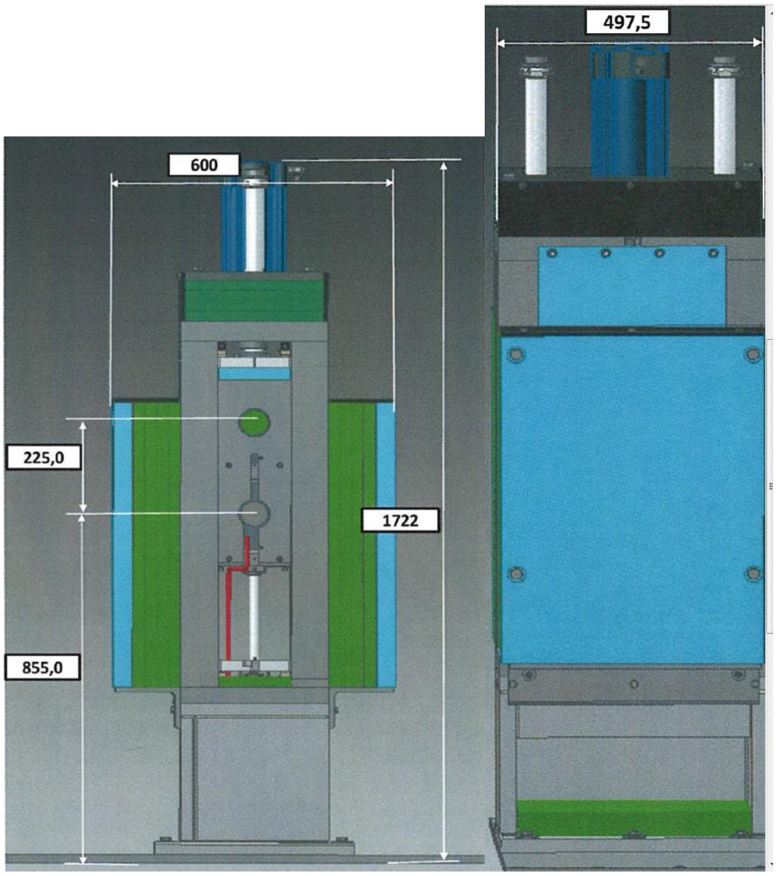


Figure E1: Front View (left) and Side View (right) of Primary Shutter

Appendix F
Neutron Guide

The $3\theta_c$ neutron guide below is property of the End-User and is outside the scope of this Statement of Work. The drawings are given for the Contractor's information. The neutron guide consists of 4 sections of 1m each with a total weight of 360kg. It provides at the exit a neutron beam of 2.5 x 10 cm cross section. The external cross section is described in the Figures F1 and F2 below. No additional weight can be placed on the guide and any shielding of the guide will have to be mechanically self-supporting. It currently rests on supporting legs, although these will be removed when integrated into the System

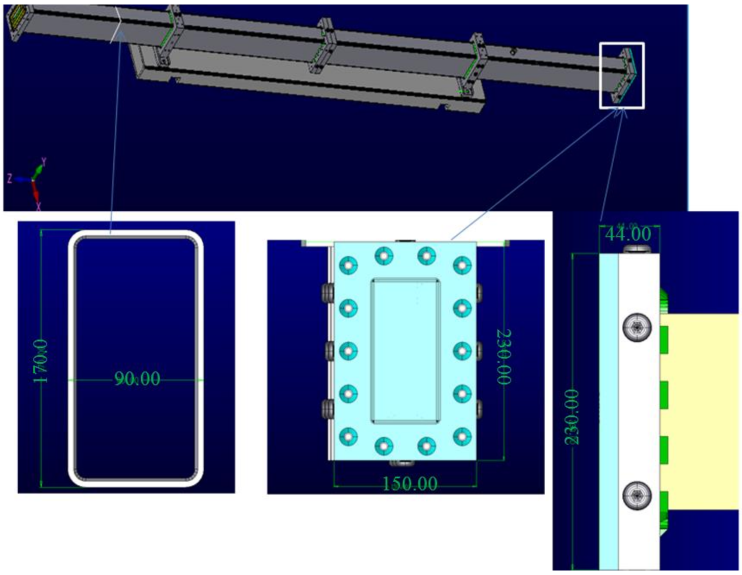


Figure F1: External guide dimensions (mm).(The supporting legs will be removed.)

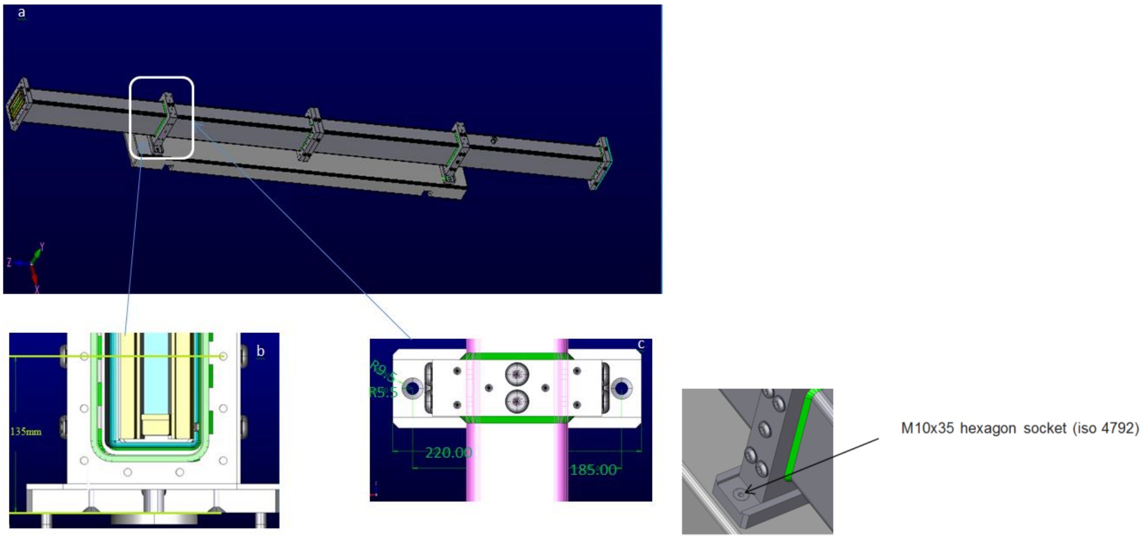


Figure F2: a : 4m guide assembly ; b : The height from the center of the guide down to the bottom surface which would be bolted to the neutron optics exchanger; c: dimensions of the fixtures.

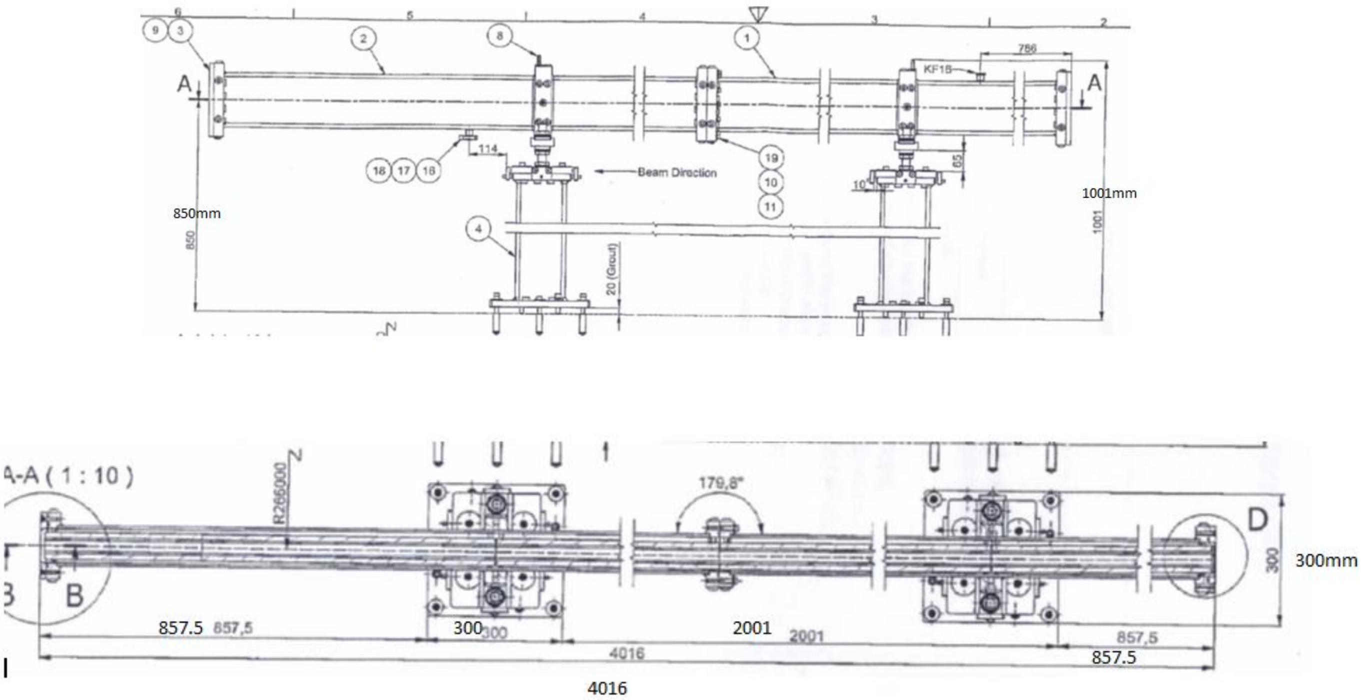


Figure F3: Length of Guide segments

Appendix G
Gamma-ray spectrometer detector, cryostat and shield

The equipment below is property of the End-User and is outside the scope of supply. The total mass of this system is 465 kg. It is based around a Canberra GR2519 Reverse Electrode Coaxial Ge (REGe) detector. The drawings are given for the Contractor's information. Further information can be supplied.

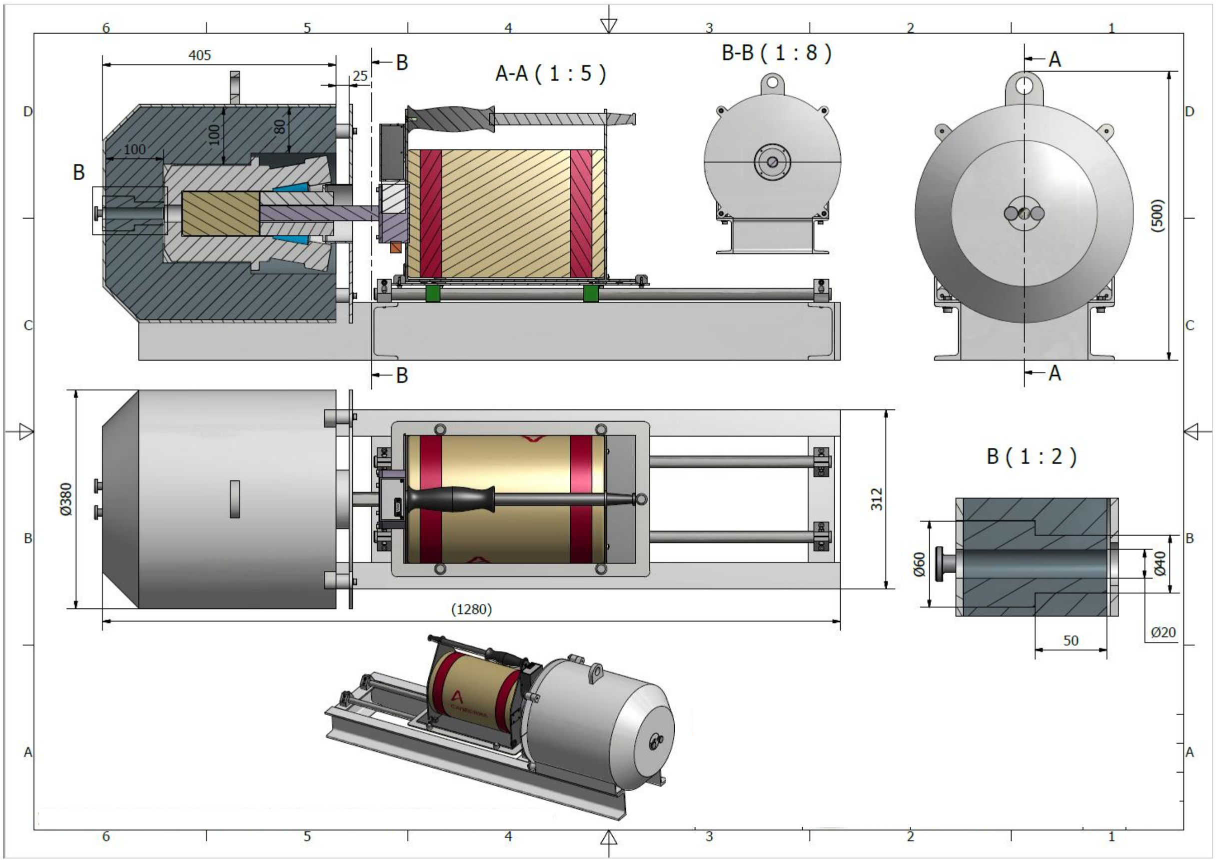


Figure G1a: Detection system with shielding

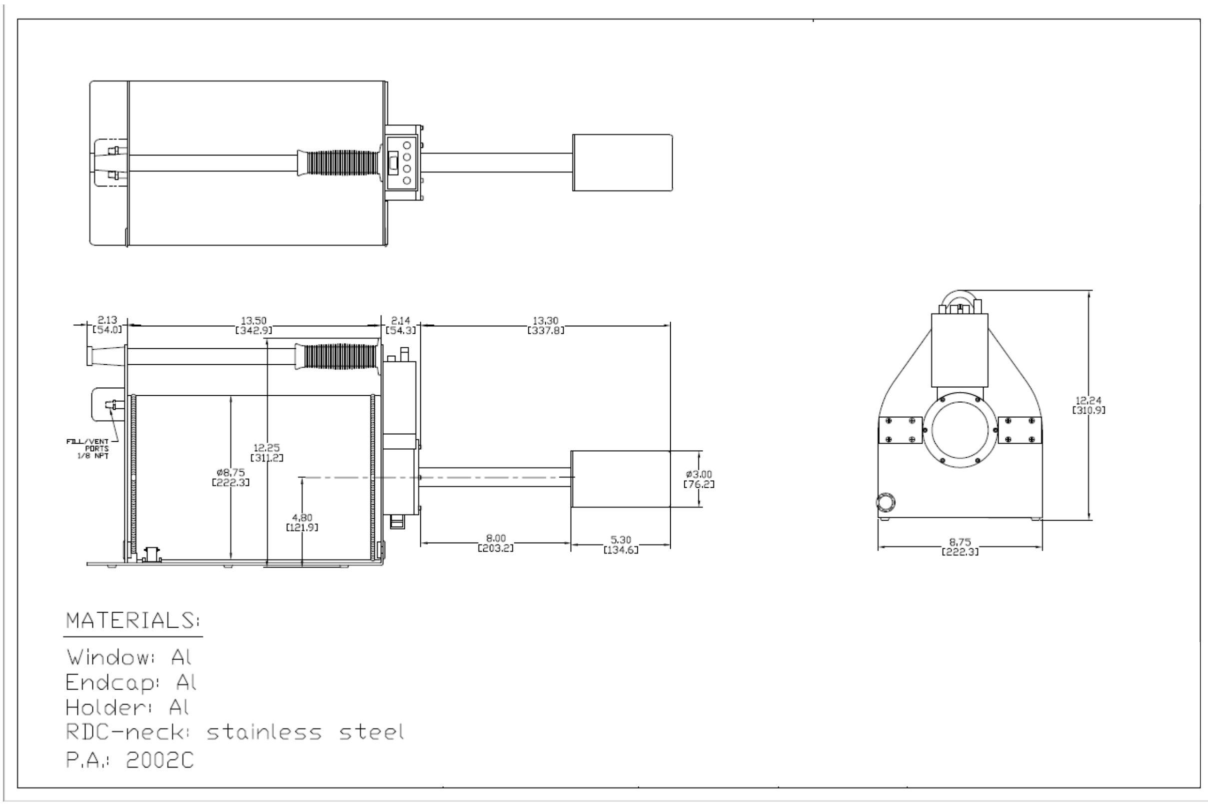


Figure G1b: Detection system dimensions without any shielding

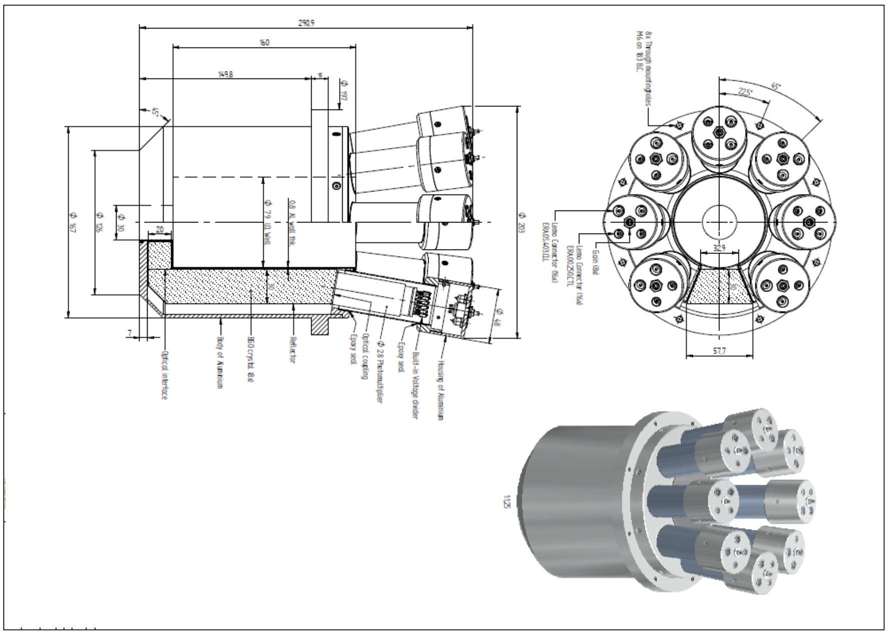


Figure G2: BGO Detector

APPENDIX H
The Neutron CCD, scintillators, and lenses, and image processing computer

The following describes equipment that is already property of the End-User and is given for informational purposes.
Figure H1 shows the visible part of the ANDOR DW-936N BV CCD camera.

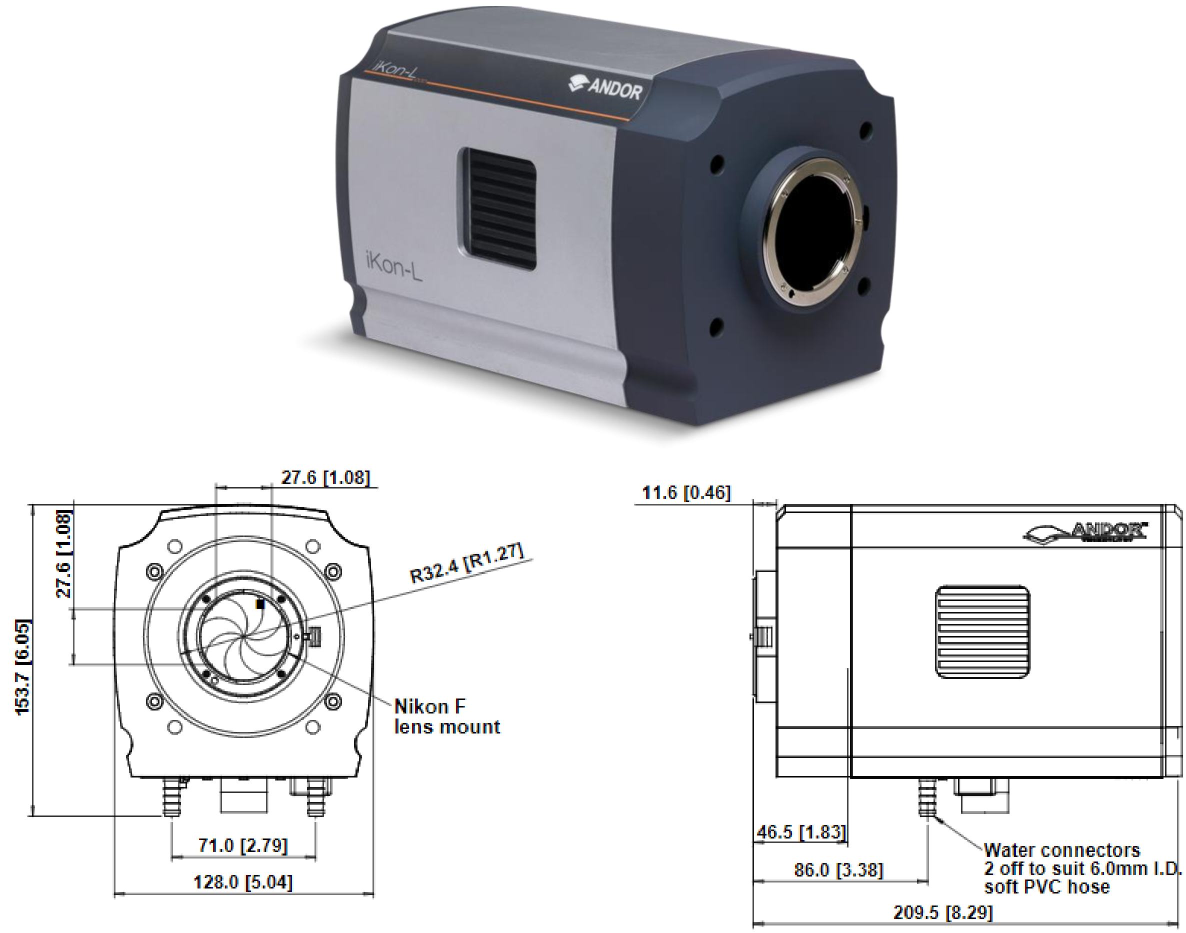


Figure H1: The ANDOR DW-936N BV CCD and external dimensions in mm [inches].

The camera is interfaced to a computer via boosted two 10-m, amplified USB cables that interface to a control PC. The computer is powerful enough to perform, image processing, and has a RAID storage system.

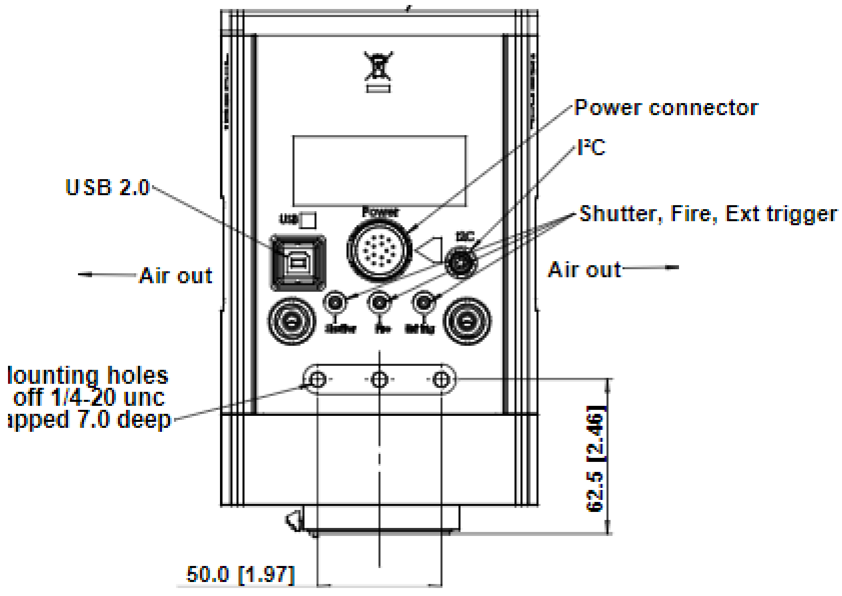


Figure H2: Mounting points of the camera body

The following components for camera are already property of the End-User:

- Nikon NIKKOR 50mm f/1.2 manual lens (Mount Type: Nikon F)
- Nikon Micro-NIKKOR 105mm f/2.8 manual lens (Mount Type: Nikon F)
- 50 micron RC-TriTec LiF/ZnS 200x200mm scintillator in front-end frame
- 100 micron RC-TriTec LiF/ZnS 200x200mm scintillator in front-end frame
- 200 micron RC-TriTec LiF/ZnS 200x200mm scintillator in front-end frame
- 450 micron SCINTACOR LiF/ZnS 250x200mm scintillator in front-end frame
- OG2 CAWO 250x200mm x-ray scintillator with carbon fibre window in square front-end frame
- Front-surfaced 200x280mm aluminium mirrors

The expected Fields of View: 80x80mm, 120x120mm with a 200mm front section.

APPENDIX I
List of shielding materials already the property of the End-User

This is for information purposes only. If convenient, the System could incorporate these materials to save money

Table I.1. List of locally available materials that could be used for shielding.

Material	Form	Quantity	Can be cut/formed locally	Remark
Pb	Lead bricks 10cm by 10cm by 5cm	640 (8t)+	N	May be used to surround guide or the camera box
Al plates	200 cm by 60 cm sheets 2mm thick	20	Y: can be cut into rectangular sheets, but not curves	
5%B4C-containing Silicone	30 cm by 90 cm sheets 2mm thick	20	Y: can be cut into rectangular sheets, flexible	Could be used for shielding the guide
Li-containing polymer	100cm by 100cm 2mm thick	1	Y: can be cut into rectangular sheets, flexible	
25%B-PE rings	5cm holed rings, 19cm diam. and 5cm thick	6	N	Remaining from collimator plug
Lead rings	5cm holed rings, 19cm diam. and 5cm thick	15	N	