March 03, 2025

QIKR Shielding PDR: Neutronics Analysis

Kursat Bekar, Neutronics Scientist

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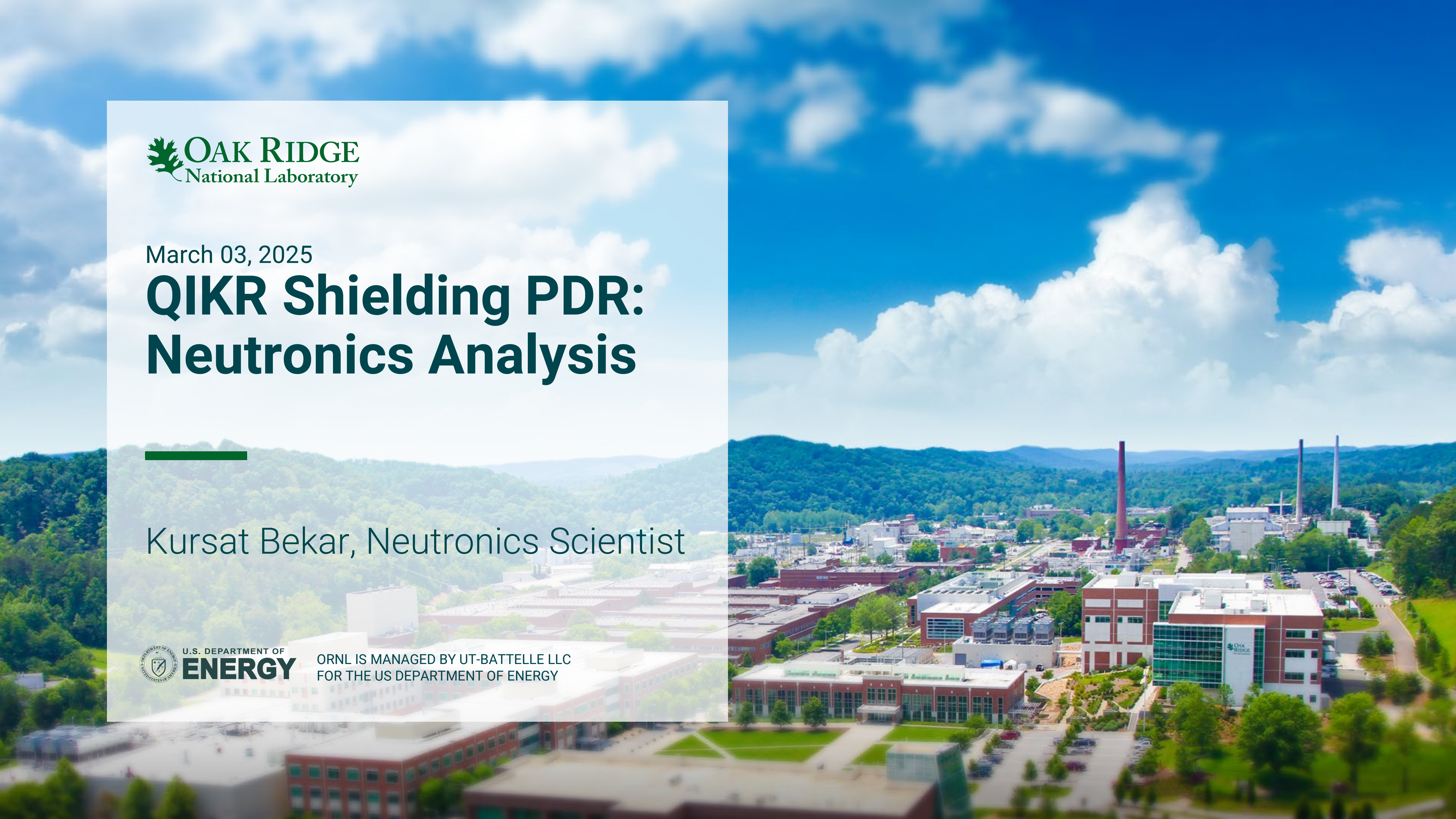
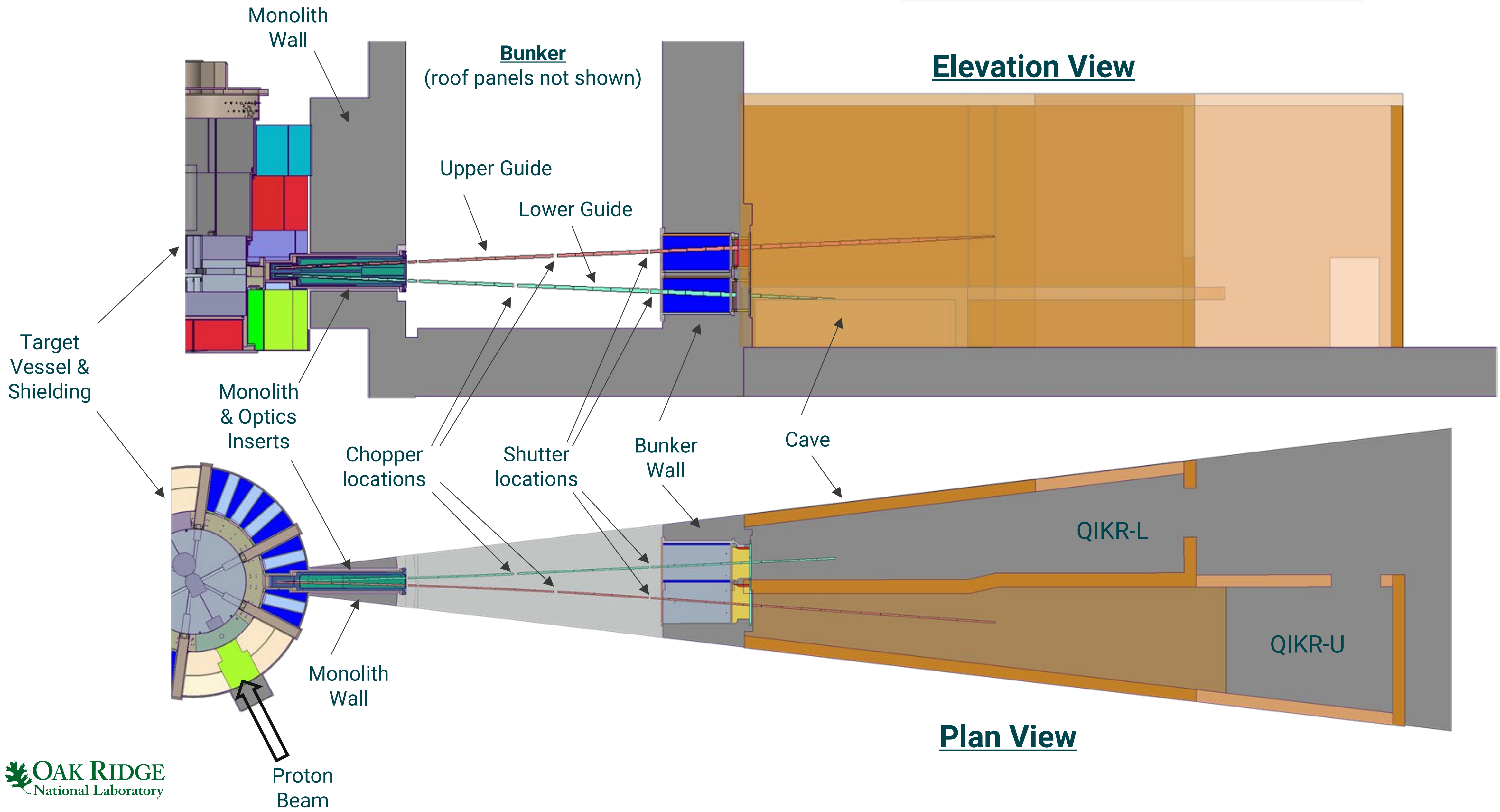


Outline

- QIKR MCNP Model
- QIKR MCNP Source Model
- QIKR Analysis for Monolith and Bunker
- QIKR Downstream Sources
- QIKR Shutter Design and Analysis
- QIKR Beam Stop Design and Analysis
- QIKR Cave Shielding Design Analysis

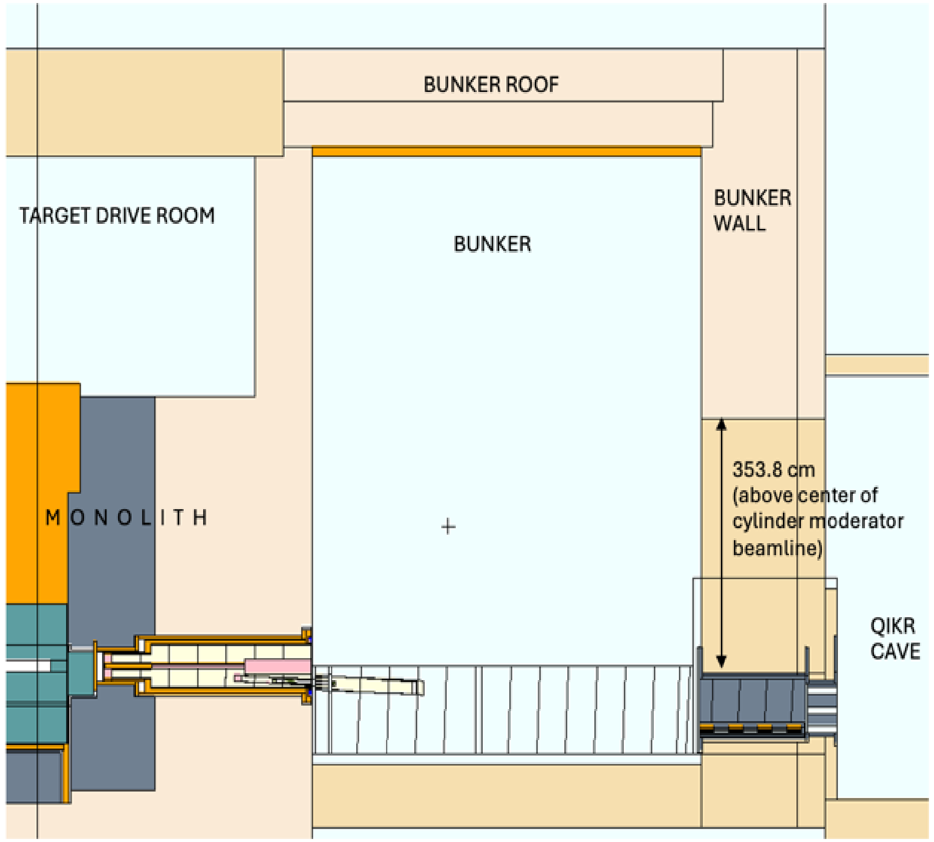
QIKR Model – Creo

Guide Shielding not shown here

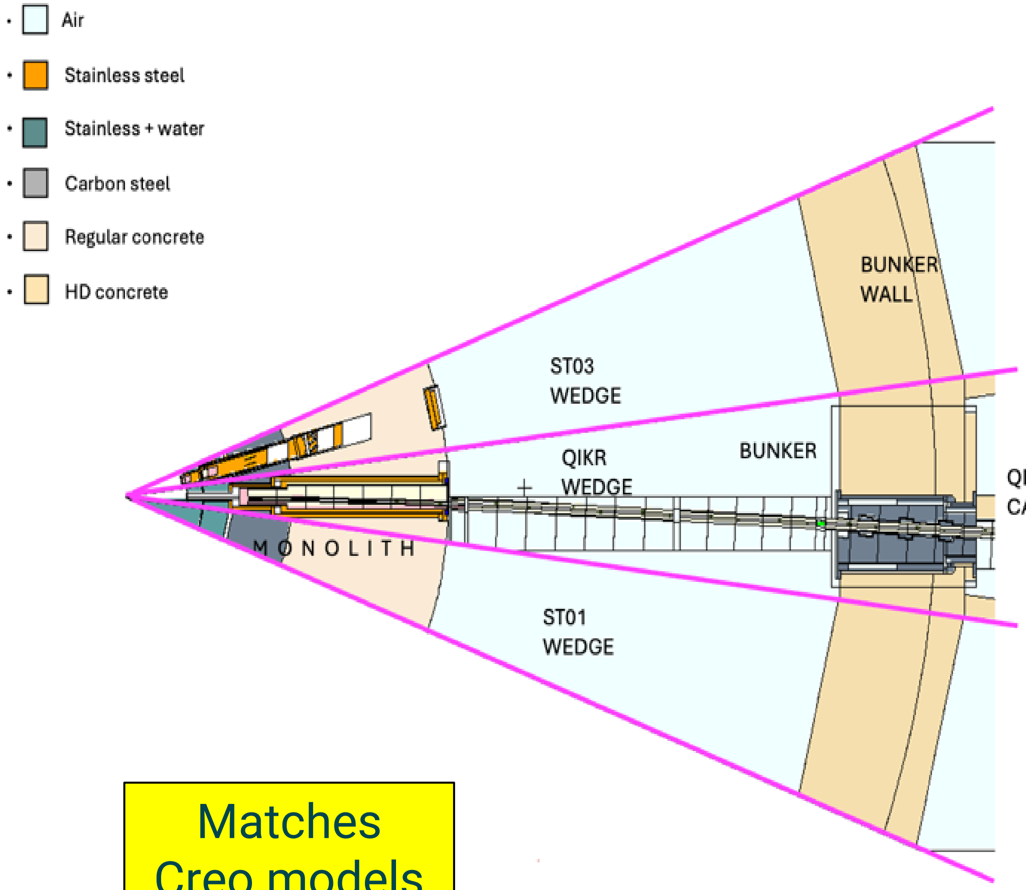


QIKR MCNP Model

A portion of QIKR MCNP model including monolith/bunker up to the QIKR instrument caves



(a) Elevation view, cut at the center of the QIKR wedge



Matches Creo models

(b) Plan view along the QIKR-U elevation

A portion of QIKR MCNP model including monolith/bunker up to QIKR instrument caves

QIKR MCNP Source Model

QIKR-SSW source

- It utilizes the direct particle information for source neutron on the source plane (neutrons are stored with their exact position, direction and energy information while crossing the source plane)
- It was generated by using MCNP's surface crossing source capability:
  - MCNP full model was simulated with a proton source (700 kW, 1.3 GeV proton beam, corresponds ~ 3.37×10^{15} p/s)
  - A rectangular source plane (28.5 x 13.5 cm^2) was located 100 cm away from the moderator surface
  - Only forward-directed neutron tracks passing through the predefined rectangular surface area were stored
  - ~ 54 million neutron tracks stored for 1 million proton, resulting in total 0.04315 n/s per source proton
  - 0.002384 n/s per source proton within 0° - 3° degree

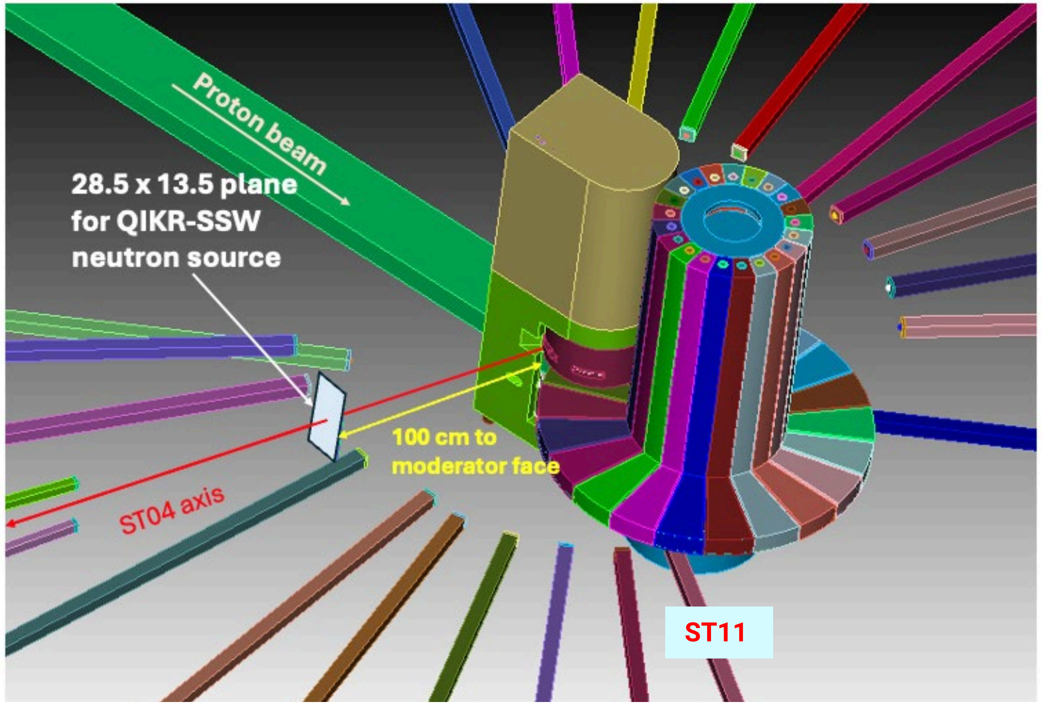


Illustration of the location of the source plane for QIKR-SSW source generation (no shielding is shown, only target moderator assembly and beamlines)

QIKR-SSW source was developed when QIKR was on ST04. Since then, QIKR location has been changed twice; first moved to ST03, and now located on ST02

QIKR MCNP Source Model

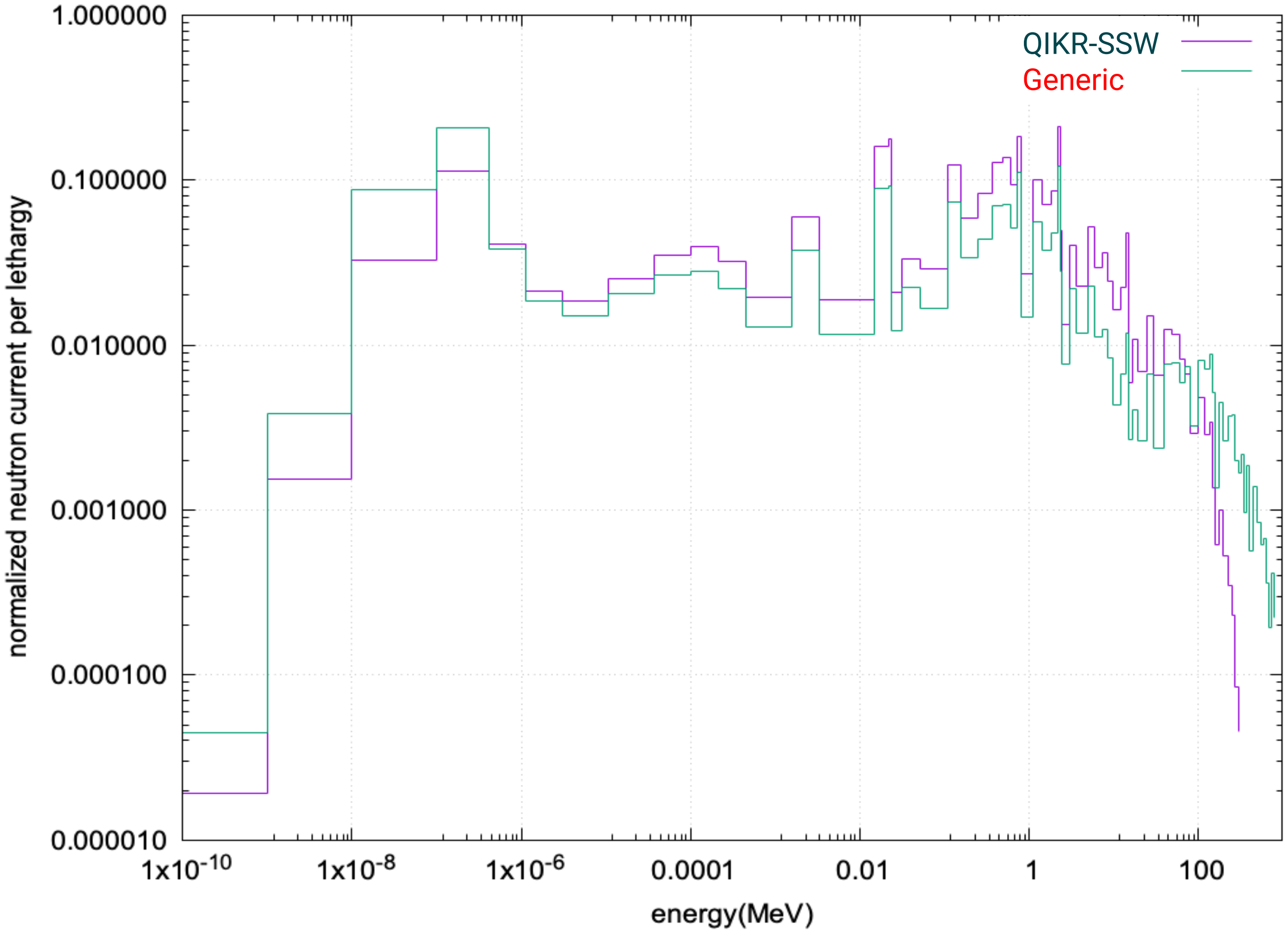
Normalized energy spectra of QIKR-SSW source vs generic neutron plane source

The generic neutron plane source was developed for STS shielding studies (documented in: *STS Project Generation of Beamline Sources – Preliminary Design,* S04030200-TRT10002)

- Used in most STS shielding studies
- Limited angular resolution
- Limited energy resolution at low energy

QIKR-SSW better represents the space-dependent energy and angular distributions of neutrons

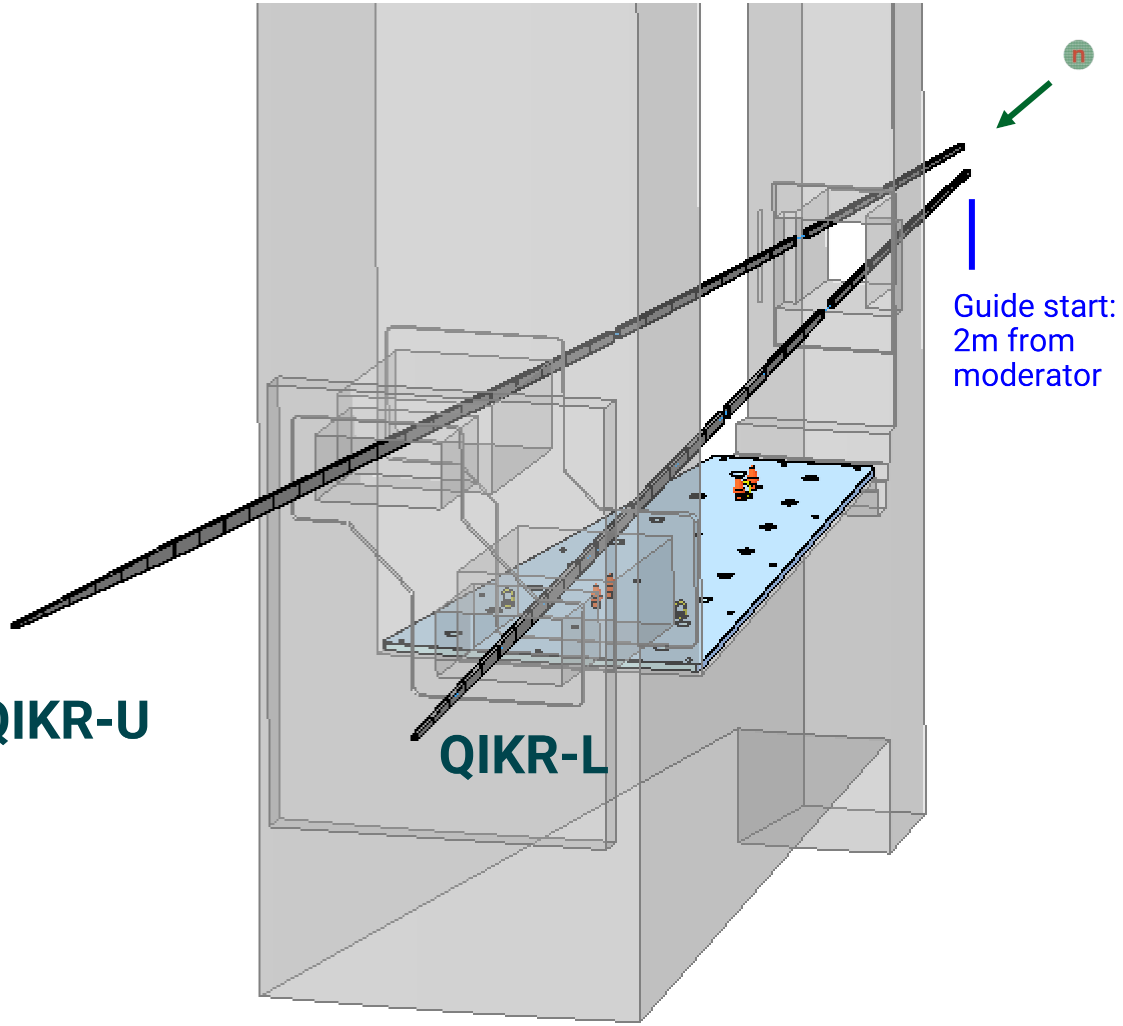
Differences in spectra at very high-energy range is mainly due to the locations of the source planes (QIKR-SSW at ST04-Generic source at ST11 locations)

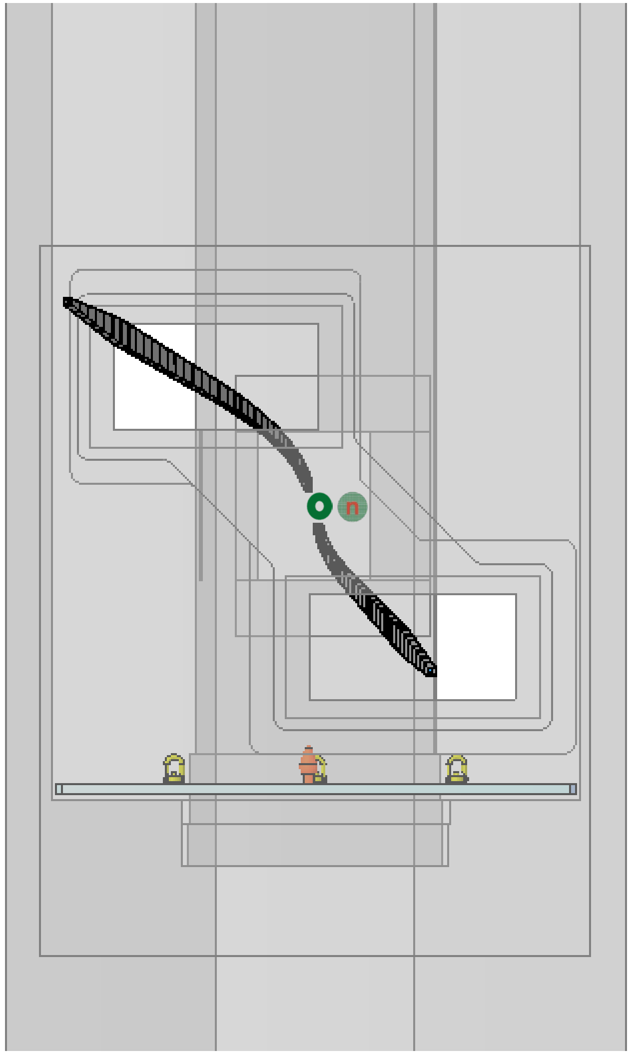


Comparison of neutron energy spectra for QIKR-SSW and generic neutron source

Generic neutron plane source generated for STS shielding studies

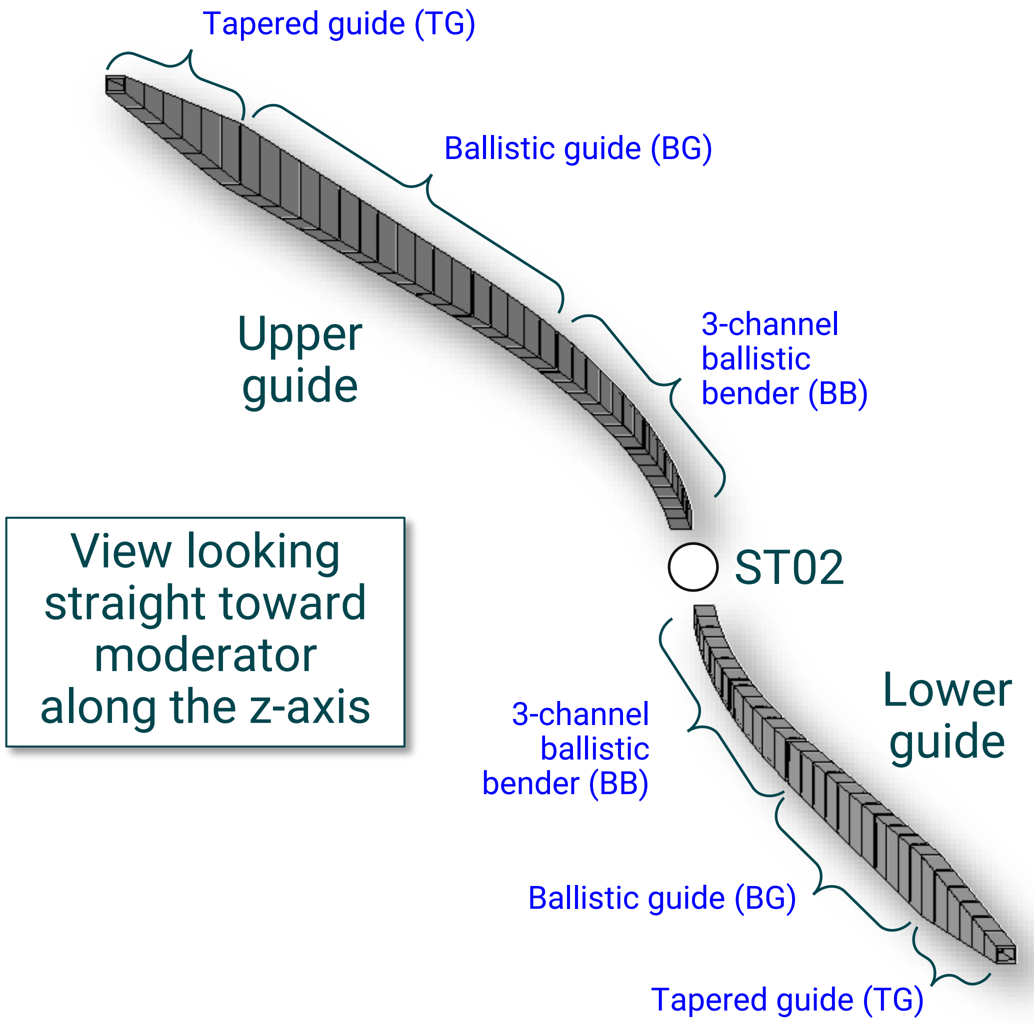
QIKR Guides – Creo

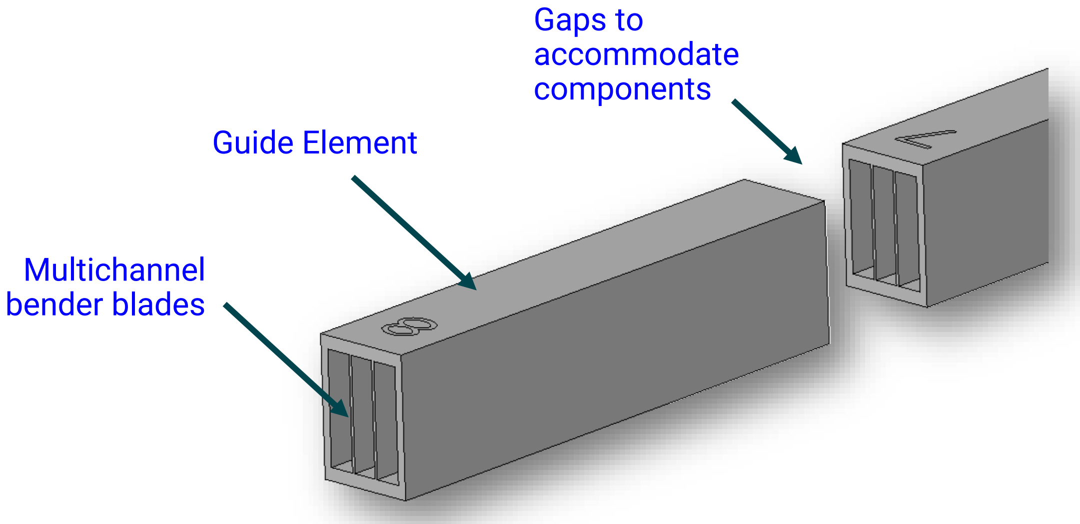




View looking straight toward moderator

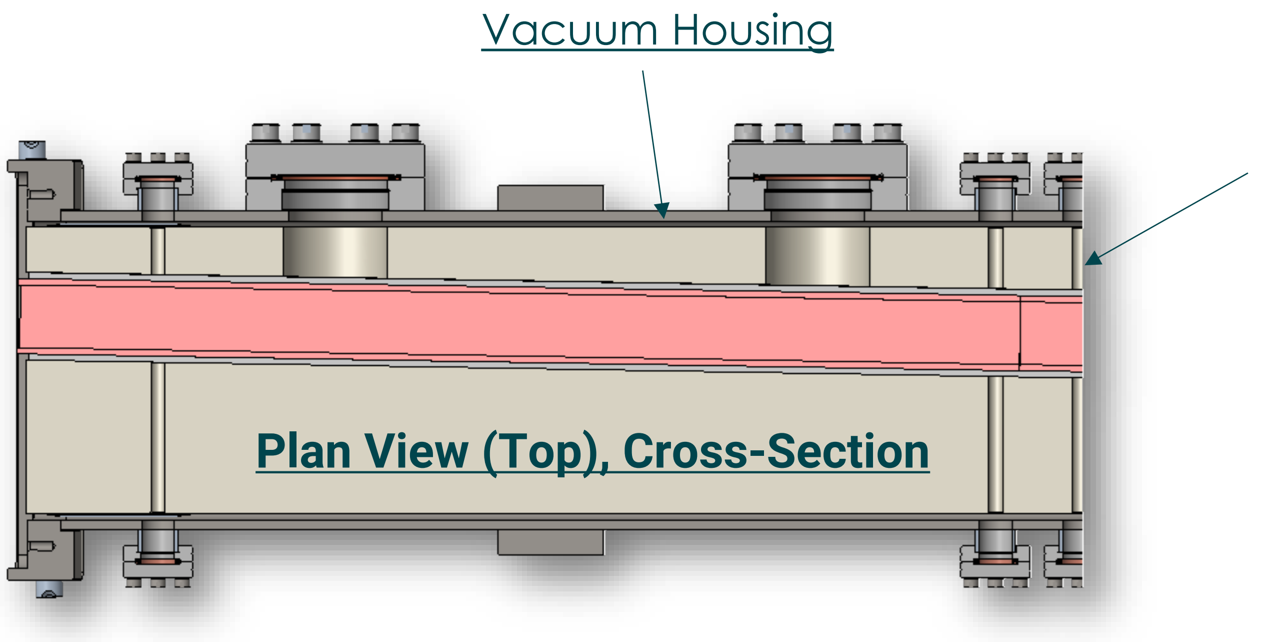
QIKR Guides – Creo





- There are three main sections in each guide path: multi-channel ballistic bender (BB), ballistic guide (BG, and tapered guide (TG). Guide height continually increases until the TG section when it decreases quickly.
- Each guide element is straight, even in the bender section
- In the bender section, each guide element is angled relative to its neighbor to approximate a 156m radius curve. The guide elements are parallel to each other in the remaining sections
  - The elements in each bender section are multichannel (3 channels)
- The upper guide angles up by 2.5° and is then rotated by 0.7° toward ST02
- The lower guide angles down by 2.5° and is then rotated by 0.75° toward ST04

Guide Shielding



Guide Shielding:

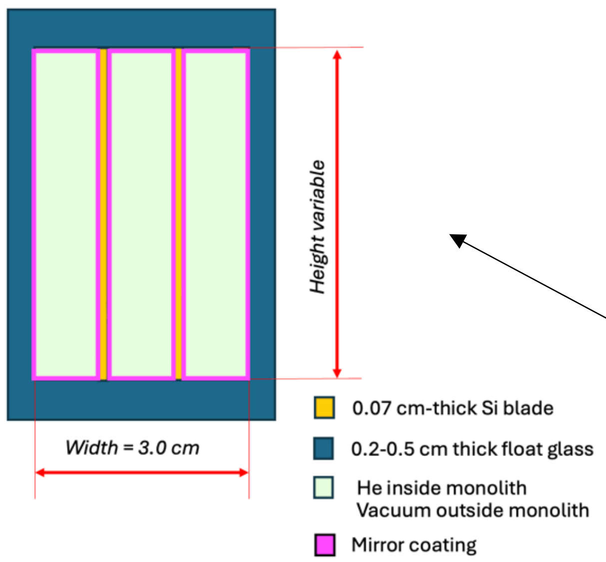
- Exterior surfaces conform to the interior of the vacuum housing (3mm clearance)
- Interior surfaces conform to the contour of the guide elements (3mm clearance)

Shielding thickness varies along the length of the guide for two reasons:

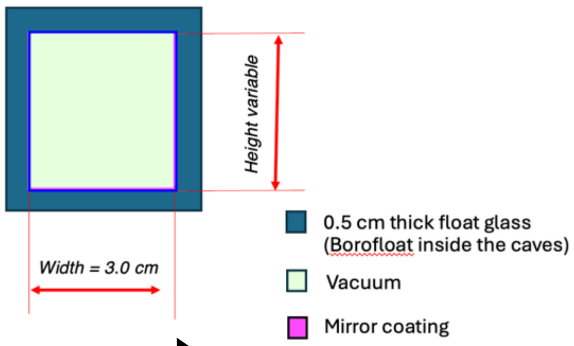
1) The guide curves within each ~3m long straight section of housing
2) The guide tapers (continually changes height) within each straight section of housing

QIKR Guide Design in MCNP model

BB guides have 3 channels
(each has equal cross-sectional area)



BG and TG guides



Matches Creo and McStas models

Guide version: 5.0, provided by Ankner in May 2024

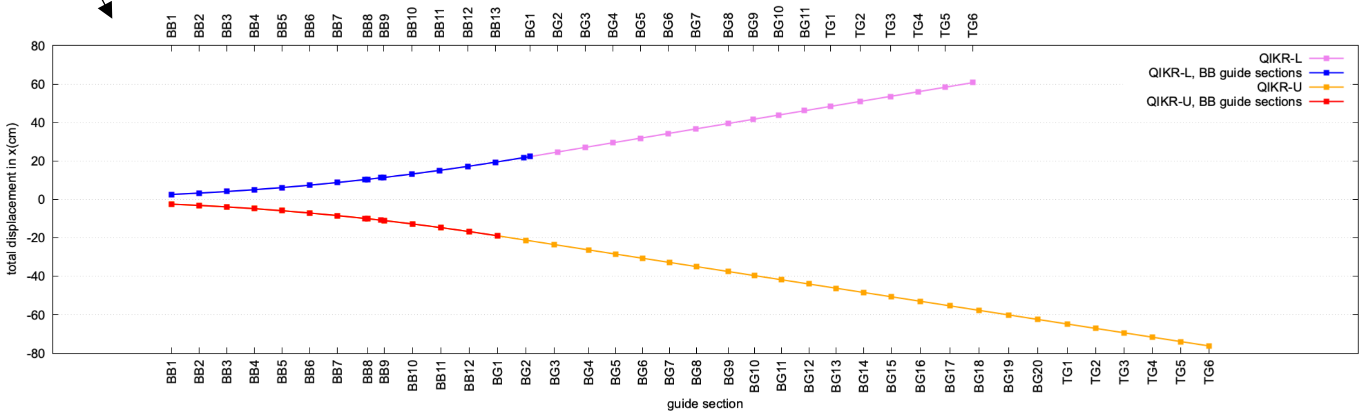
Guide segment	QIKR-L	QIKR-U
BB (ballistic bender)	13	12
BG (ballistic guides) Float glass	11	20
TG (tapered guides)	6	6

# of elements

QIKR-L and QIKR-U are curved beamline

- QIKR-L (lower guide): angled 2.5° downward from the horizontal and total 2.95 ° rotation from the QIKR-Z axis in the horizontal plane (only BB guide section)
- QIKR-U (upper guide): angled 2.5° upward from the horizontal and total -2.773 ° rotation from the QIKR-Z axis in the horizontal plane (only BB guide section)

- A steel vacuum housing (cross-sectional area of 15.24 cm by 20.339 cm) encloses each guide section
- The space between the vacuum housing and the guide substrate is filled with a steel shield of varying thickness, leaving a 0.3 cm gap on each side



Projection of the QIKR beam paths in the horizontal plane

QIKR Guide Design for MCNP model

Guide version: 5.0, provided by Ankner in May 2024

QIKR-L mirror coatings

Guide section	Top	Bottom	Left	Right
BB1 - BB7	2.5	2.5	2.0	4.0
BB8 - BB13	2.5	2.5	2.0	4.0
BG1 - BG11	0.45	0.45	3.5	3.5
TG1 - TG6	5.0	5.0	3.5	3.5

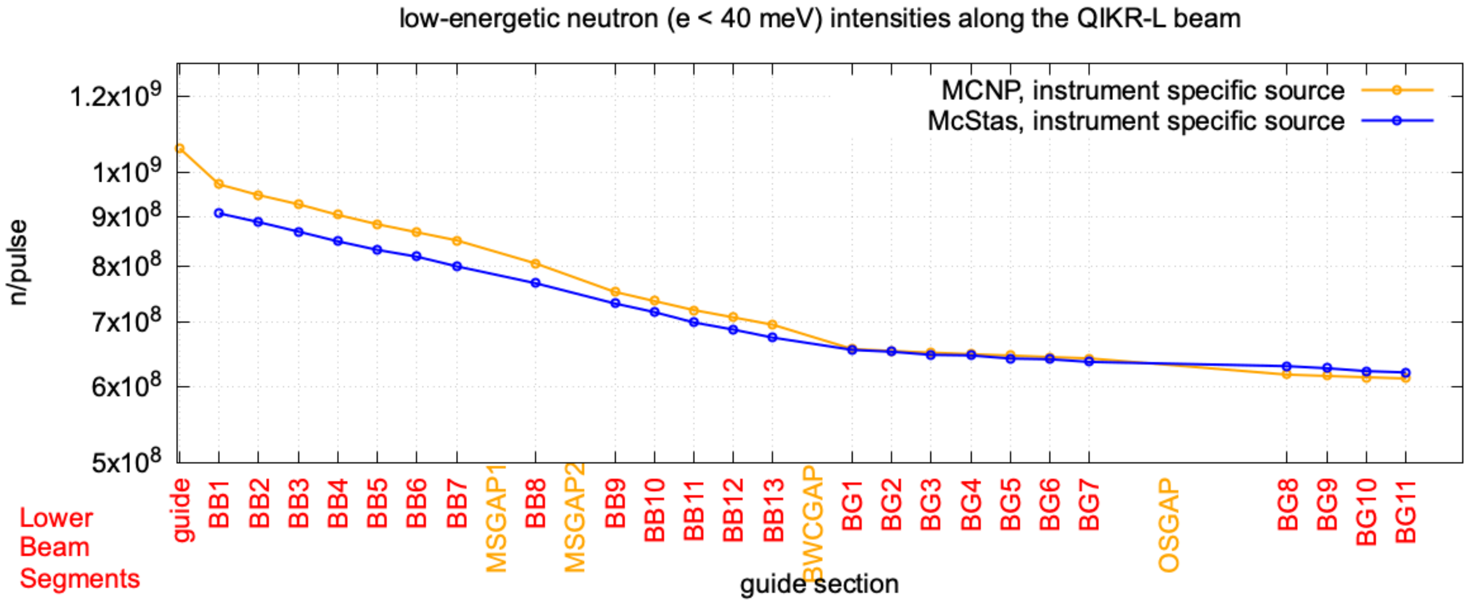
QIKR-U mirror coatings

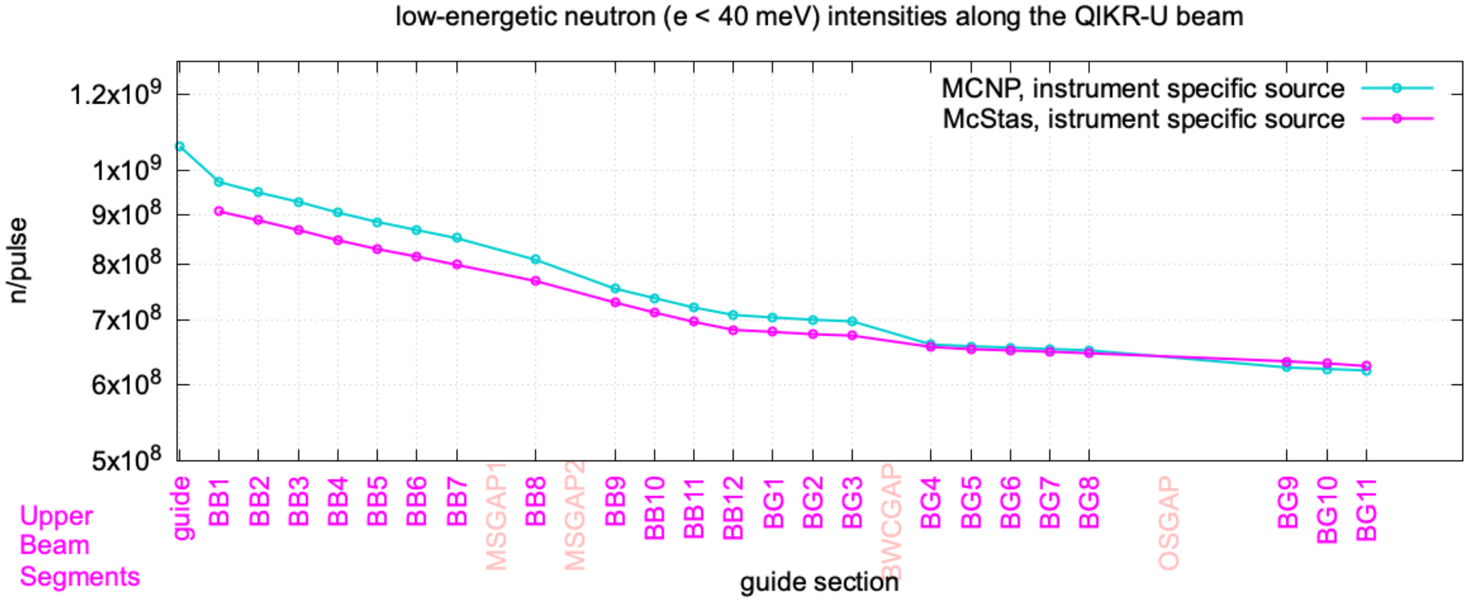
Guide section	Top	Bottom	Left	Right
BB1 - BB7	3.0	3.0	4.0	2.0
BB8 - BB13	3.0	3.0	4.0	2.0
BG1 - BG3	2.0	2.0	3.5	3.5
BG4 - BG8	1.5	1.5	3.5	3.5
BG9 - BG20	0.45	0.45	3.5	3.5
TG1– TG6	5.0	5.0	3.5	3.5

These mirror configurations used in McStas model were also used in MCNP guide model (MCNP neutron mirror physics capability) to simulate the low-energetic neutron motion more realistically inside the guide

McStas is a neutron ray-trace simulation package used for guide design

Agreement Between MCNP and McStas





MCNP and McStas agree within 10% for reflected (ie, low energy) neutrons. Therefore, the MCNP model is correctly capturing the intended mirror surface performance.

The same low-energetic instrument-specific source were used in both MCNP and McStas.

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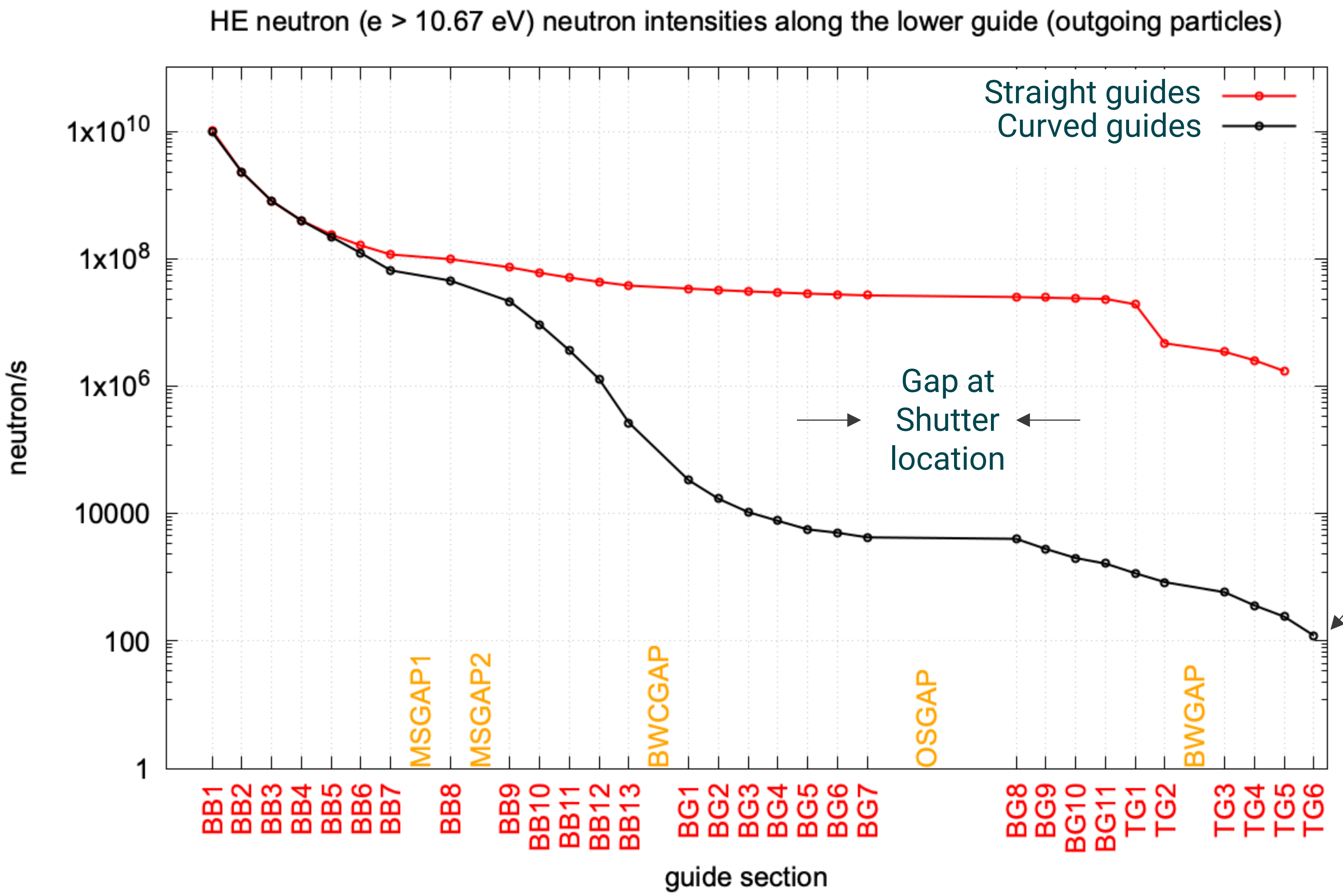
Analysis for Monolith/Bunker

Kursat Bekar, Neutronics Scientist

How well QIKR curved guides reduce the high-energetic neutrons?



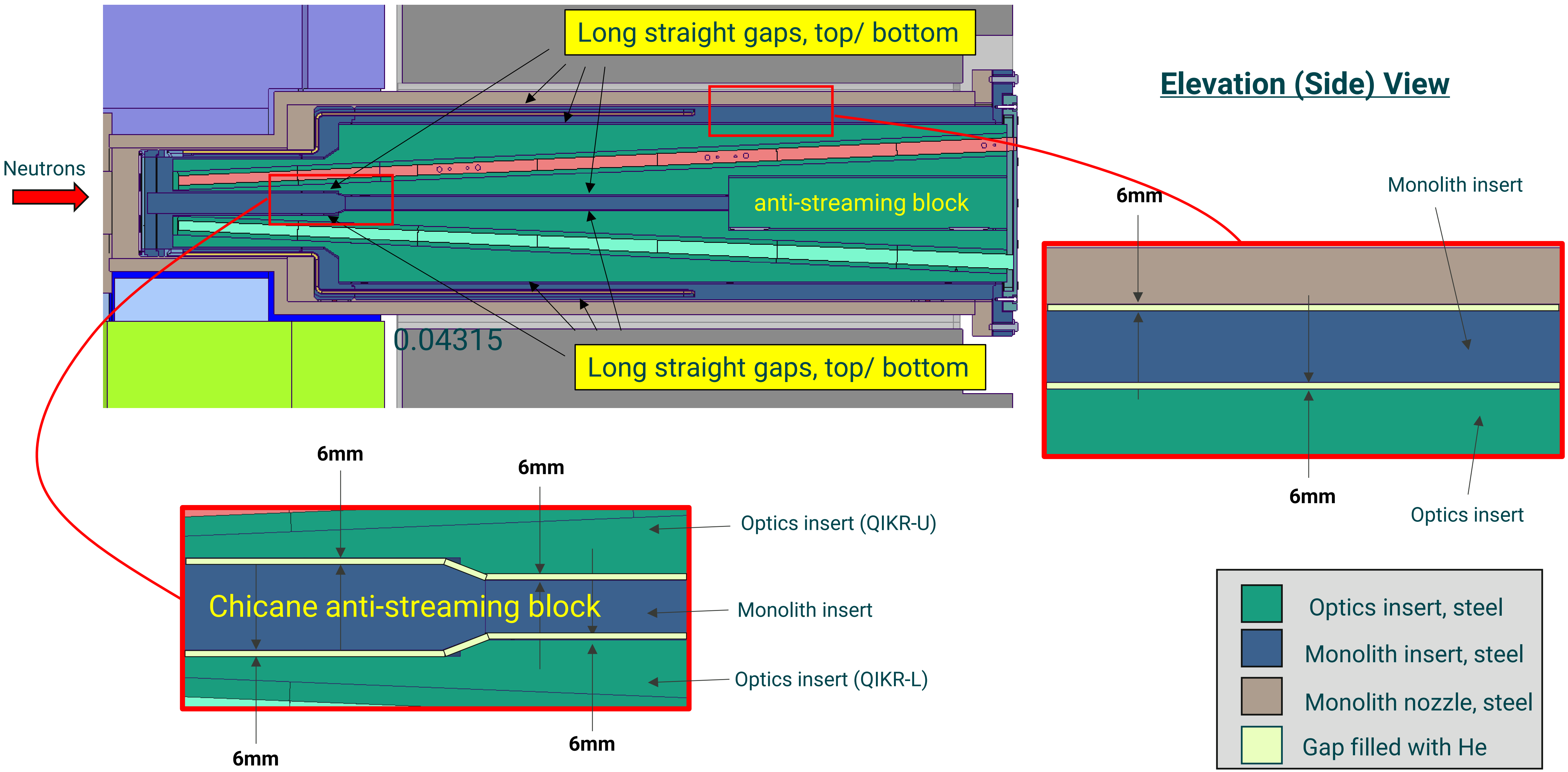
High energetic neutron intensities at the end of guide sections for the cases with and without rotation

QIKR guide design (curved guide) helps to reduce the high-energetic neutrons **in the beam** by ~ 4 orders of magnitude at the shutter location

NOTE: There are still some high energy neutrons entering the cave through the guide. This is important for the beam stop design.

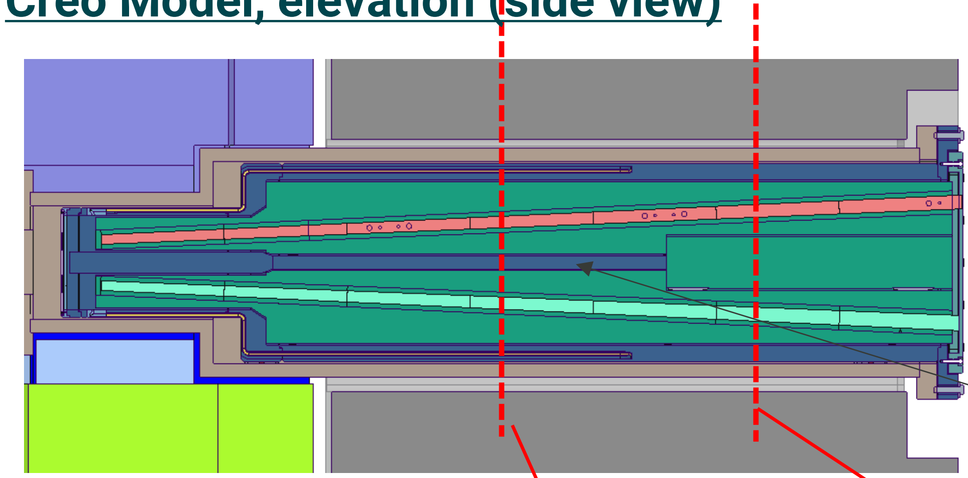
QIKR MCNP model was used with QIKR-SSW source for these simulations

Potential Streaming Paths: QIKR Monolith & Optics Insert Gaps – Creo Models



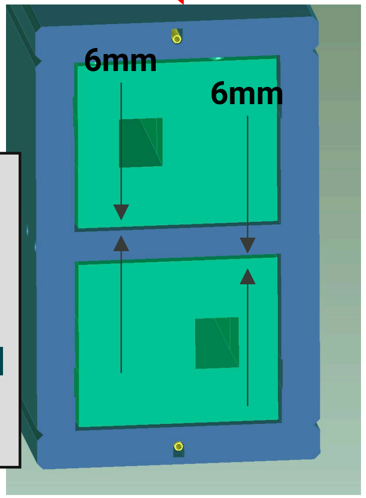
Potential Streaming Paths: QIKR Monolith & Optics Insert Gaps – Creo Models

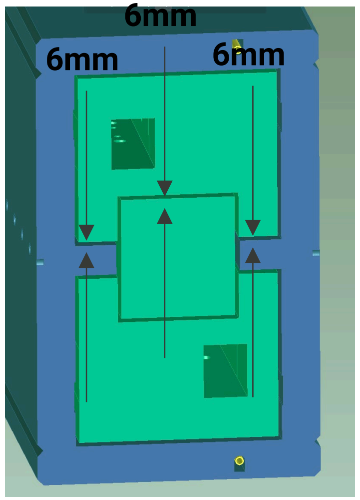
Creo Model, elevation (side view)



monolith insert (shelf)

Cut Views at the dashed lines

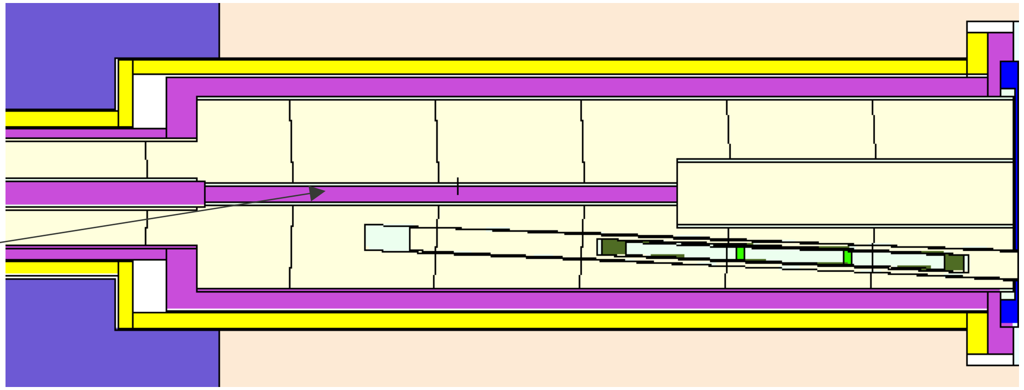




- Optics insert, steel
- Monolith insert, steel
- Monolith nozzle, steel
- Gap filled with He

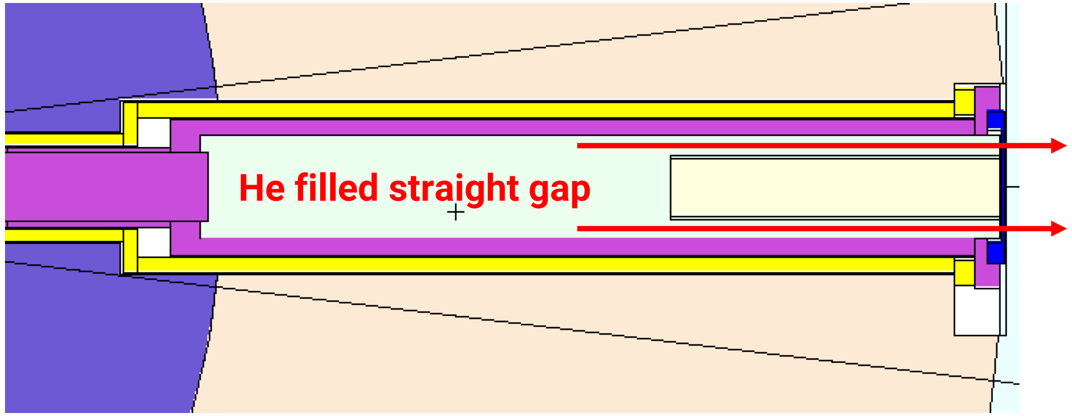
Long straight gaps between shelf and optical inserts

MCNP Model Elevation (Side) View

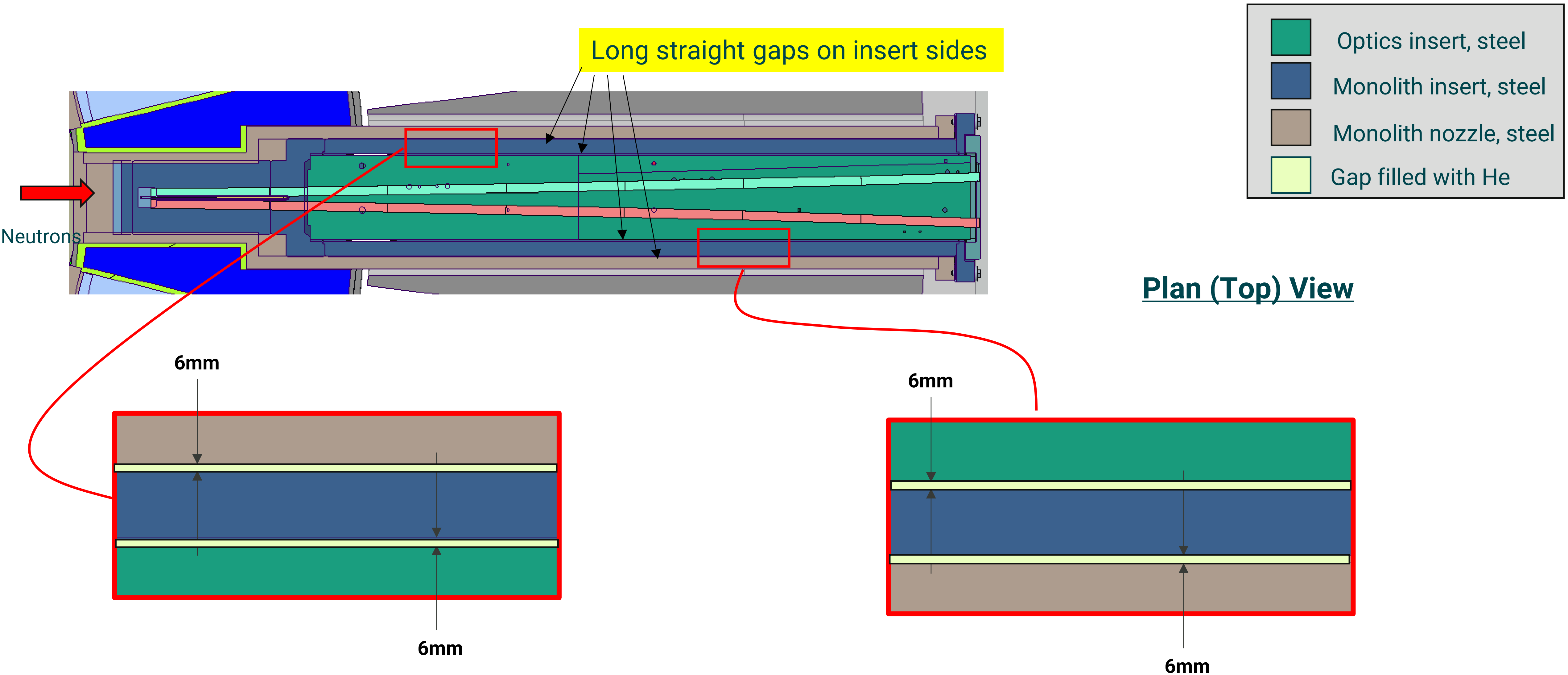


MCNP Model plan view

(cut-view at a location 2.5 cm above the moderator center)



Potential Streaming Paths: QIKR Monolith & Optics Insert Gaps – Creo Models



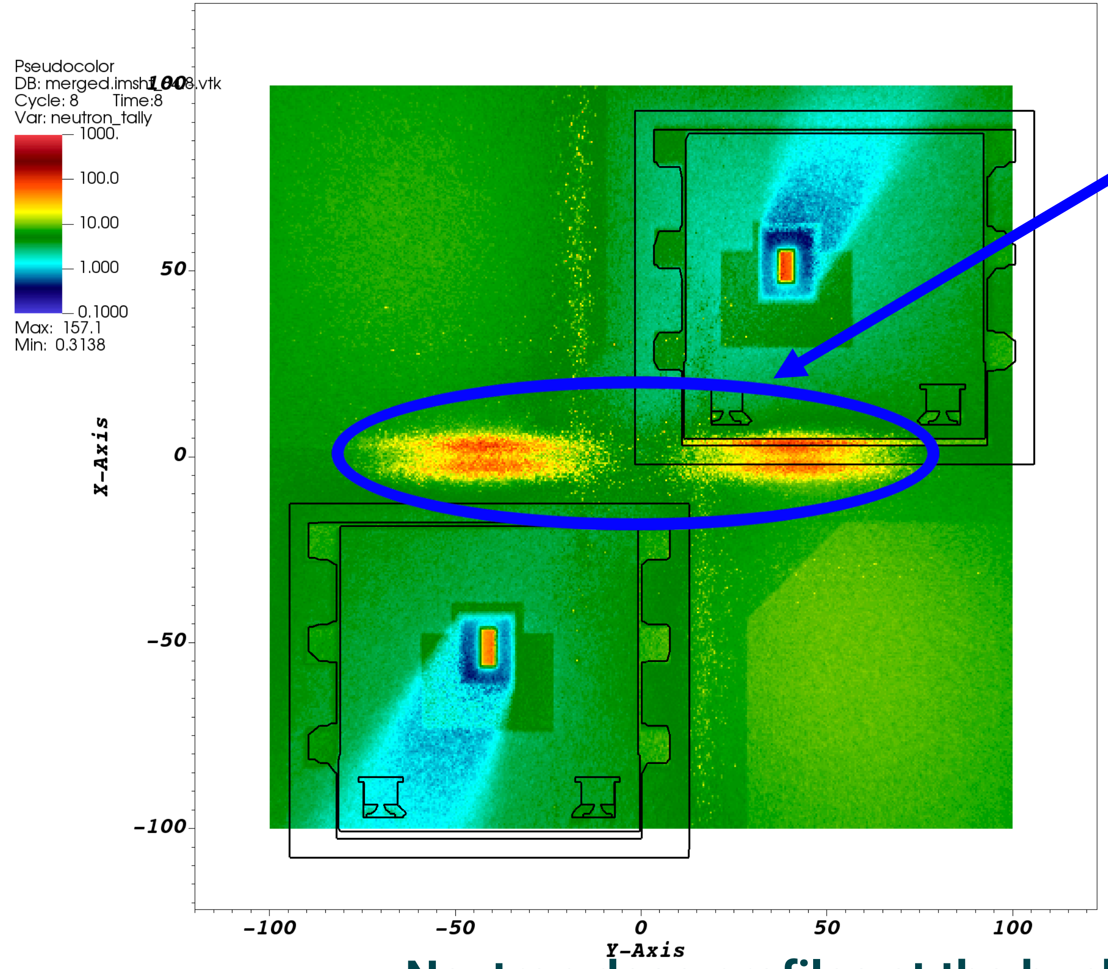
Effects of Gaps in/around QIKR Monolith/Optic inserts on Bunker Wall

neutron dose rates (mrem/hr)

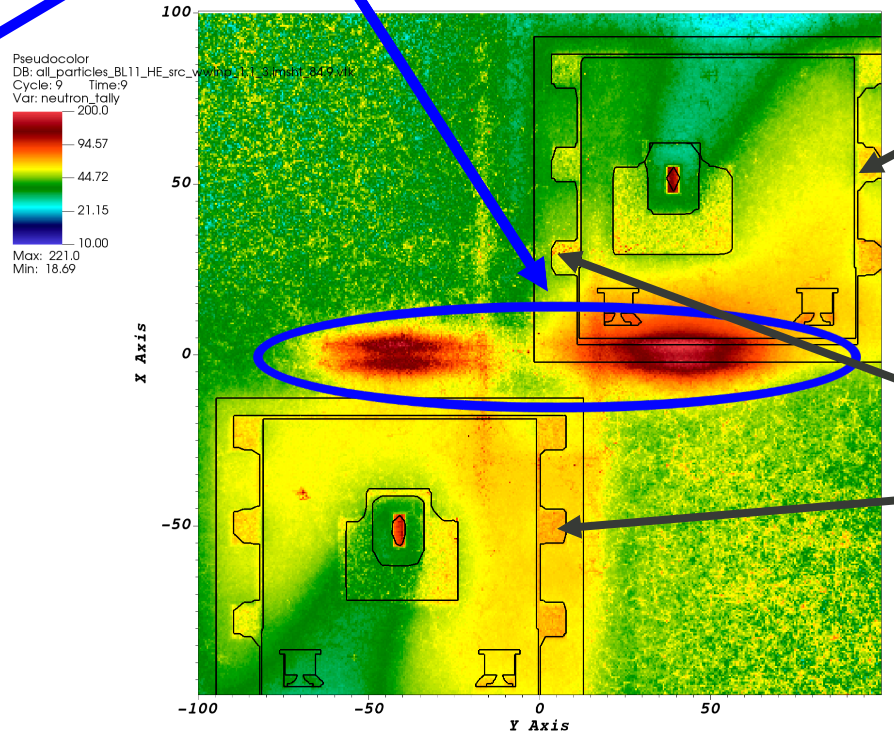
- **No line-of-sight neutrons are shown on bunker wall??**
  Thick steel shield around guide reduces high-energetic neutrons (line-of-sight neutrons) impact on bunker wall significantly

- **These are the HE neutrons which stream through gaps around/in monolith/optic inserts**

Only very high energetic neutrons (E > 10 MeV)



neutrons (E > 10.67 eV)



Cable channels

We should consider removing the inner cable channels

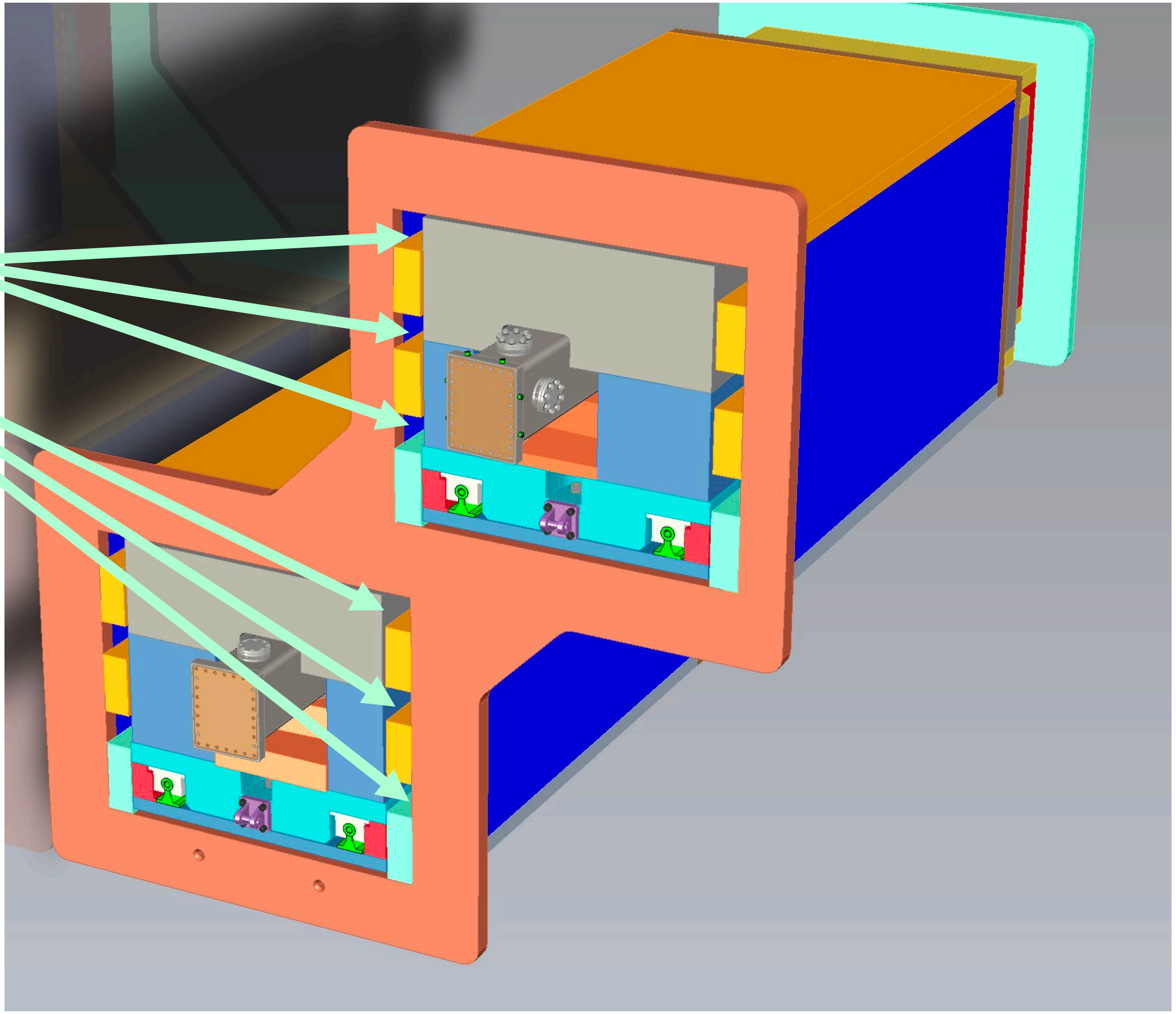
user: 5kq
Wed Jan 10 01:27:00 2024

Neutron dose profiles at the bunker wall (view from the bunker area)

user: 5kq
Wed Dec 20 08:18:03 2023

Analysis for Bunker pass-thru

Cable channels line up with the gaps in/around monolith/optic inserts (potential streaming paths)

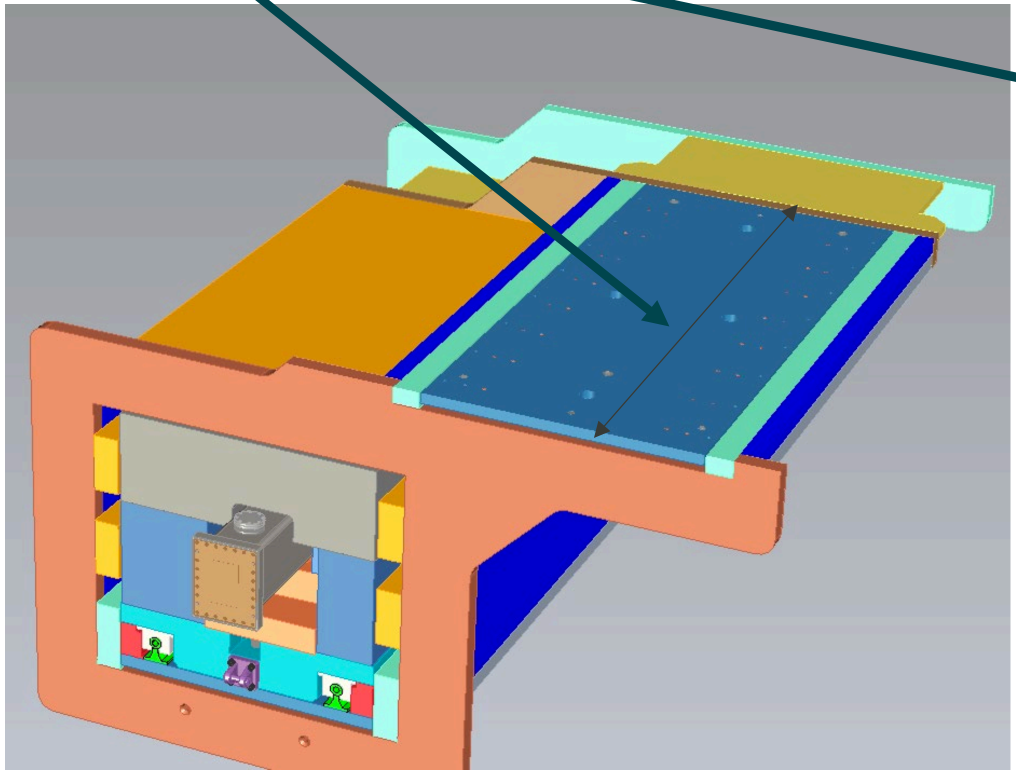


Analysis for Bunker pass-thru

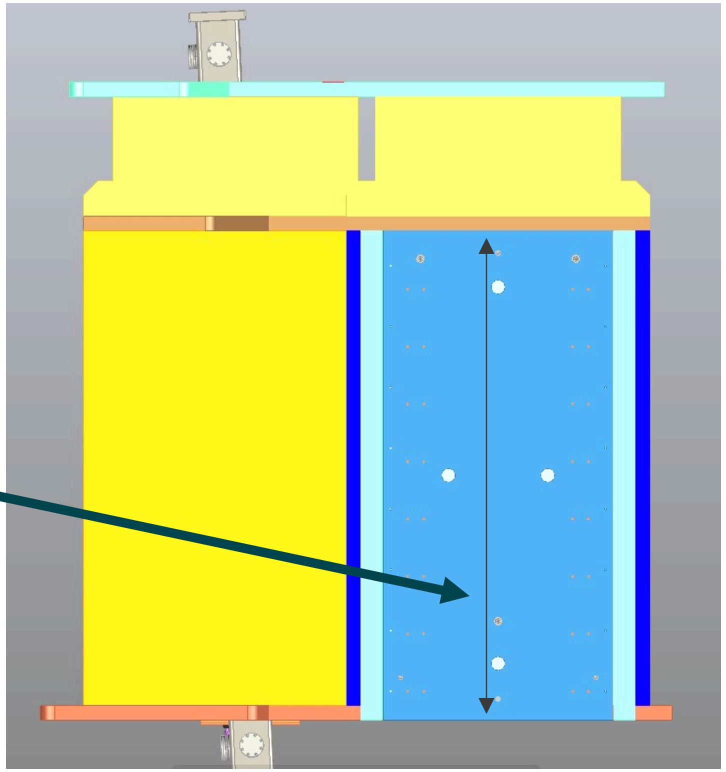
Gap under this plate extends almost all the way

Potential streaming path for the neutrons/photons from the bunker area to the cave

could elevate dose rates inside the cave



Cut-view through bunker pass-thru close just above the bottom gap



Cut-view through bunker pass-thru close just above the bottom gap (plan view)

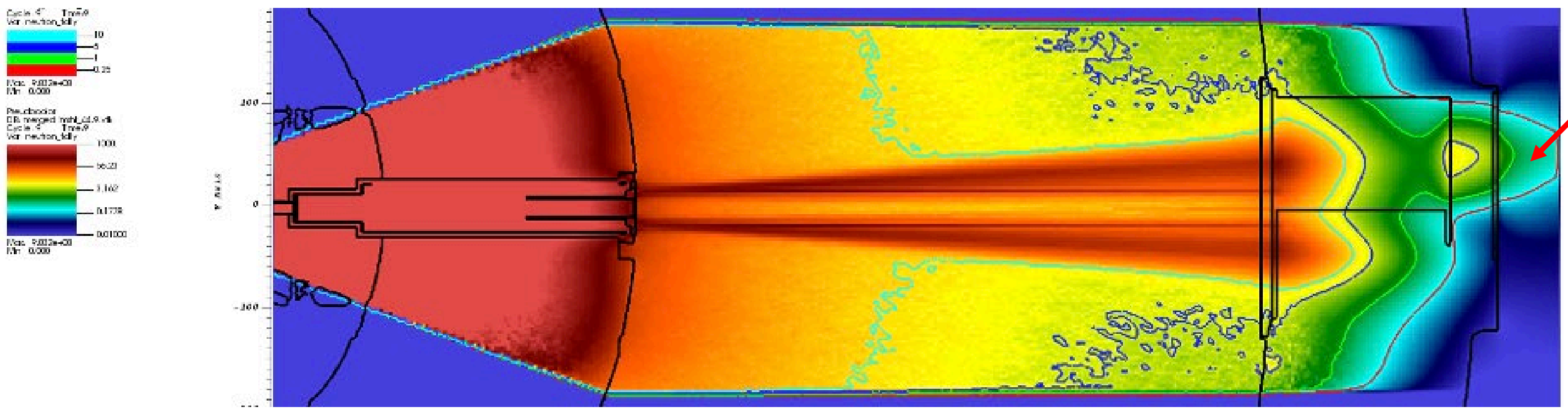
In the actual design, this gap will be filled with regular density concrete (RDC). The MCNP model includes this as well, though the effect of removing it was investigated.

Analysis for Bunker pass-thru

neutron dose rates(mrem/h)
horizontal cut-view at the moderator elevation (plan view)

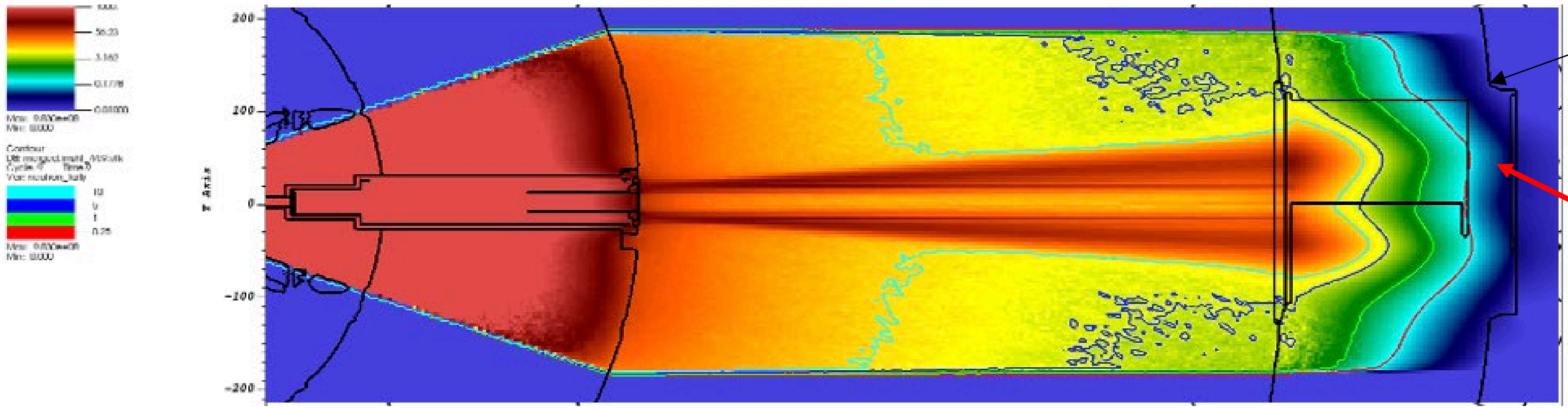
elevated dose rates inside the cave

bottom gap without grout



This matches reality and shows the pass-thru is not allowing significant radiation into the cave

bottom gap with grout



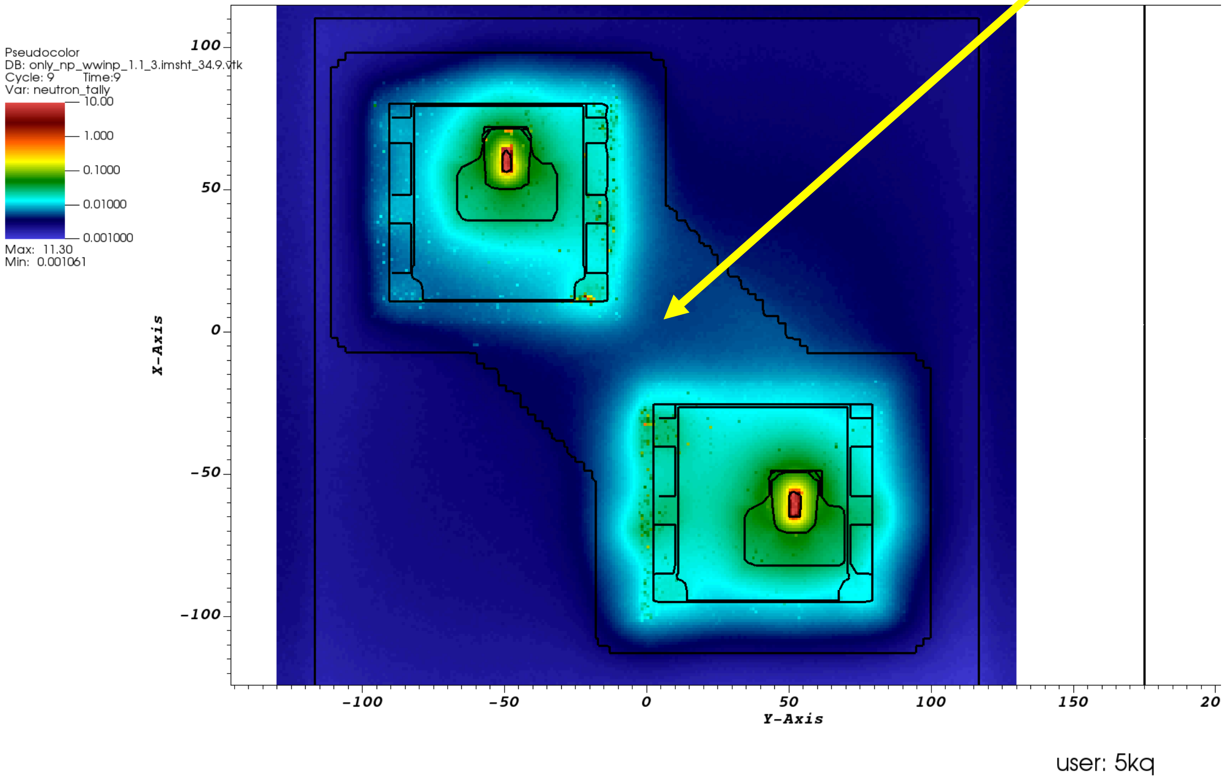
problem resolved

Analysis for Bunker Passthrough

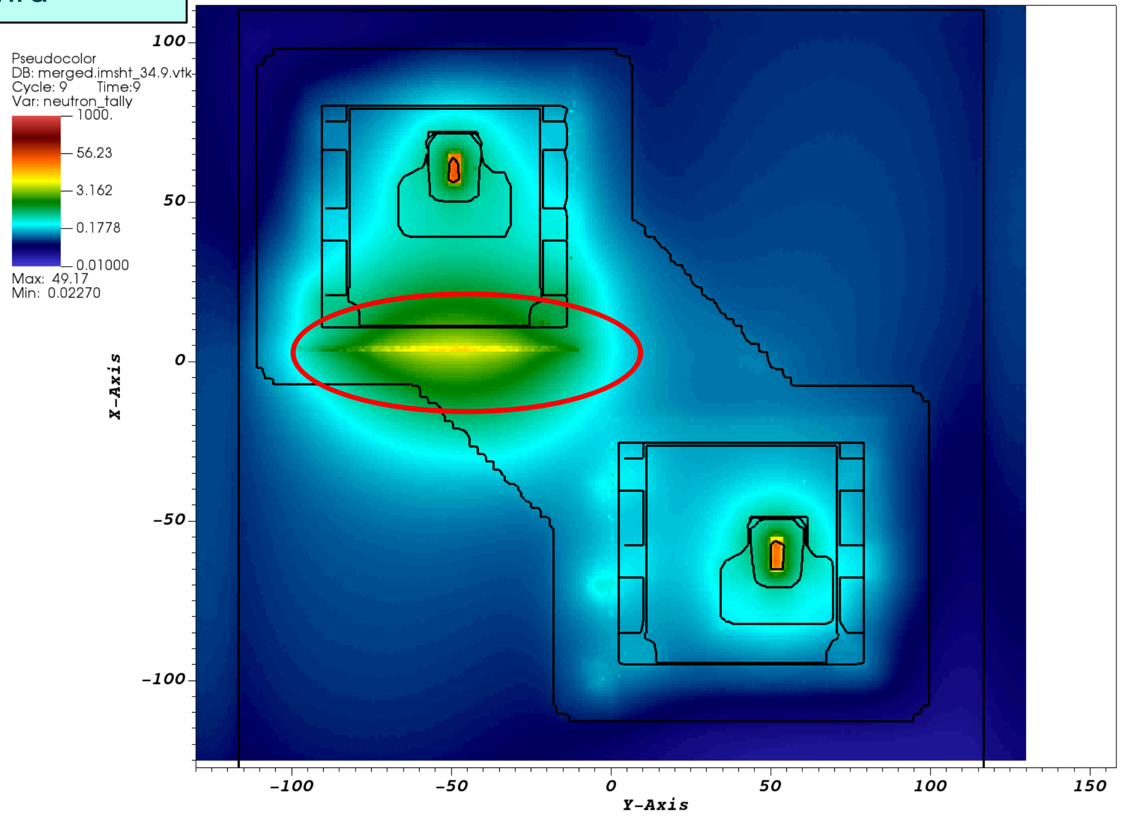
neutron dose rates (mrem/h)

This matches reality and shows the only significant radiation entering the cave is through the guides themselves, not through the bunker wall or pass-thru

Neutron streaming through bottom gap elevates the neutron dose rate above 5 mrem/h at the upstream cave locations (QIKR-U cave)



With grout



Without grout

Vertical cut-view at the exit face of the bunker pass-thru (view from inside the cave)

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QIKR Downstream Neutron Sources

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QIKR-L and QIKR-U Downstream Neutron Sources

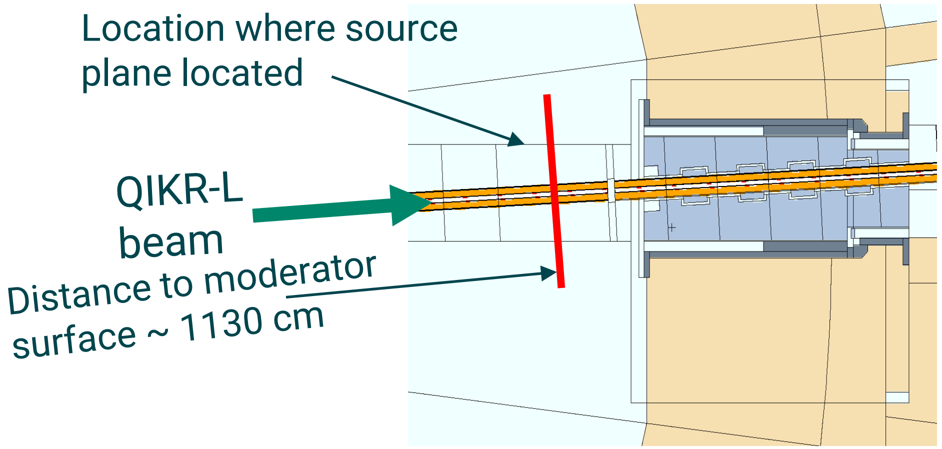
Simulations with QIKR-SSW are timely calculations especially for downstream calculations

- **Require QIKR MCNP full model even a calculation at the very downstream locations (e.g. beam stop design) → longer simulation time**
- **Require detail optimization for variance reduction to improve the statistics in MCNP results → longer analyst time**

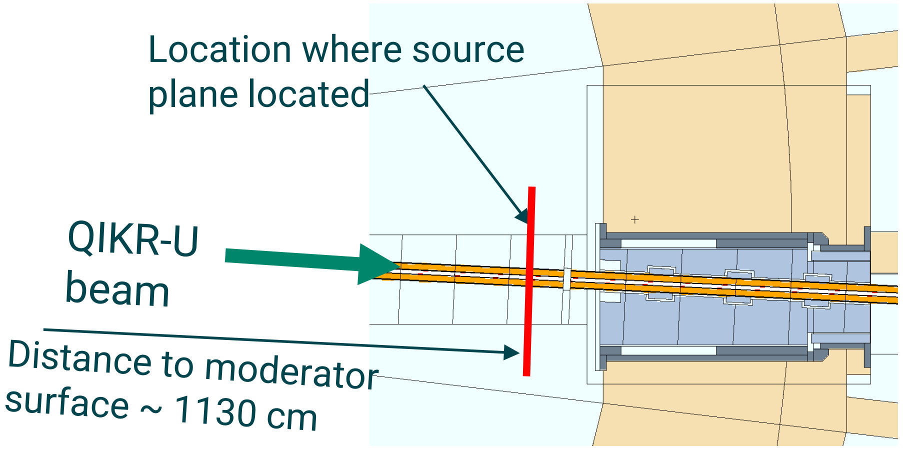
Two new sources were developed for downstream calculations to speed up the downstream calculations

- **beamline specific source for QIKR-U**
- **beamline specific source for QIKR-L**

Downstream sources were obtained by performing MCNP simulations with QIKR MCNP Full model with QIKR-SSW neutron source



QIKR-L source plane location
View along the QIKR-L beam elevation



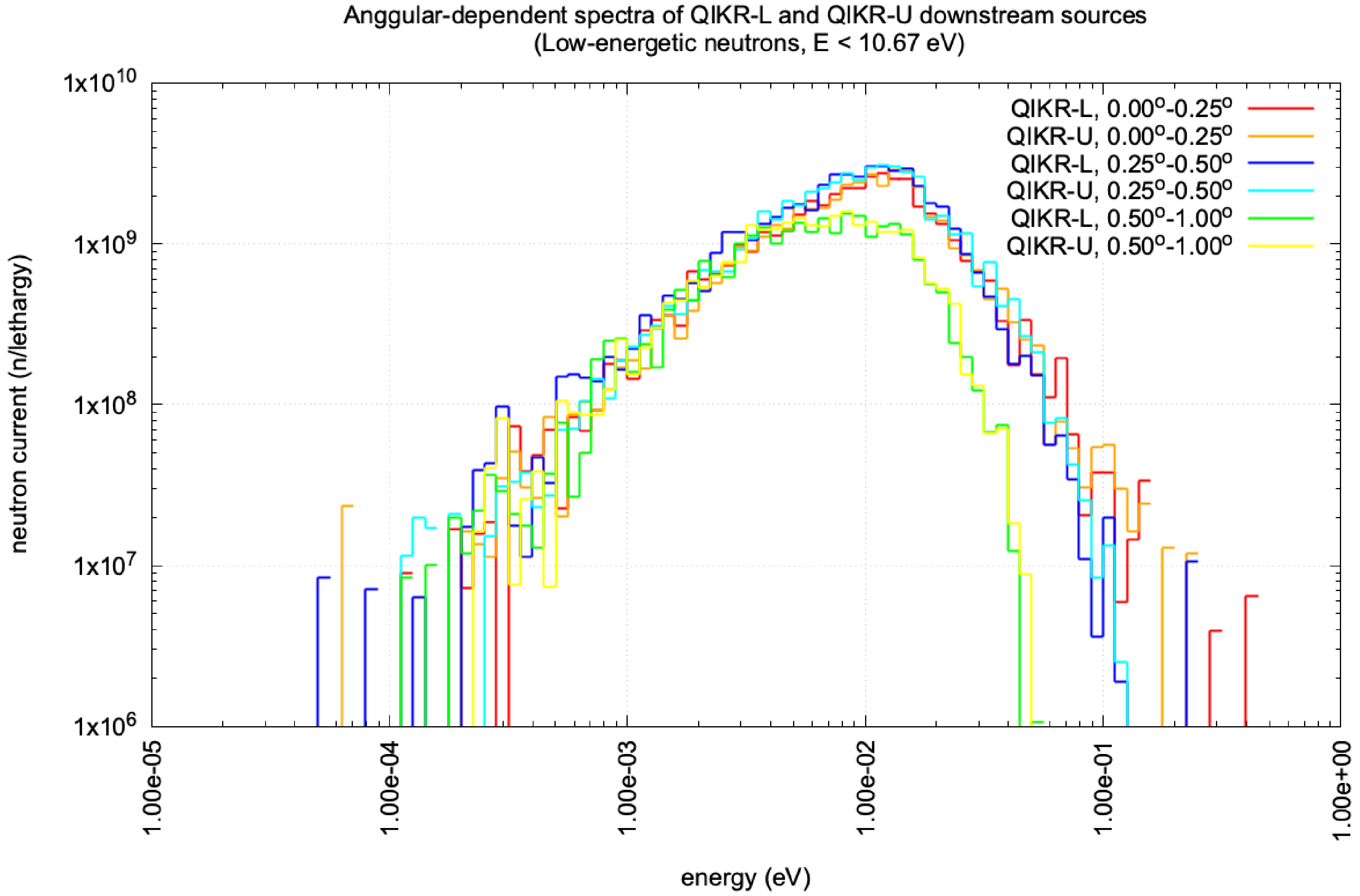
QIKR-U source plane location
View along the QIKR-U beam elevation

QIKR-L and QIKR-U Downstream Neutron Sources

	QIKR-U downstream source	QIKR-L downstream source
Distance to moderator surface	~ 1080 cm	~ 1080 cm
Source surface area	**6.957 x 3 cm^2**	**8.496 x 3 cm^2**
Spatial distribution	Uniform	Uniform
Angular distribution	6 angular bins **(0-0.25, 0.25-0.50, 0.50-1.0, 1.0-1.5, 1.5-2.0, > 2.0)**	6 angular bins **(0-0.25, 0.25-0.50, 0.50-1.0, 1.0-1.5, 1.5-2.0, > 2.0)**
Energy distribution	Each angular bin has its spectrum	Each angular bin has its spectrum
Low-energetic portion (E < 10.67 eV) Neutron intensity	1.368 x 10^{10} n/s	1.367 x 10^{10} n/s
High-energetic portion (E > 10.57 eV) Neutron intensity	~ 8.93 x 10^3 n/s	~ 10.87 x 10^3 n/s

These new sources were used in the analysis for QIKR ***shutters***, ***beam stops*** and ***cave shielding***.

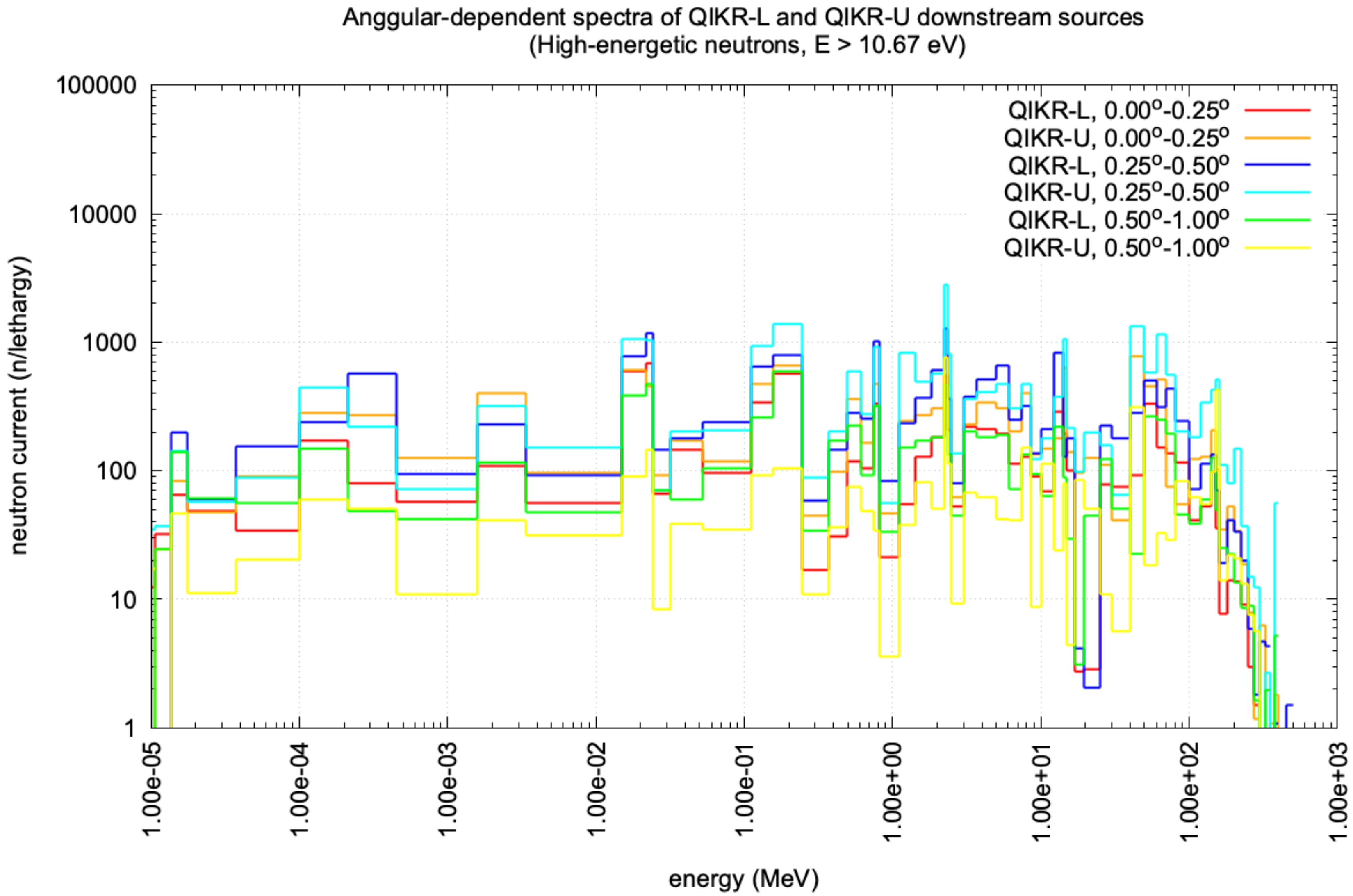
QIKR-L and QIKR-U Downstream Neutron Sources



Majority of low-energetic neutrons are in the first three angular bins:
0.0—0.25, 0.25-0.50, and 0.5-1.0 degree bins

	QIKR-L	QIKR-U
Angular bins (degrees)	fraction	fraction
0 – 0.25	0.354	0.356
0.25-0.50	0.413	0.408
0.50-1.00	0.223	0.229
> 1.0	0.010	0.007

QIKR-L and QIKR-U Downstream Neutron Sources



Majority of high-energetic neutrons are in the first three angular bins:
0.0—0.25, 0.25-0.50, and 0.5-1.0 degree bins

	QIKR-L	QIKR-U
Angular bins (degrees)	fraction	fraction
0 – 0.25	0.195	0.340
0.25-0.50	0.456	0.464
0.50-1.00	0.192	0.068
> 1.0	0.157	0.128

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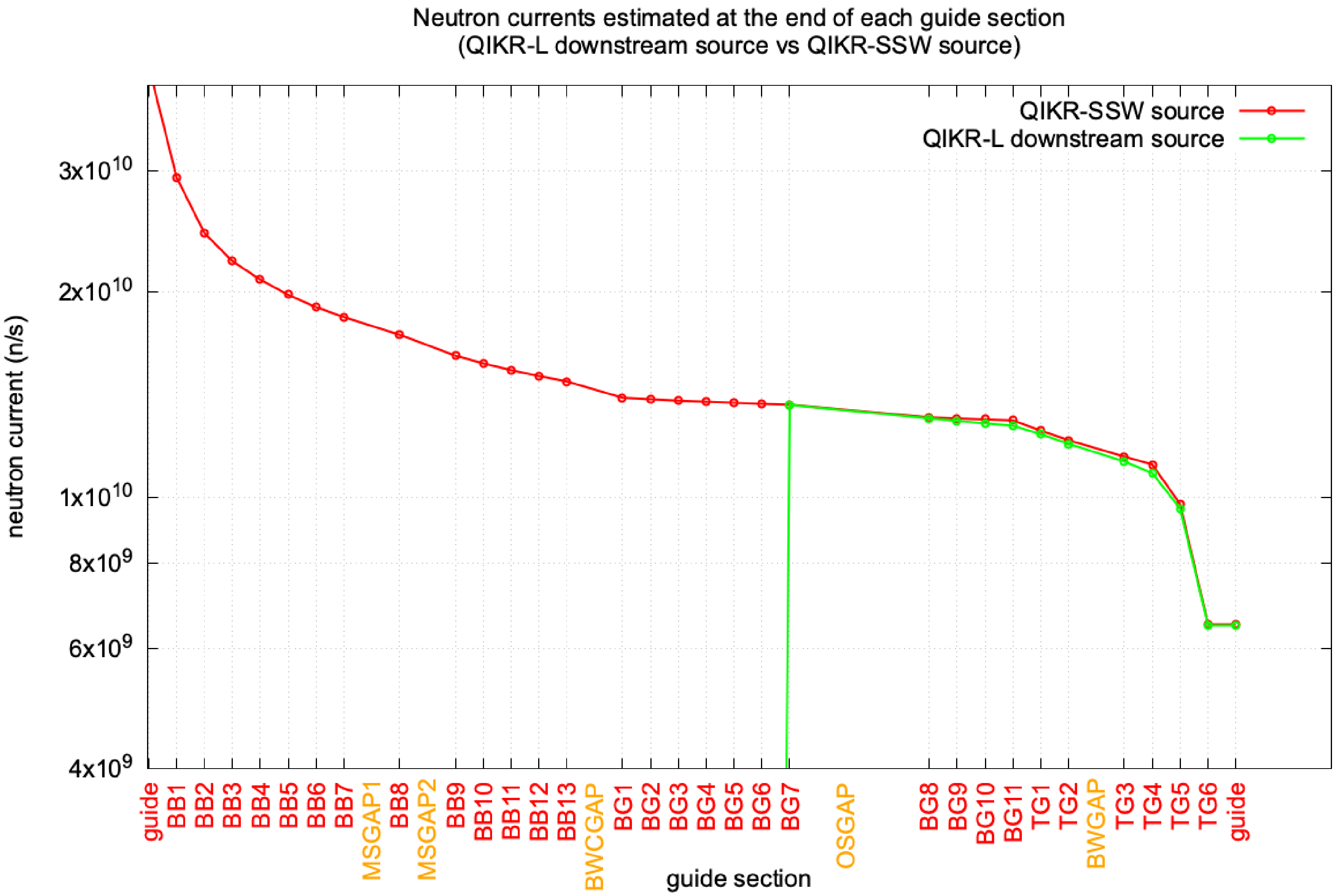
Downstream Neutron Source Verification



QIKR MCNP model were simulated for QIKR-L with both QIKR-SSW and QIKR-L downstream source

the difference is less than 1% at each guide section end and the sample location

QIKR downstream source reduce the overall simulation time by a ~7 factors while providing the accuracy with the same level of uncertainties

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QIKR Preliminary Shutter Designs

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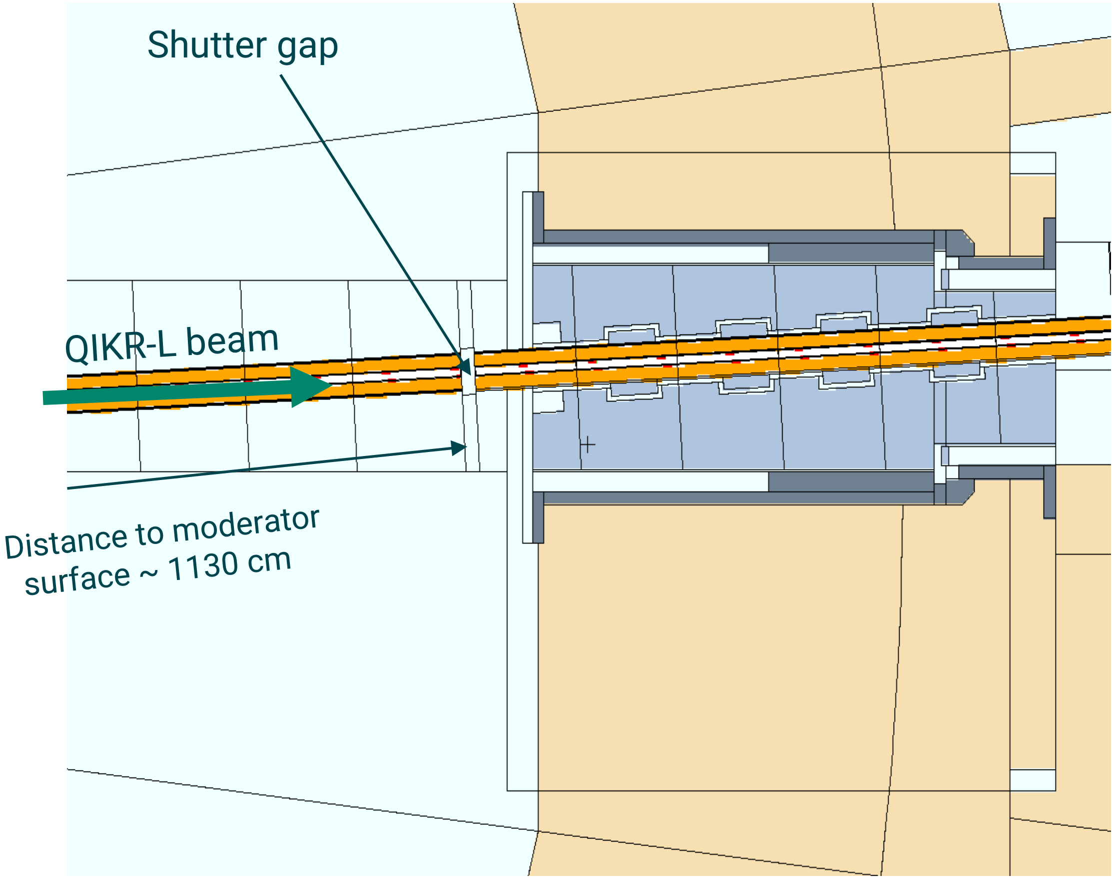
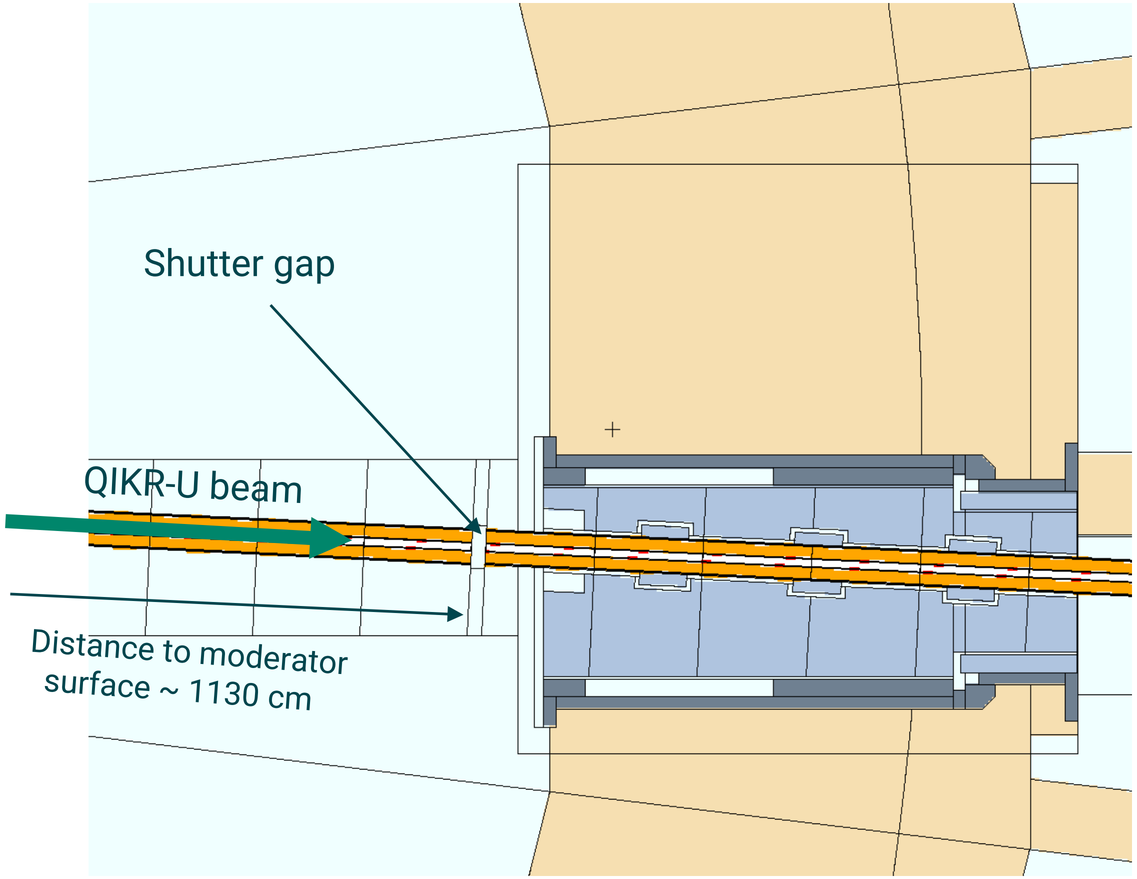
QIKR Preliminary Shutter Designs



QIKR-L shutter location
View along the QIKR-L beam elevation



QIKR-U shutter location
View along the QIKR-U beam elevation

QIKR Preliminary Shutter Designs

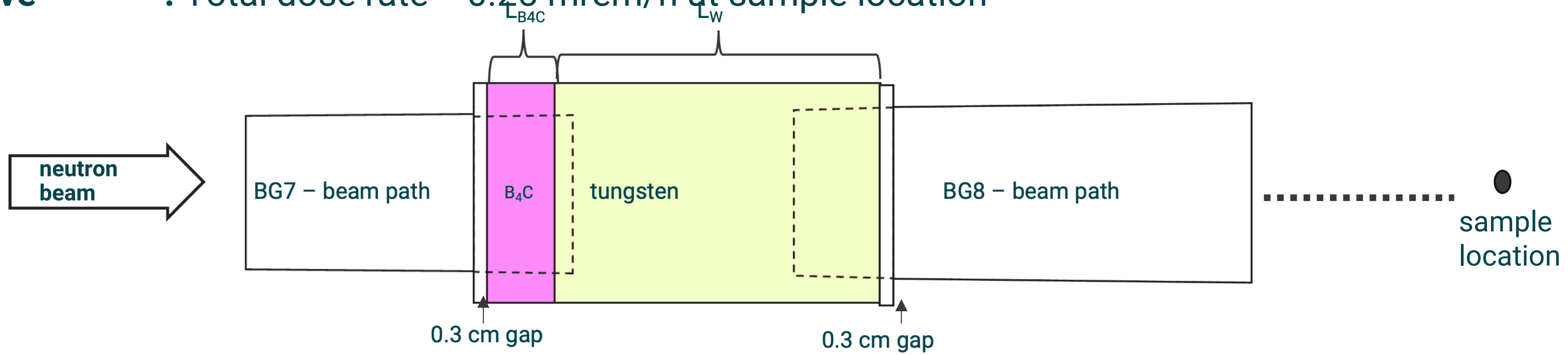
Design criterion: Shutter beam blocker should reduce the total dose rates to 0.25 mrem/h at the sample location

Shutter beam blocker consists of a B4C front plate followed by a thick tungsten block (Note that shutter cross-sectional area is slightly larger than the beam path)

- B4C plate → block low-energetic neutrons in the beam
- W plate → block photons as well as high-energetic neutrons in the beam

In the optimization calculations:

- Dynamic shutter gap (0.3 x 2 + L_{B4c} + L_W) ➔ The lengths of the BG7 and BG8 guide sections are shortened depending on the increase in the shutter gap
- **Parameter space:** L_{B4c} = [0.0, 2.0] and L_W = [0.0, 10.0]
- **Objective** : Total dose rate = 0.25 mrem/h at sample location

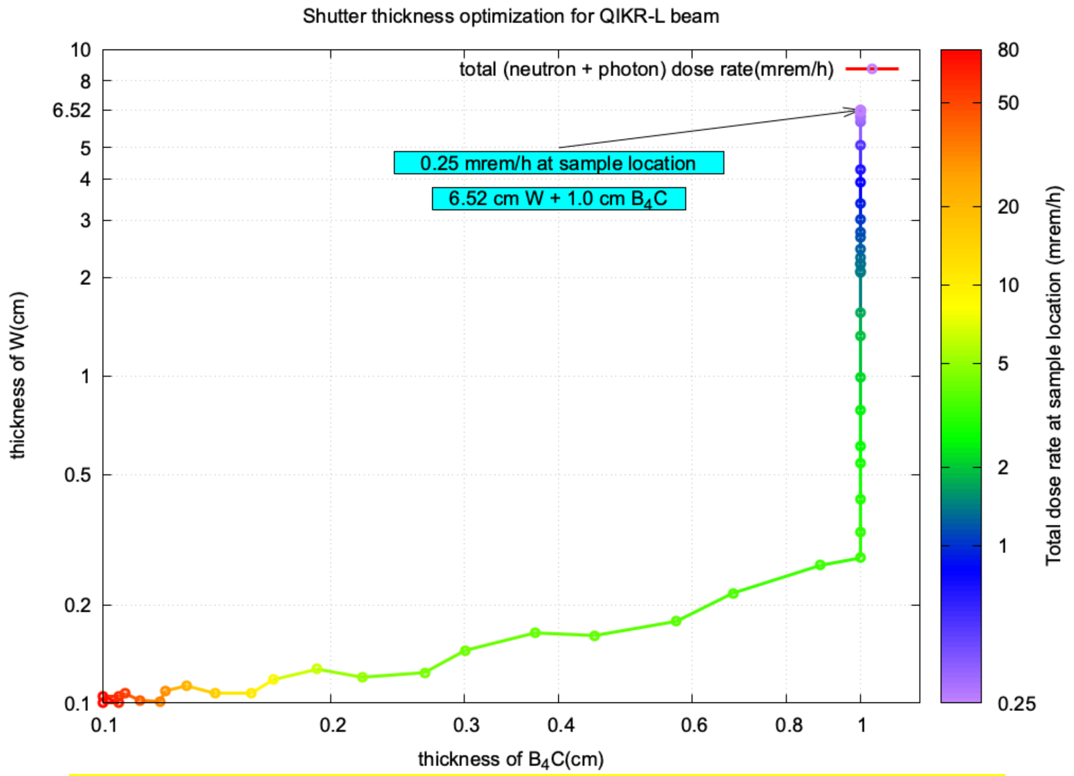


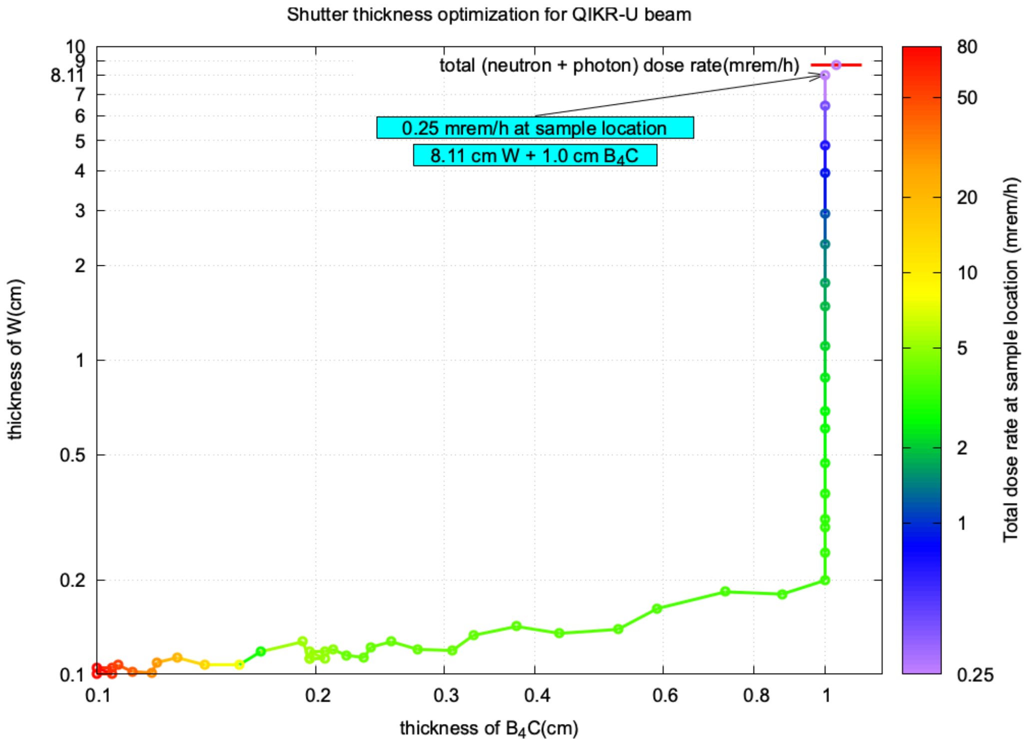
A schematic view of shutter beam blocker placed in the shutter gap

QIKR Preliminary Shutter Design

Design criterion: Shutter beam blocker should reduce the total dose rates to 0.25 mrem/h at the sample location

Total dose rates refer to neutron + photon, over entire range (0-1.3 GeV)





QIKR-L → L_{B4c} = 1.0 cm and L_W = 6.52 cm

QIKR-U → L_{B4c} = 1.0 cm and L_W = 8.11 cm

Low-energetic neutron ratio (QIKR-U/QIKR-L) ~ 1
High-energetic neutron ratio (QIKR-U/QIKR-L) ~ 1.22

➔ Longer W blocker in QIKR-U compared to QIKR-L one

In Creo, 10cm of tungsten was used for both beamlines to be conservative

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QIKR Preliminary Shutter Design

Why QIKR-U has larger high-energetic neutron intensity compared to QIKR-L:

- The different initial rotations of the beamlines with respect to the moderator (0.75° for QIKR-L and 0.70° for QIKR-U)
- The total curvature of the beamlines, which is 2.95° for QIKR-L and 2.733° for QIKR-U

Therefore, QIKR-U beam blocker is longer than the QIKR-L beam blocker

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March 03, 2025

QIKR Preliminary Beam Stop Designs

Kursat Bekar, Neutronics Scientist

U.S. DEPARTMENT OF ENERGY

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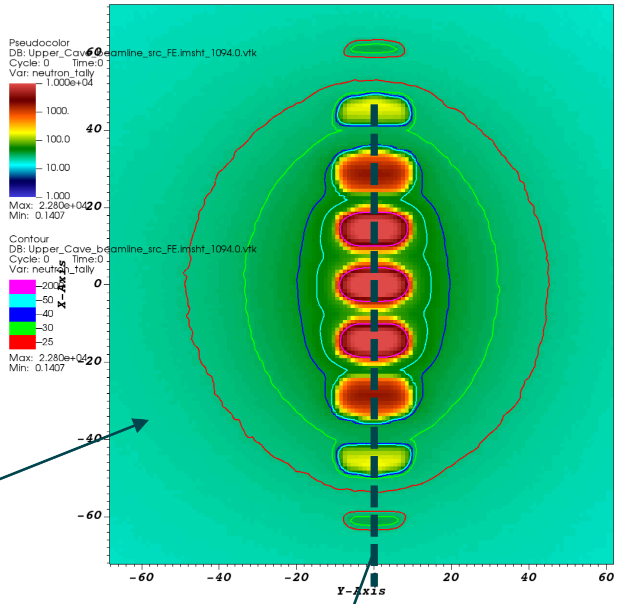
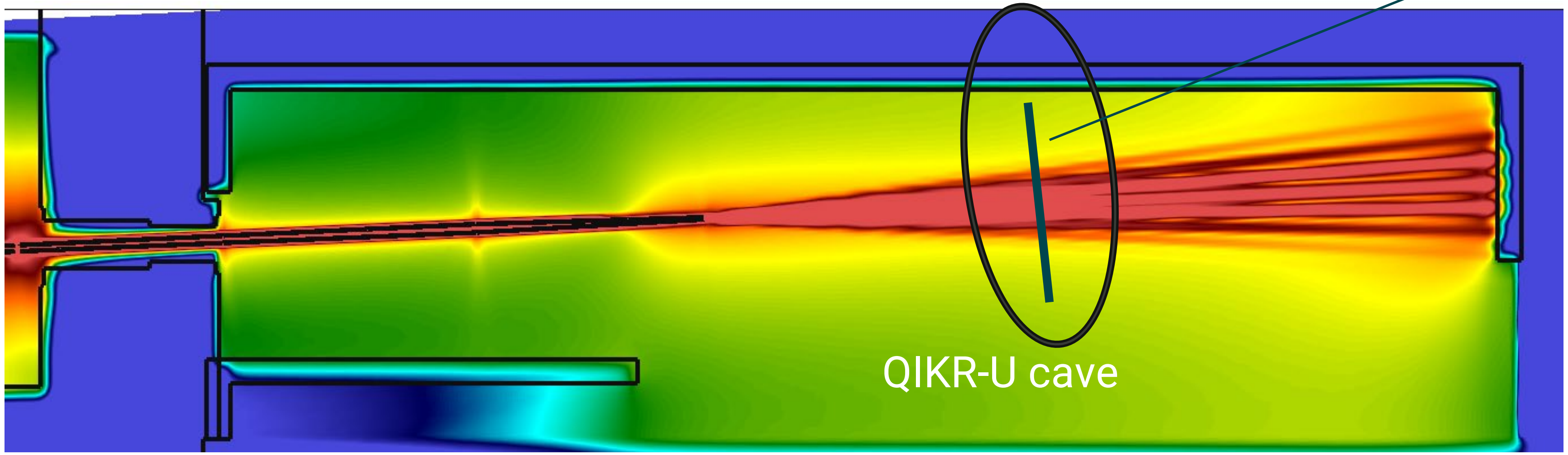
QIKR Preliminary Beam Stop Designs: What drives the beam stop designs?

QIKR guide design splits the neutron beam in the central beam inclined by 2.5° from horizontal direction and two or more additional weaker beams diverging from the central beam in vertical direction as depicted below figures.

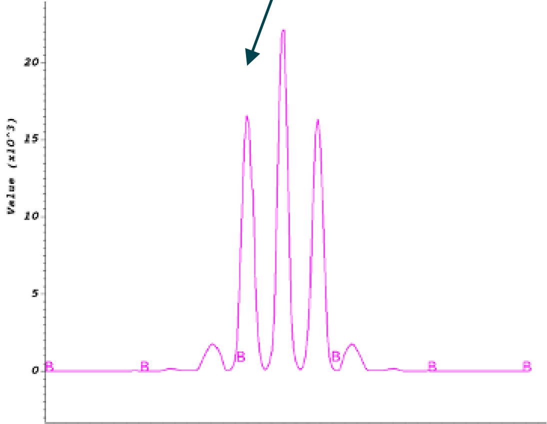
Dose contour maps obtained with **white beam (no obstruction between guide exit and beam stop location)** at the beam stop locations are used to estimate the height and width of the beam stop.



Vertical cut-view perpendicular to the center beam



Neutron dose rate profiles
Vertical cut-view along the QIKR-U beam



Intensities of each beam components at the specified location

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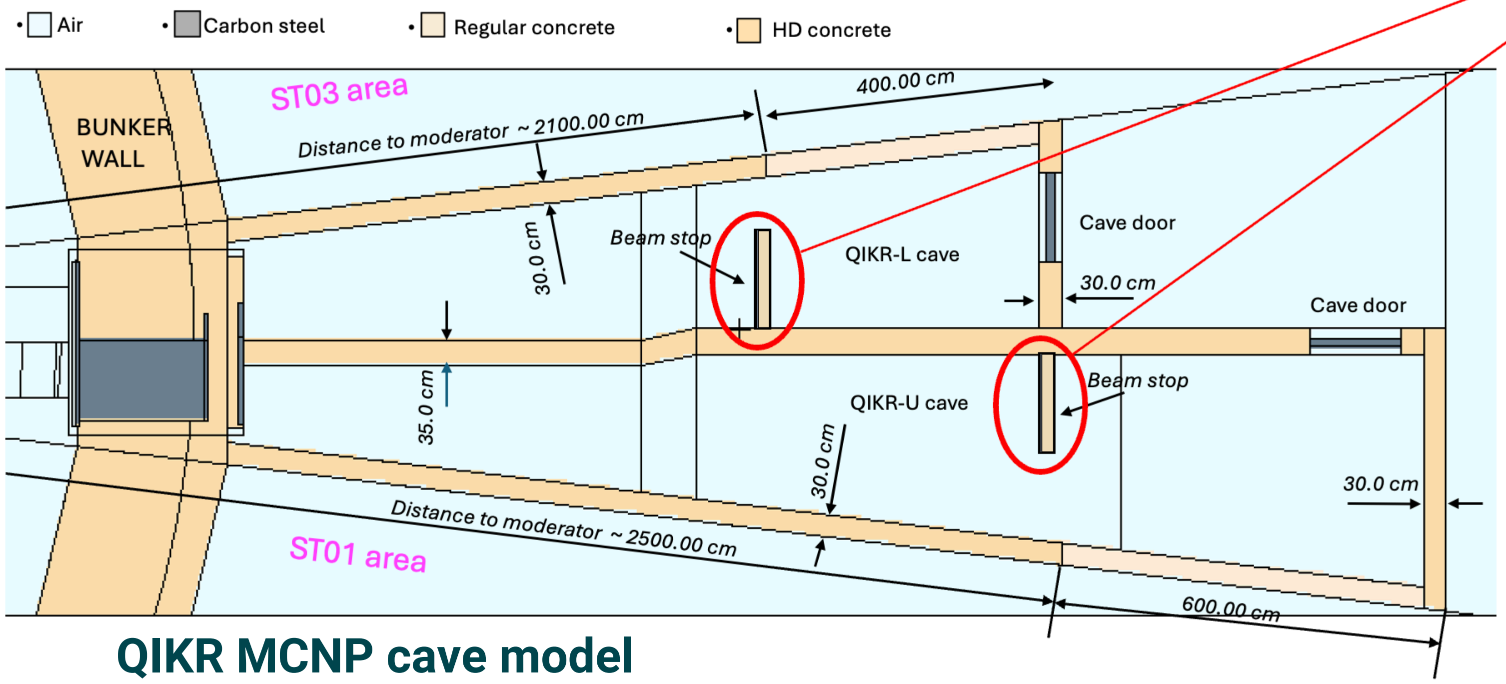
QIKR Preliminary Beam Stop Designs

Beam stops are placed 500 cm away from the guide exits

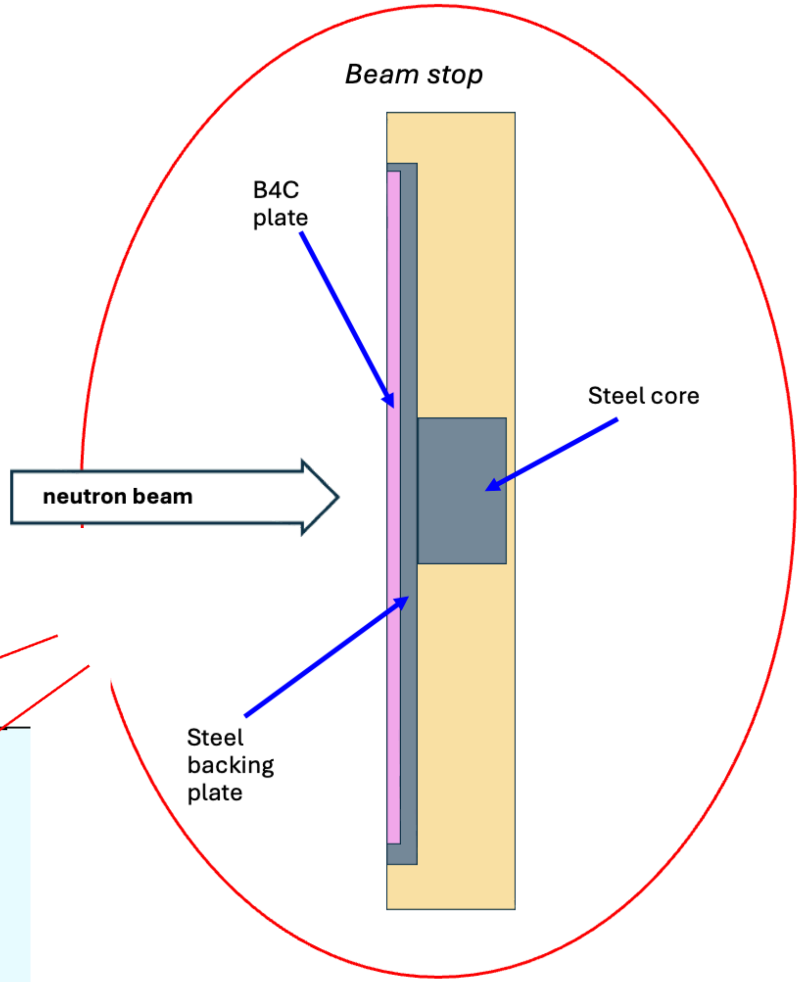
The same preliminary beam stop design was used for cave shielding analysis for both QIKR-L and QIKR-U.

QIKR-L and QIKR-U downstream sources were used in the beam stop analysis

NO SLITS in the beam stop calculations
(white beam, no obstruction in the beam)

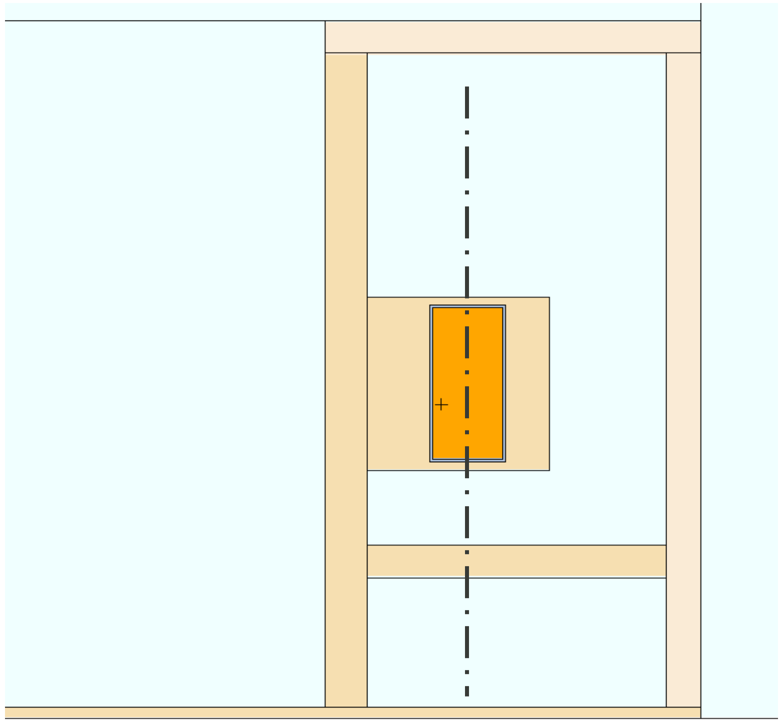


QIKR MCNP cave model
Horizontal cut-view at the moderator elevation

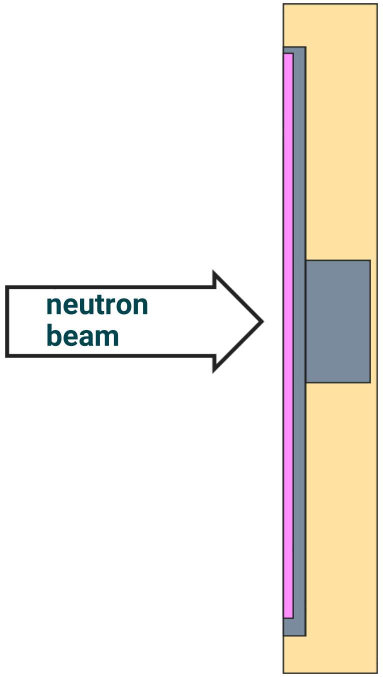


Vertical cut-view at beam stop centerline

QIKR Preliminary Beam Stop Designs



Front view of QIKR-U beam stop (view from cave upstream)



Vertical cut-view at the beam stop centerline

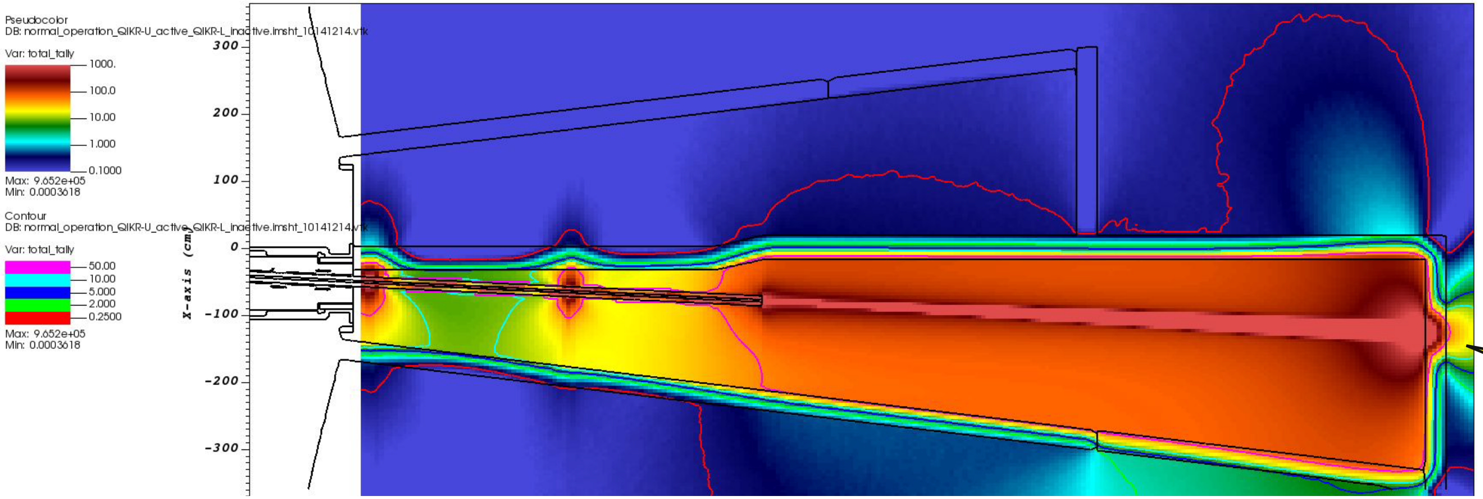
Beam stop dimensions:

- 0.5 cm thick B4C front-plate (H=140cm, W=60 cm)
- 0.5 cm thick steel backing plate (H=145cm, W=65cm)
- 5 cm thick center steel core for HE neutrons (H=20cm, W=20cm)
- 10 cm thick HDC enclosing above components (H=160 cm, W=125 cm)

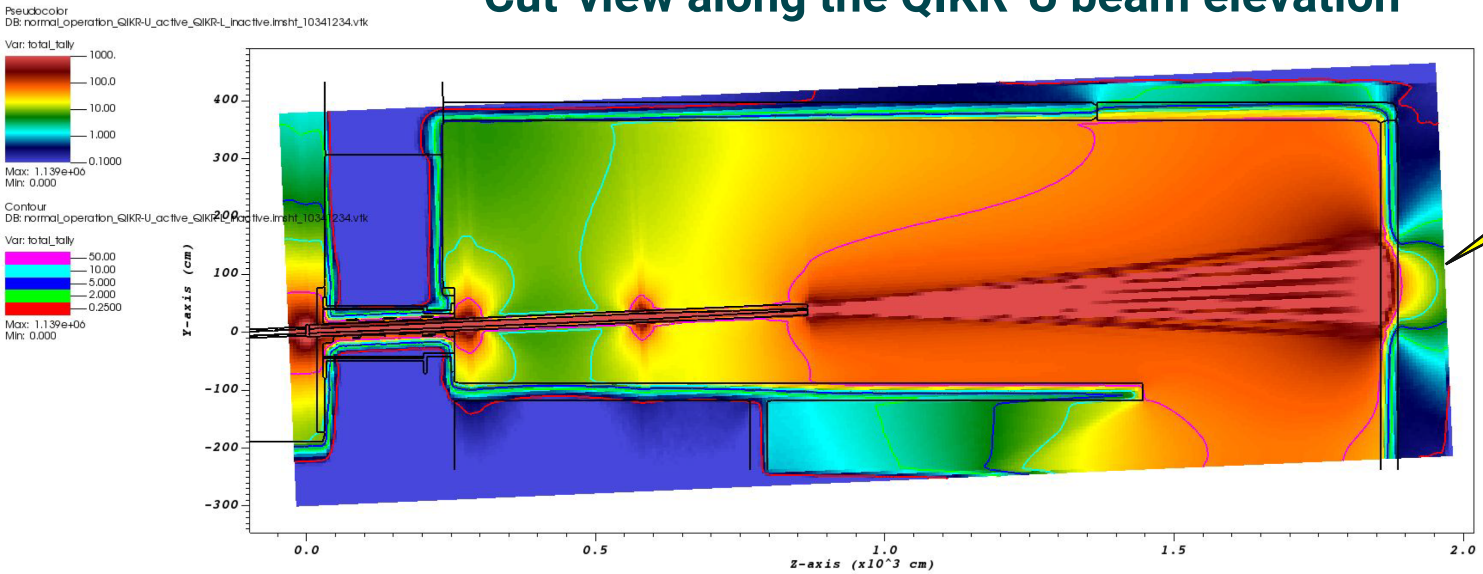
Wide B4C front-plate → for low-energetic neutrons
Center steel core → for photons and high-energetic neutrons in the center beam component
HDC → for photons

Larger beam stop cross-sectional area also helps limit the dose rates under normal operation and accident conditions

QIKR Preliminary Beam Stop Designs: QIKR-U



Cut-view along the QIKR-U beam elevation



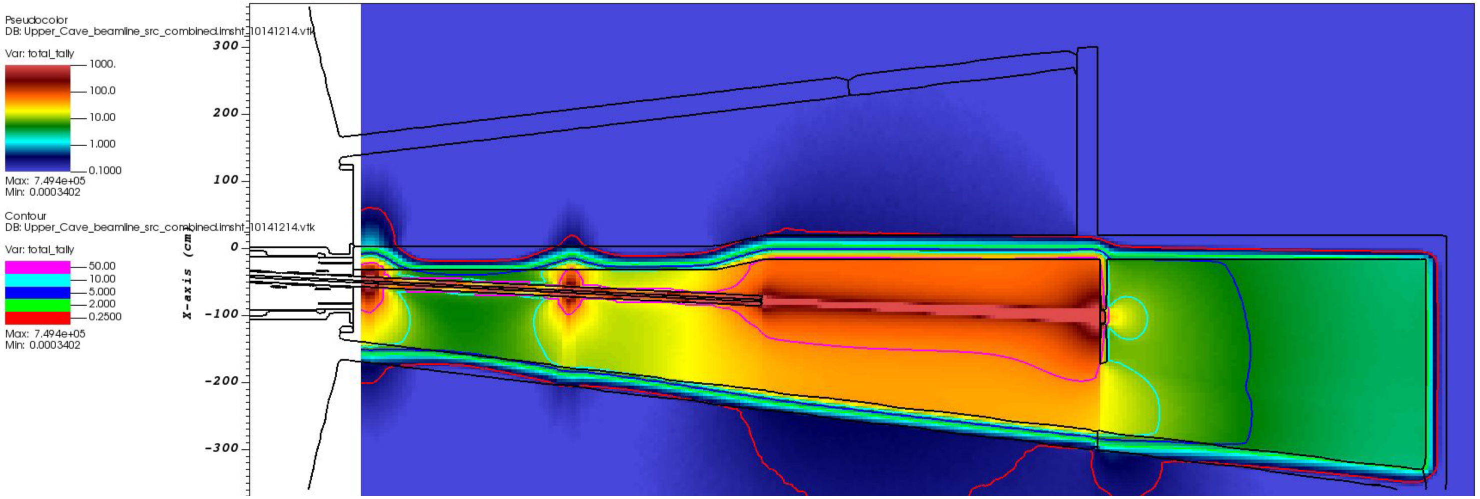
Vertical cut-view along the QIKR-U beam

Total (neutron + photon) dose rates outside the enclosure when beam stop is not in the cave

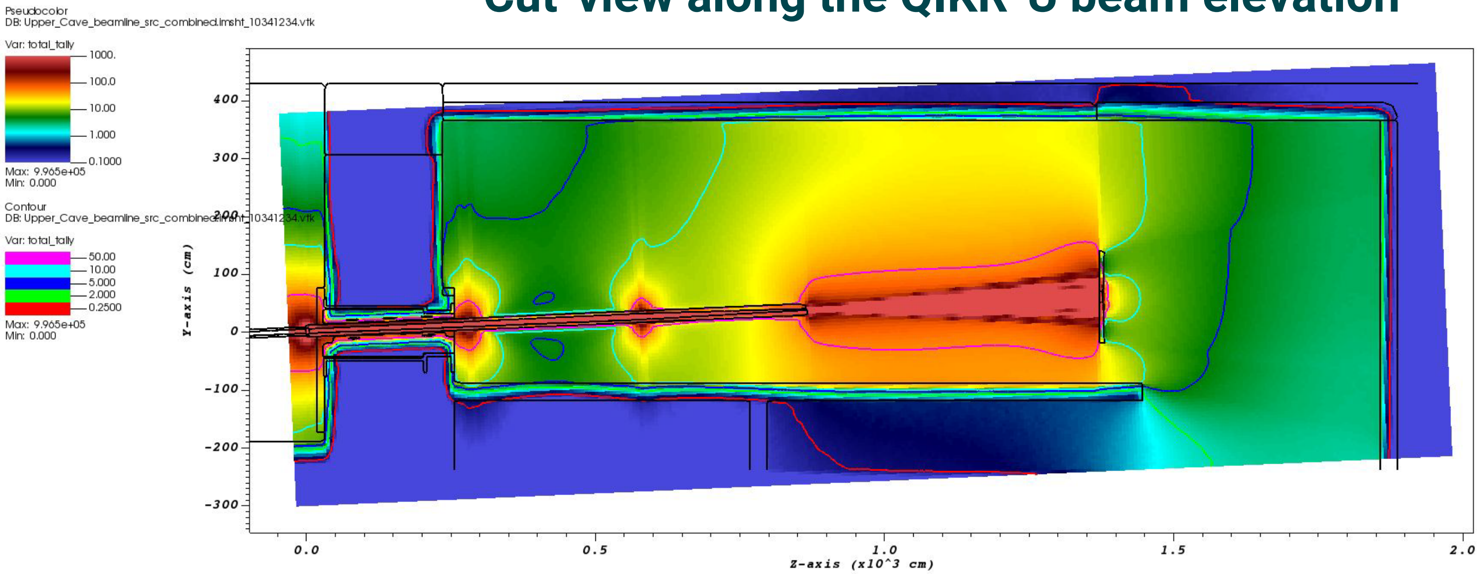
18.7 mrem/h
Outside the enclosure
(30 cm from the wall)

Note: Dose profiles obtained when only QIKR-U is active (shutter open)

QIKR Preliminary Beam Stop Designs: QIKR-U



Cut-view along the QIKR-U beam elevation



Vertical cut-view along the QIKR-U beam

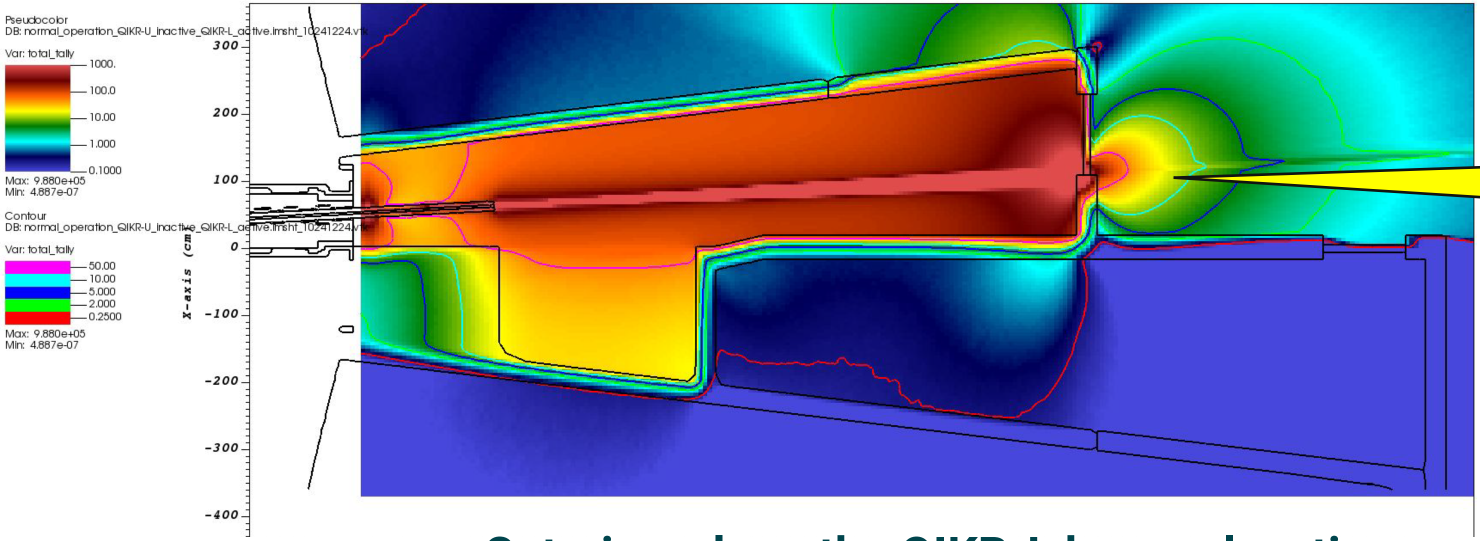
Total (neutron + photon) dose rates outside the enclosure when beam stop is in the cave

Dose rates are within the limit outside the enclosure (30 cm from the wall)

Details will be discussed in QIKR Cave Shielding Analysis

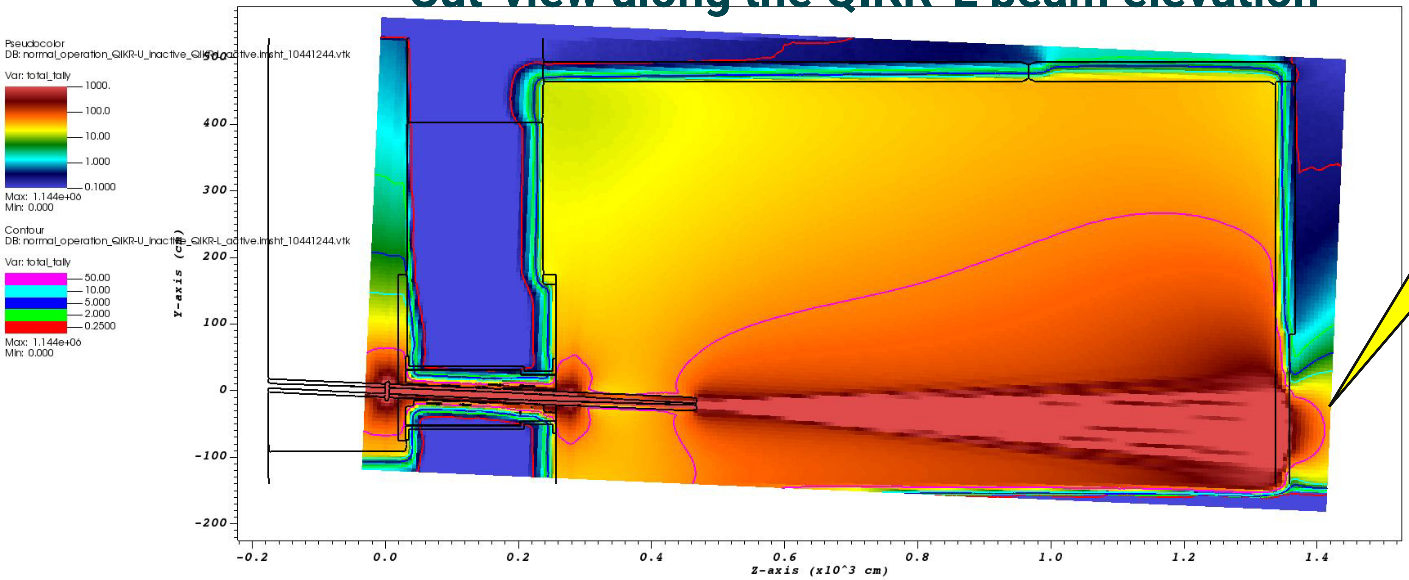
QIKR Preliminary Beam Stop Designs: QIKR-L

Total (neutron + photon)
dose rates outside the enclosure
when beam stop is not in the cave



176.1 mrem/h
Outside the enclosure
(30 cm from the wall)

Cut-view along the QIKR-L beam elevation



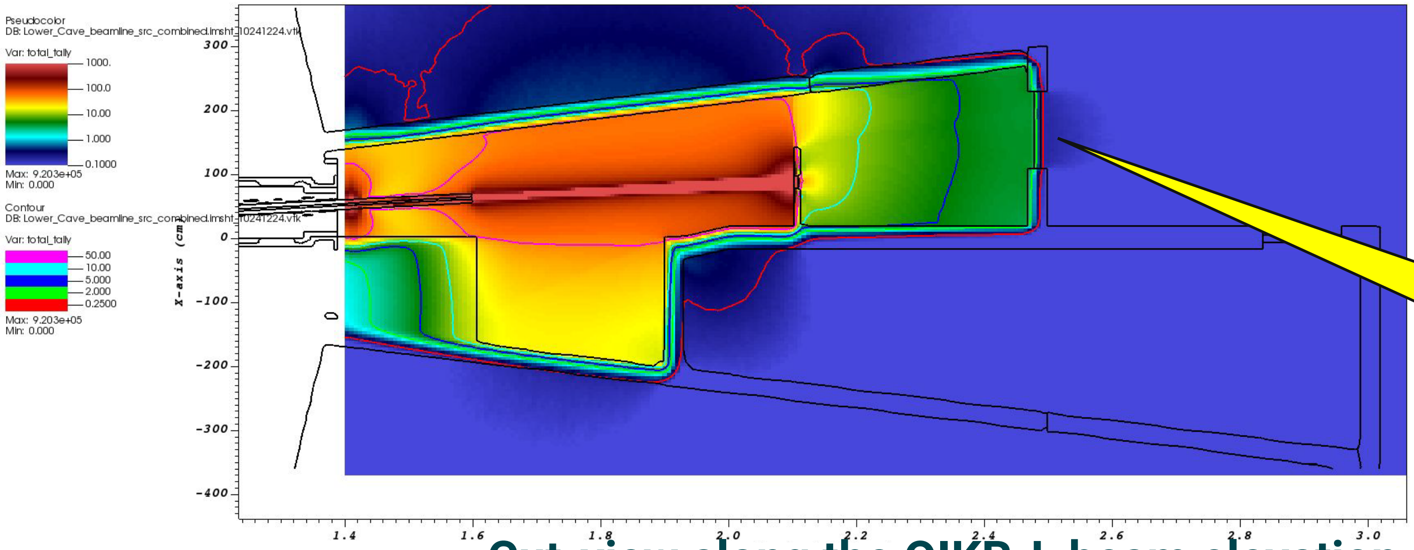
Vertical cut-view along the QIKR-L beam

The back door of the QIKR-L cave is in the QIKR-L beam path, resulting in higher dose rates outside the enclosure

Note: Dose profiles obtained when only QIKR-L is active (shutter open)

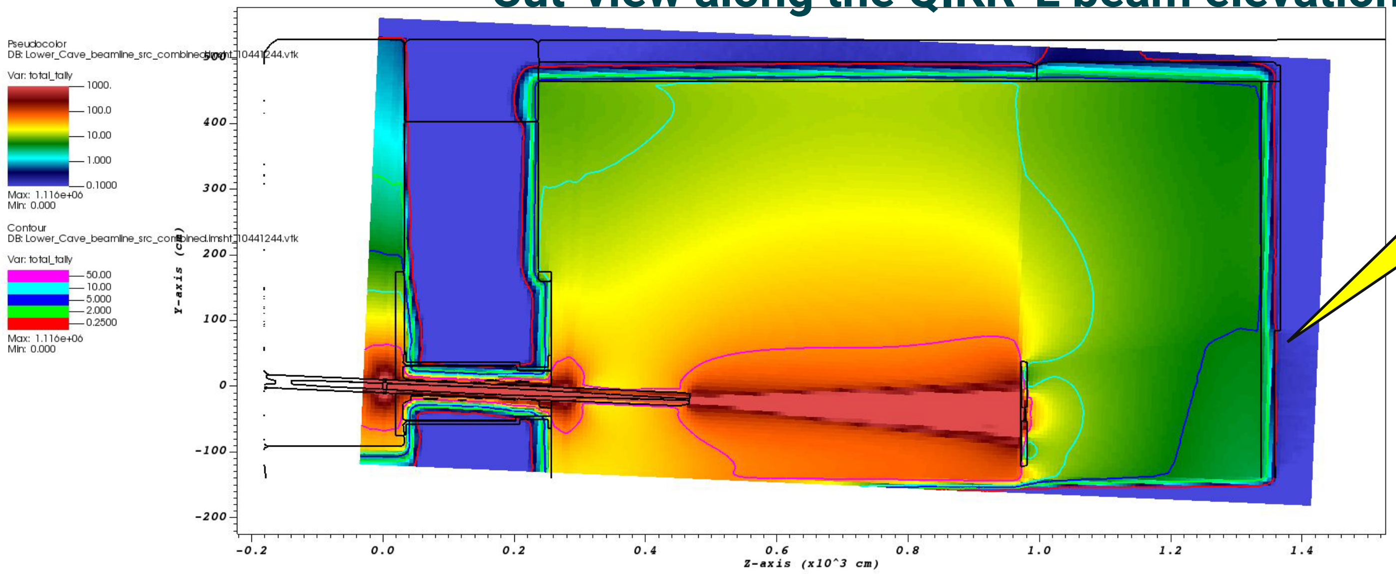
QIKR Preliminary Beam Stop Designs: QIKR-L

Total (neutron + photon)
dose rates outside the enclosure
when beam stop is in the cave



Cut-view along the QIKR-L beam elevation

Dose rates are within the limit outside the enclosure (30 cm from the wall)



Vertical cut-view along the QIKR-L beam

Details will be discussed in QIKR Cave Shielding Analysis

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March 03, 2025

QIKR Cave Shielding Analysis

Kursat Bekar, Neutronics Scientist

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QIKR Instrument Cave Shielding Analysis– Preliminary Design

Acceptance Criteria for QIKR Shielding Design

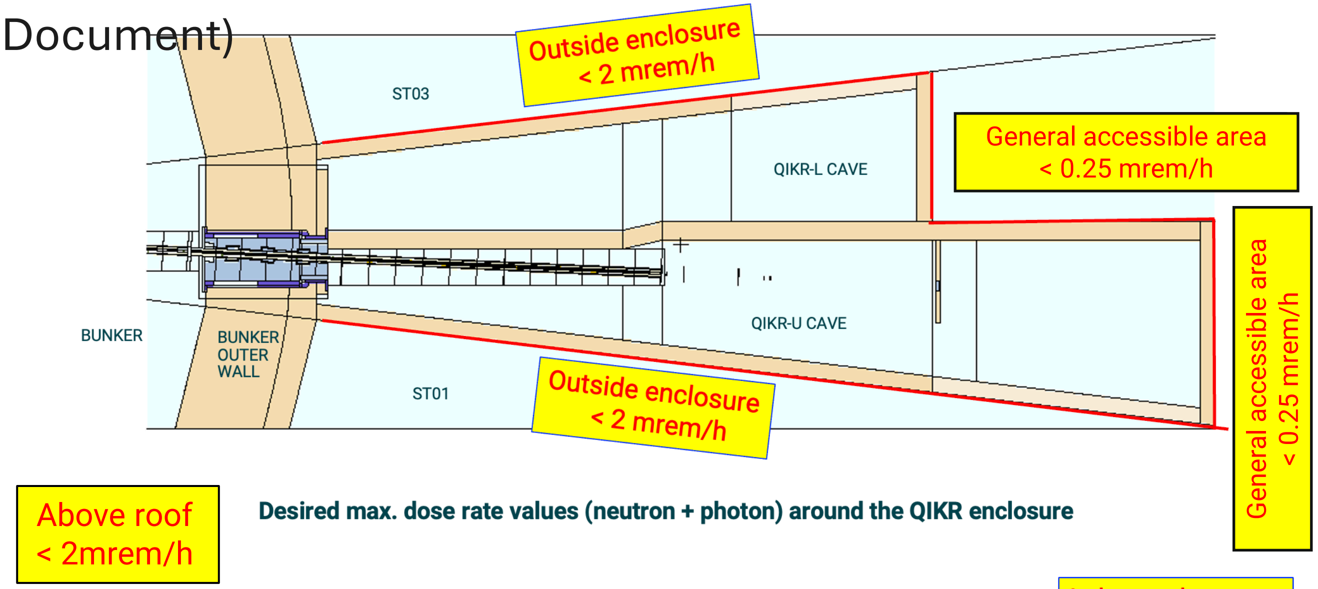
(QIKR Cave Acceptable Dose Rates Design Criteria Document)

Normal operation:

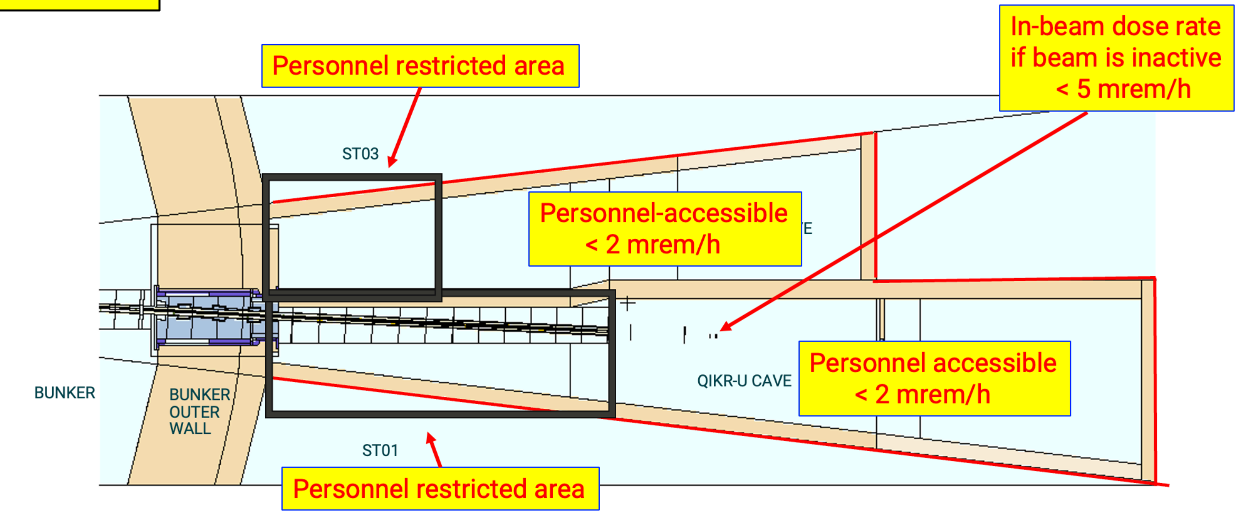
- 0.25 mrem/h at generally accessible areas outside the QIKR Instrument Caves
- 2 mrem/h allowed in the areas between the outer wall of the QIKR instrument cave and the shielding of the adjacent beamlines
- 2 mrem/h in the user-accessible areas within the cave and 5 mrem/h at the sample location when the beam is inactive

Accident condition:

- Dose rates will be documented to provide information for implementation of Instrument Personal Protection System



Desired max. dose rate values (neutron + photon) around the QIKR enclosure



Desired max. dose rate values (neutron + photon) inside the QIKR enclosure

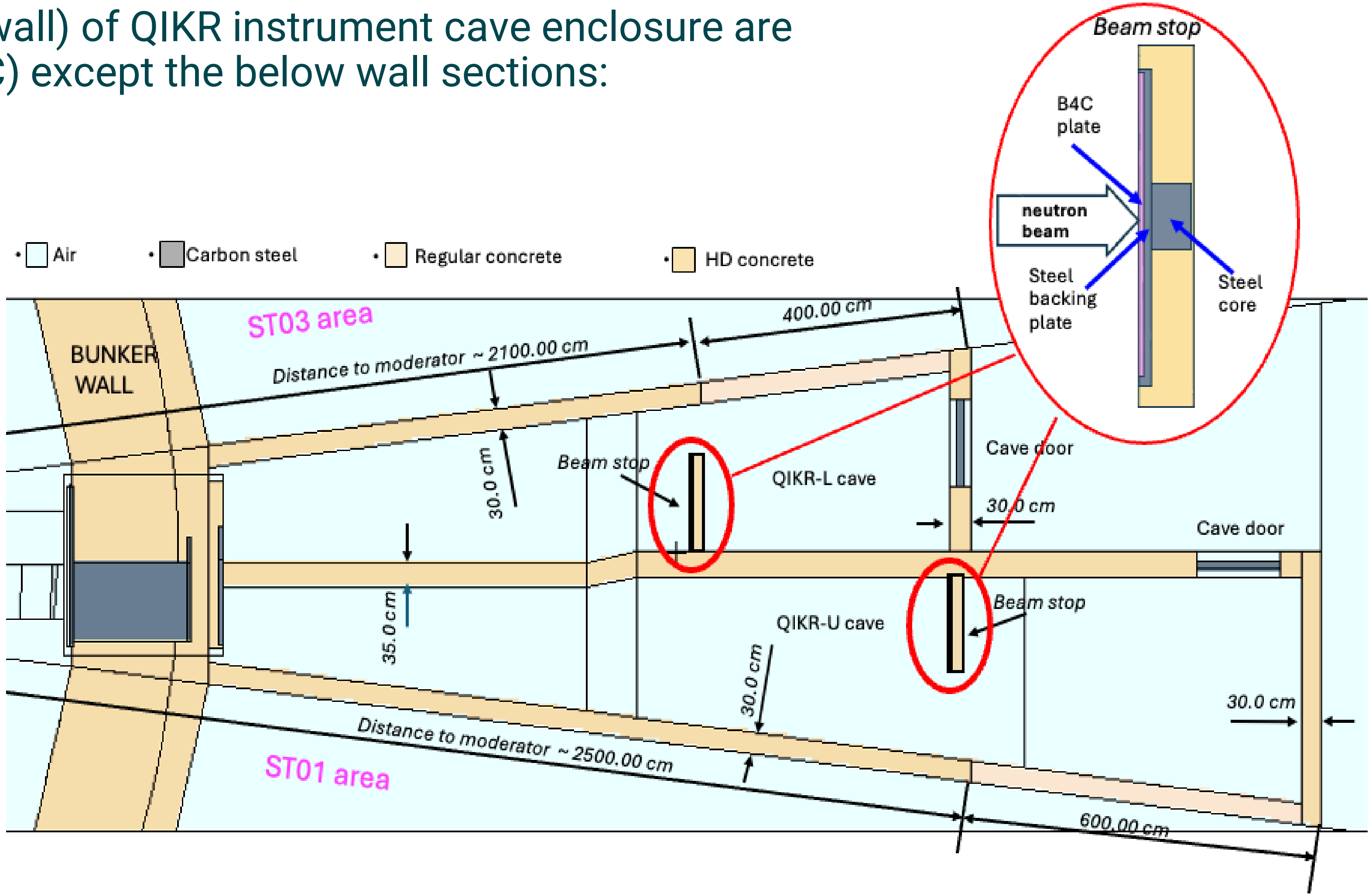
QIKR Cave Shielding Analysis

All outside walls (side walls and back wall) of QIKR instrument cave enclosure are 30 cm-thick high-density concrete(HDC) except the below wall sections:

- **Regular density concrete (RDC) wall section between ST03 and QIKR-L cave:** starting from ~21 m ending about ~25 m (distances are measured from the moderator face)
- **RDC wall section between ST01 and QIKR-U cave:** starting from ~25 m ending about ~ 30 m (distances are measured from the moderator face)
- The wall separating QIKR-U and QIKR-L caves is 35 cm-thick HDC

Beam stops are always present in the MCNP model

<u>QIKR-L and QIKR-U downstream sources</u> were used in cave shielding analysis



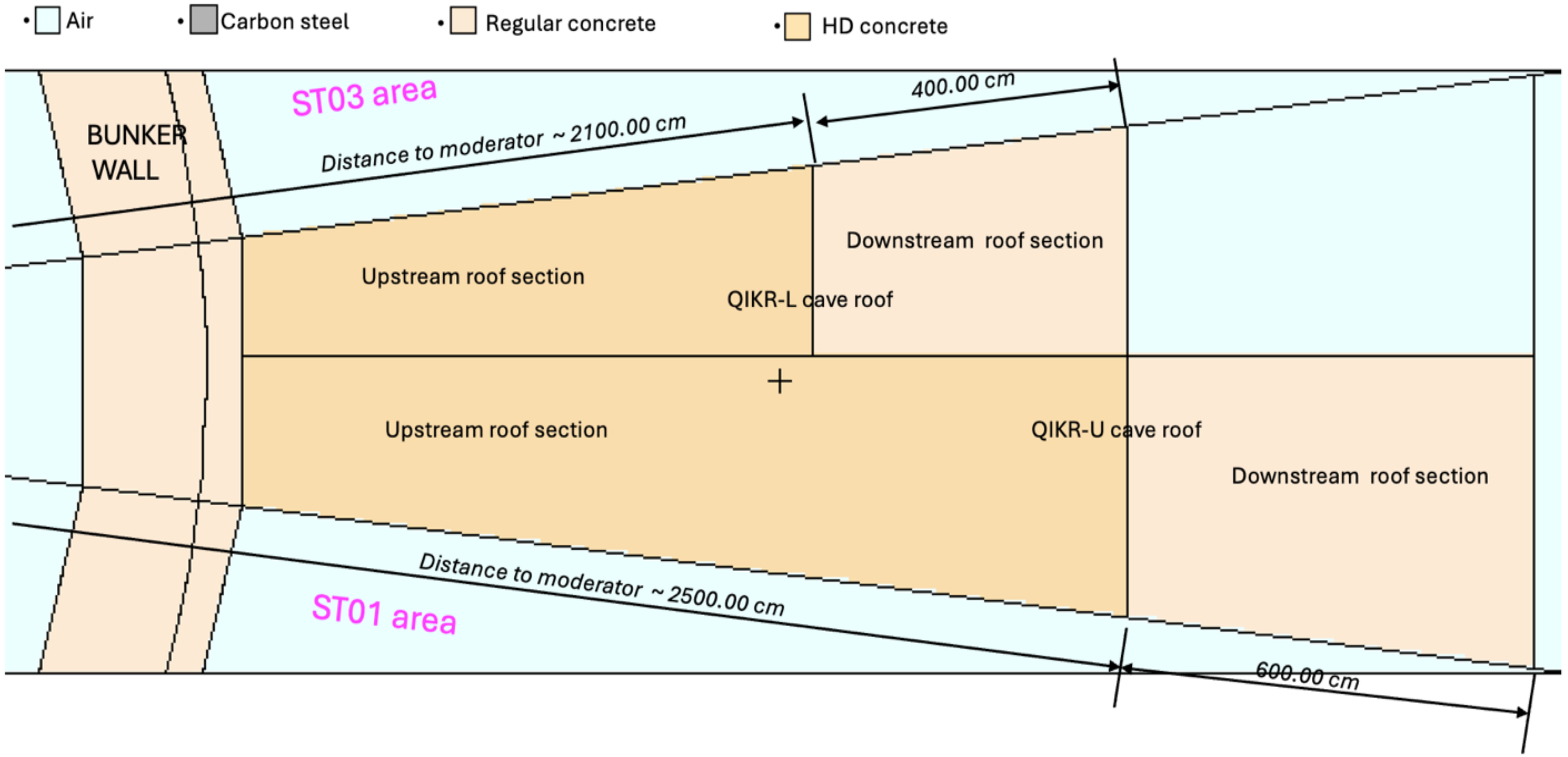
QIKR MCNP cave model
Horizontal cut-view at the moderator elevation

QIKR Cave Shielding Analysis

Same geometry and concrete types as is used in the Creo model

30 cm-thick HDC and RDC sections are used for each QIKR roof:

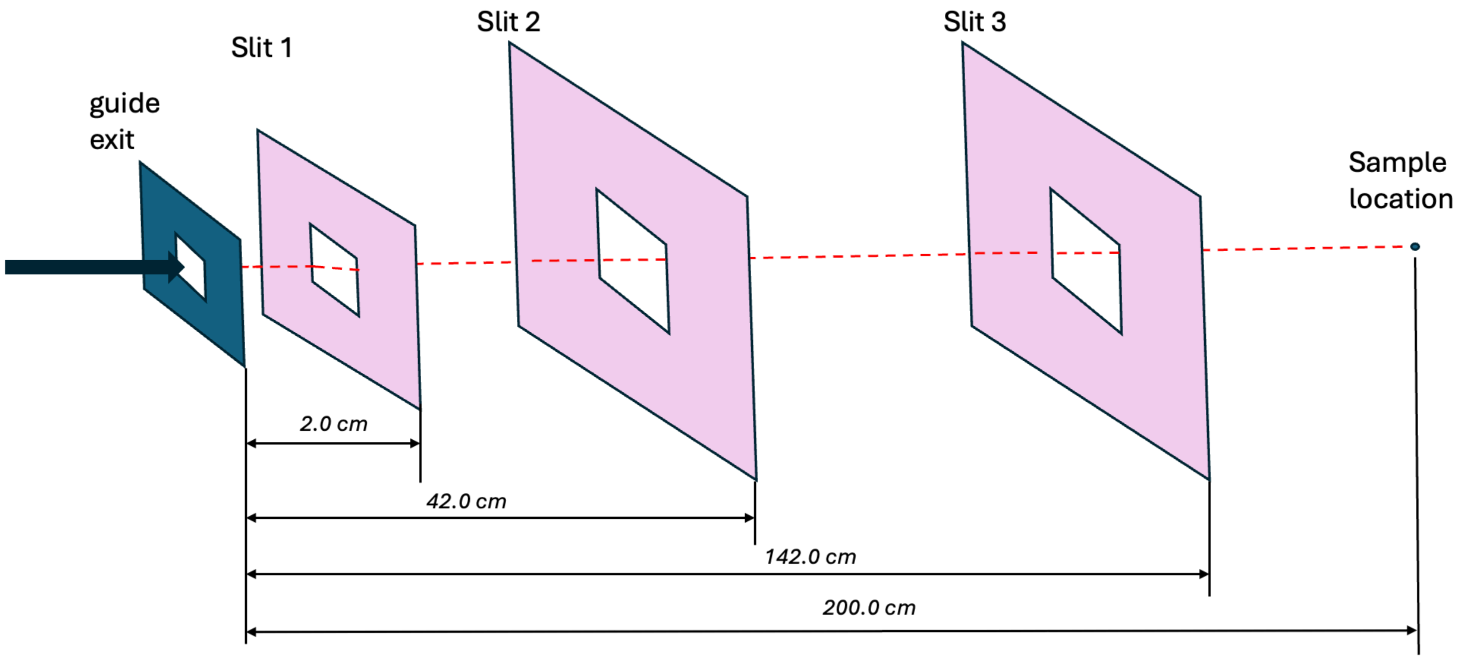
- QIKR-U cave HDC-RDC transition line is ~ 25 m away from the moderator surface
- QIKR-L cave HDC-RDC transition line is ~ 21 m away from the moderator surface



<u>QIKR-L and QIKR-U downstream sources</u> were used in cave shielding analysis

QIKR MCNP cave model
View from above the roof

QIKR Cave Shielding Analysis: SLITS in the model



0.5 cm thick B4C plates with center opening were used for SLITs

Dimensions

Slit1: 16 x 21 x 0.5 cm^3

Slit2: 31 x 31 x 0.5 cm^3

Slit3: 31 x 31 x 0.5 cm^3

Max. apertures

Slit1: 3 x 3 cm^2

Slit2: 8 x 8 cm^2

Slit3: 8 x 8 cm^2

Slit geometries and locations provided by John Ankner

Accident condition, normal operation → full apertures were set **(3 x 3, 8 x 8 and 8 x 8 cm^2)**

For normal operation scenario, performing calculations with full aperture rather than using maximum opening is a conservative approach (max. opening in slits when operation normally is 0.9 x 2.5, 0.5 x 2.5, 0.2 x 2.5 cm^2)

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QIKR Cave Shielding Analysis

No significant radiation coming through bunker pass-thru; therefore, cave analysis are carried out only with beam sources(see slide 23)

Assumption: Negligible radiation into the cave from adjacent beamlines and shields

The analysis simulated different normal operating modes and potential accident conditions by performing a series of QIKR-L and QIKR-U calculations:

- Normal operation (white beam, water sample at the sample location)
  - **Both QIKR-L and QIKR-U are active** → dose rates outside the cave enclosure
  - **QIKR-L is active, QIKR-U is inactive** → dose rates inside the QIKR-U cave
  - **QIKR-U is active, QIKR-L is inactive** → dose rates inside the QIKR-L cave

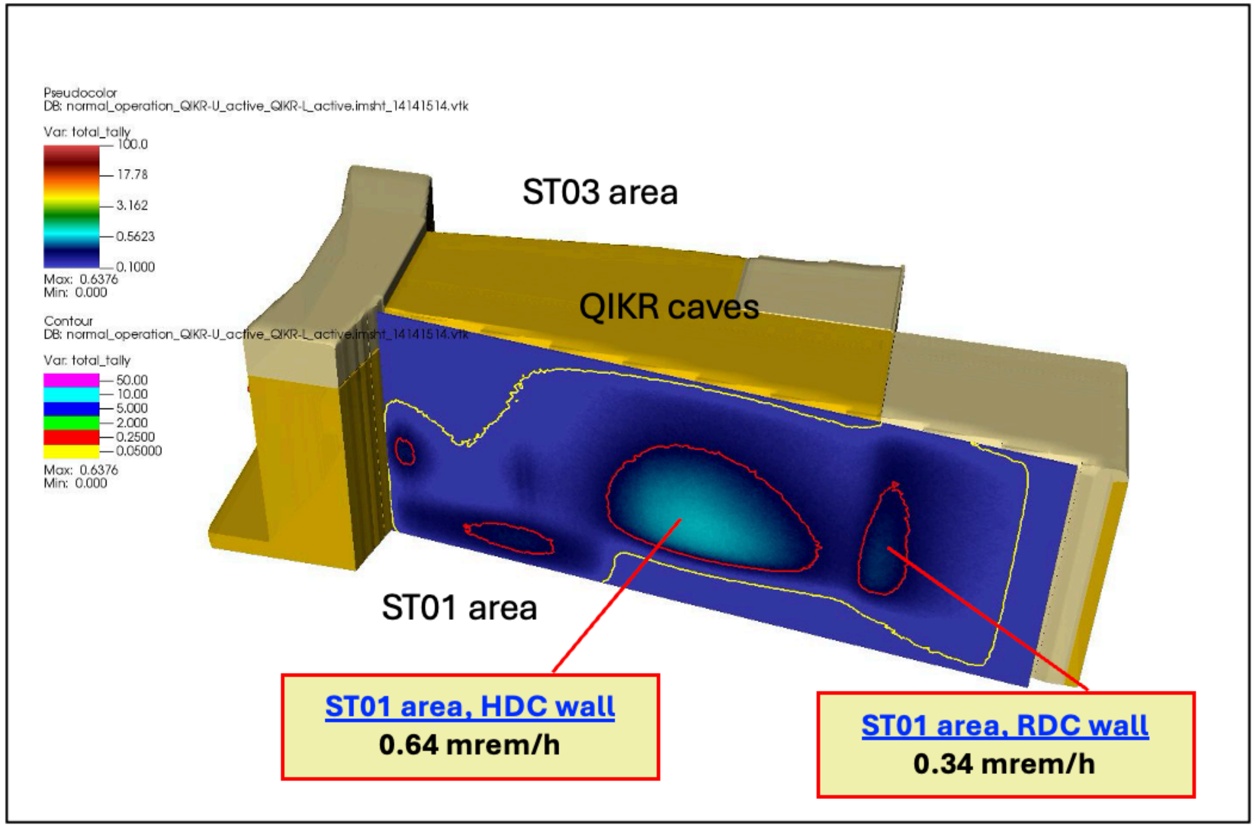
Active = shutter open
Inactive = shutter closed

- Accident condition (white beam, steel sample at the sample location)
  - **Accident in QIKR-L cave while QIKR-U is active** → dose rates outside the cave enclosure
  - **Accident in QIKR-U cave while QIKR-L is active** → dose rates outside the cave enclosure
  - **Accident in QIKR-L cave while QIKR-U inactive** → dose rates inside the QIKR-U cave
  - **Accident in QIKR-U cave while QIKR-L inactive** → dose rates inside the QIKR-L cave

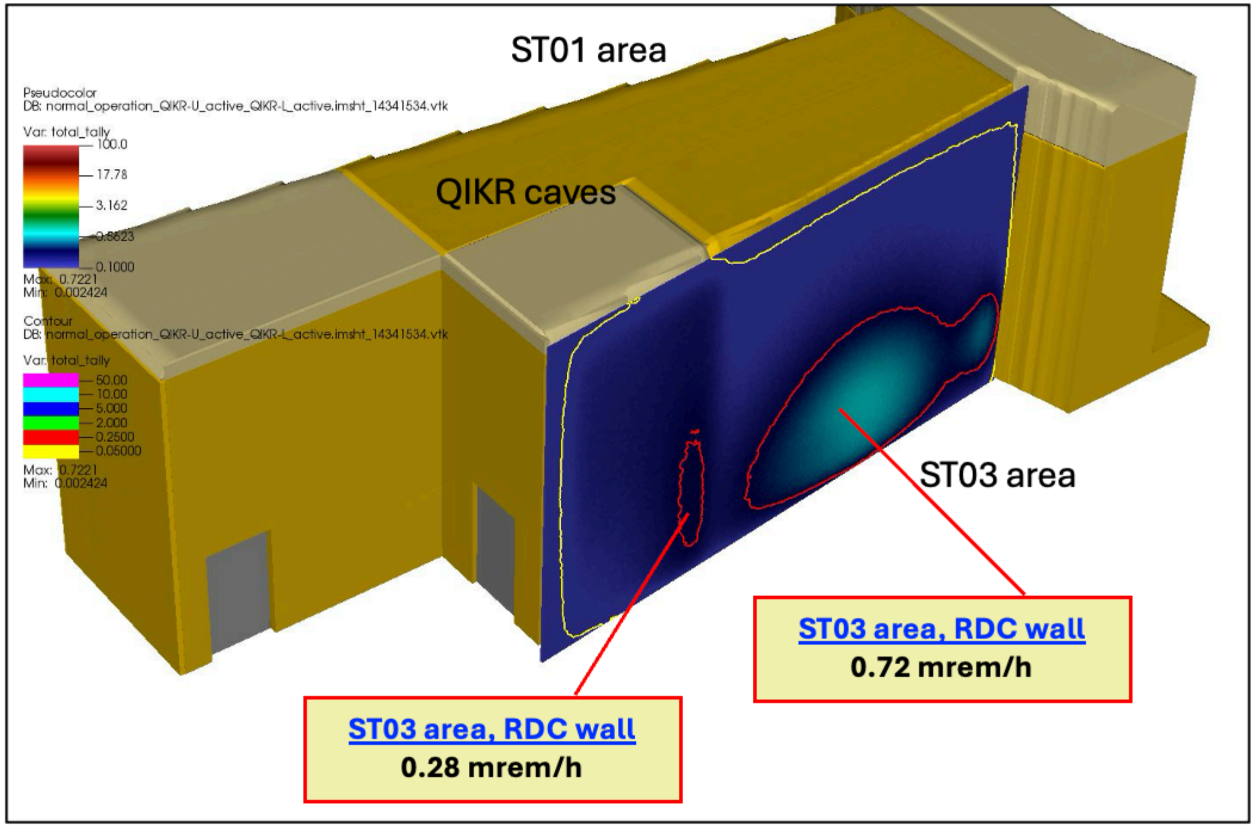
QIKR Cave Shielding Analysis: Normal Operation

Normal operation, QIKR-L and QIKR-U operate normally
- White beam - **Water sample** - With Slits (full aperture)

Red contour lines show the 0.25 mrem/h total dose boundary



(a) Dose profiles along the outer wall of the QIKR enclosure on the ST01 side



(b) Dose profiles along the outer wall of the QIKR enclosure on the ST03 side

Dose profiles calculated at 30 cm away from the cave outer walls when both beamlines are operating normally.

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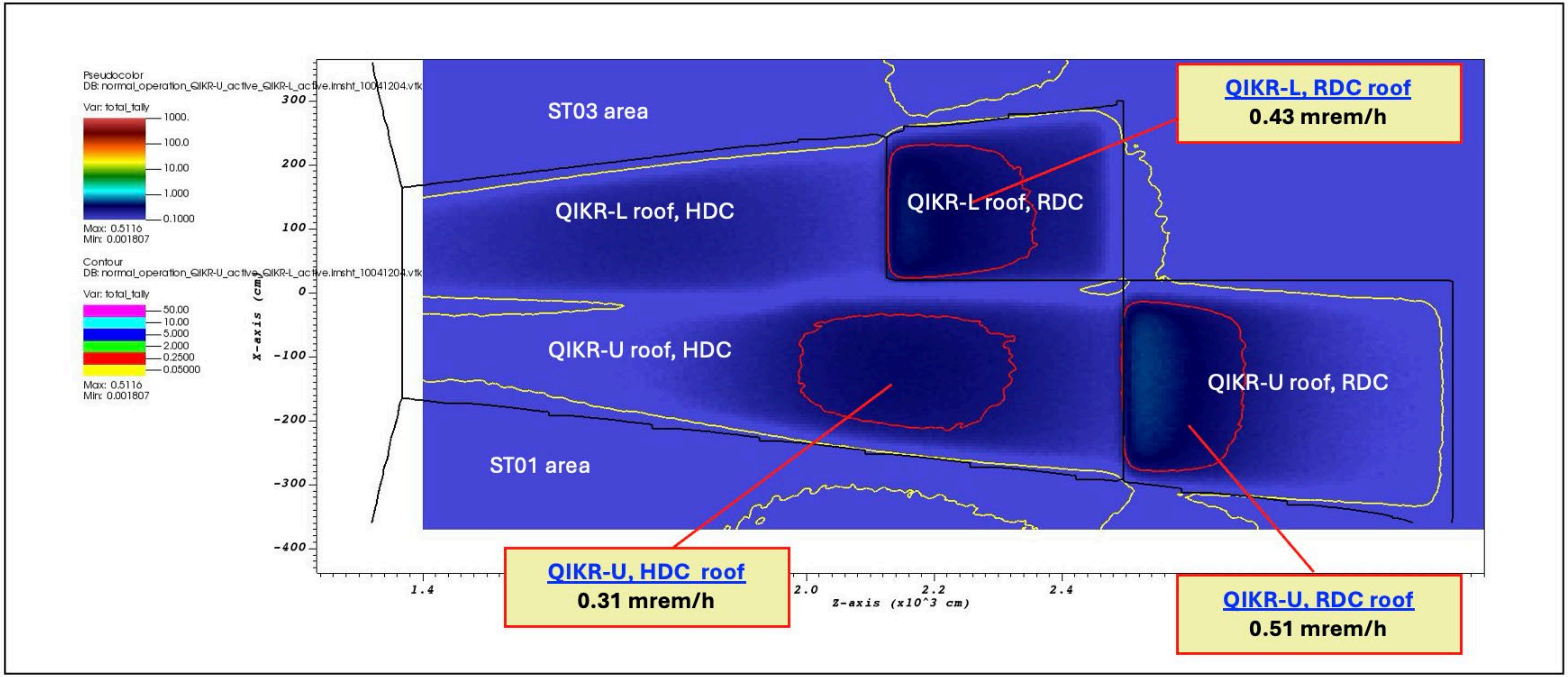
QIKR Cave Shielding Analysis: Normal Operation

Normal operation, QIKR-L and QIKR-U operate normally
- White beam - **Water sample** - With Slits (full aperture)

Red contour lines show the 0.25 mrem/h total dose boundary



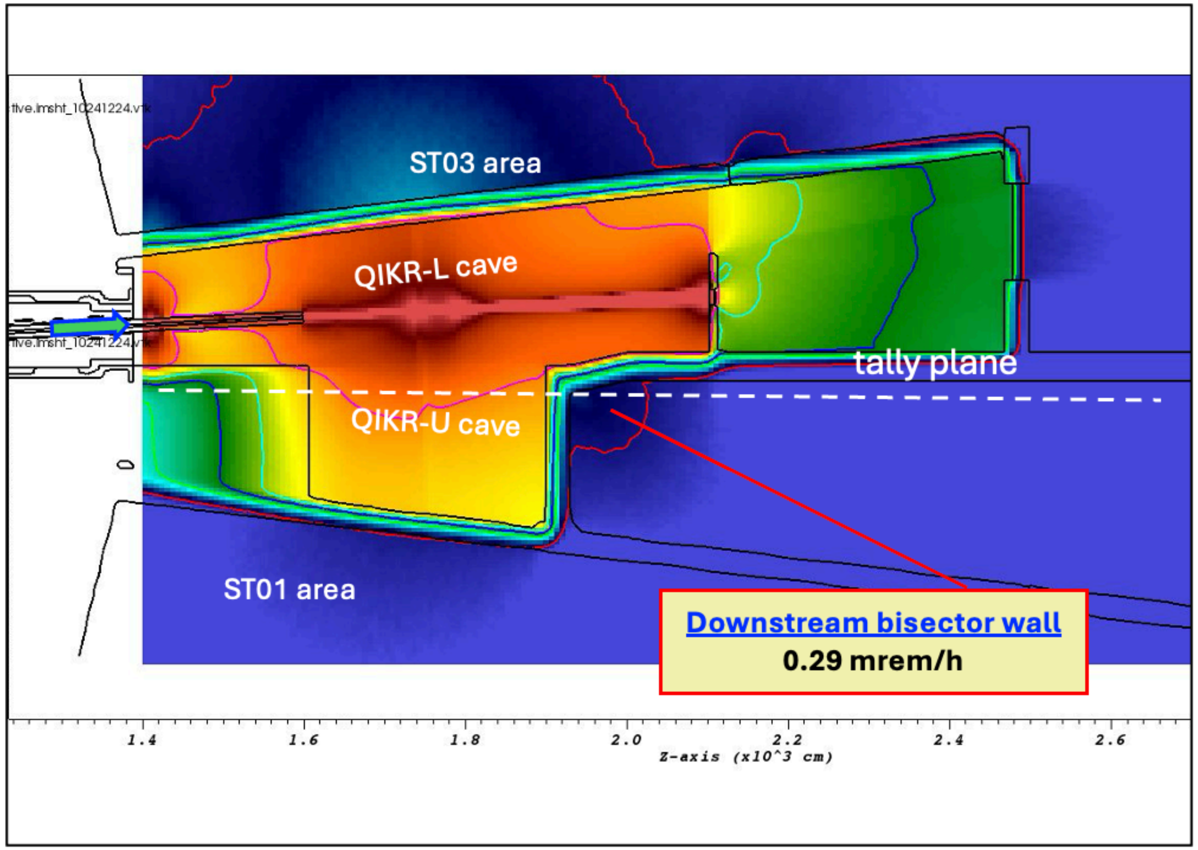
Dose profiles at 30 cm above the instrument caves roof (plan-view) when both beamlines are operating normally.

QIKR Cave Shielding Analysis: Normal Operation

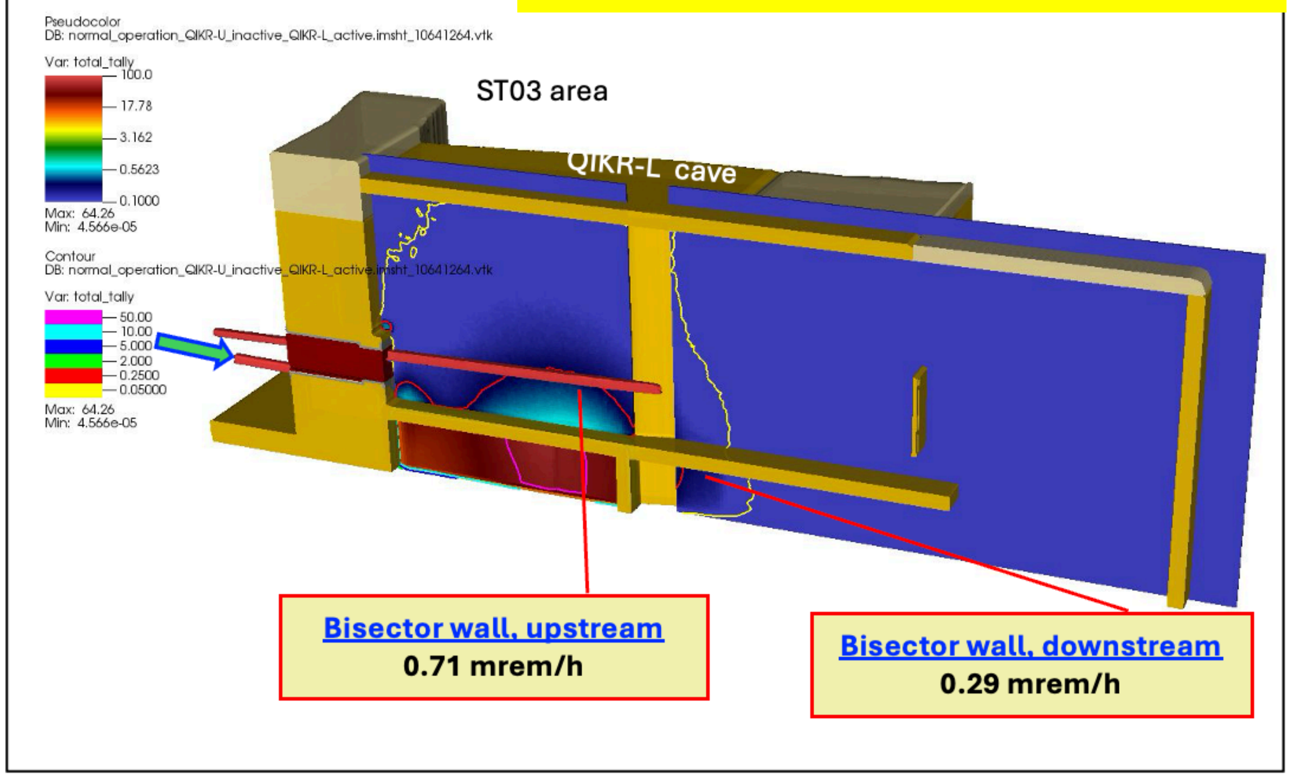
Normal operation, **One beamline is active, the other is inactive (used to estimate the dose rates inside the caves)**

- White beam - **Water sample** - With Slits (full aperture)

Red contour lines show the 0.25 mrem/h total dose boundary



(a) Dose profile along the QIKR-L elevation
(QIKR-L active, QIKR-U is inactive)



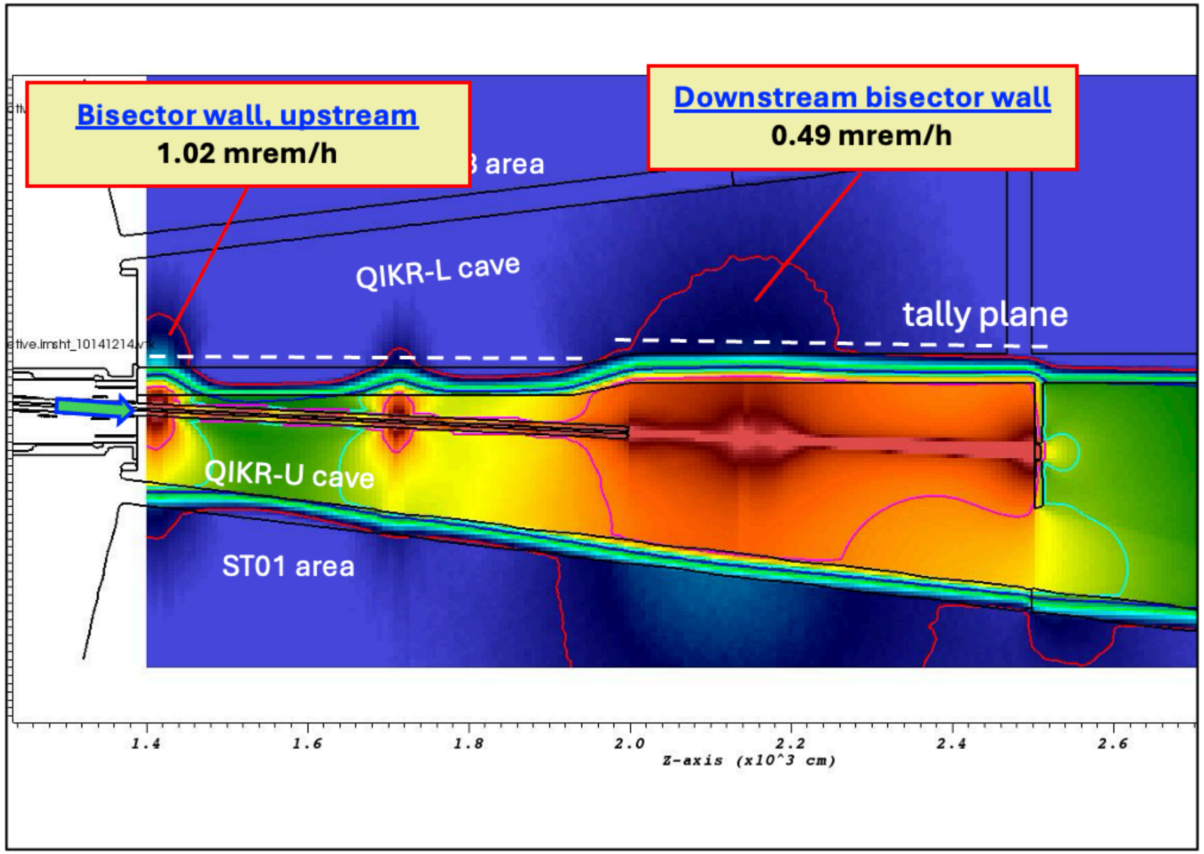
(b) Dose profiles at 30 cm away from the bisector wall inside QIKR-U cave
(QIKR-L active, QIKR-U is inactive)

Dose profiles when one beam is operating normally, and the other is inactive.

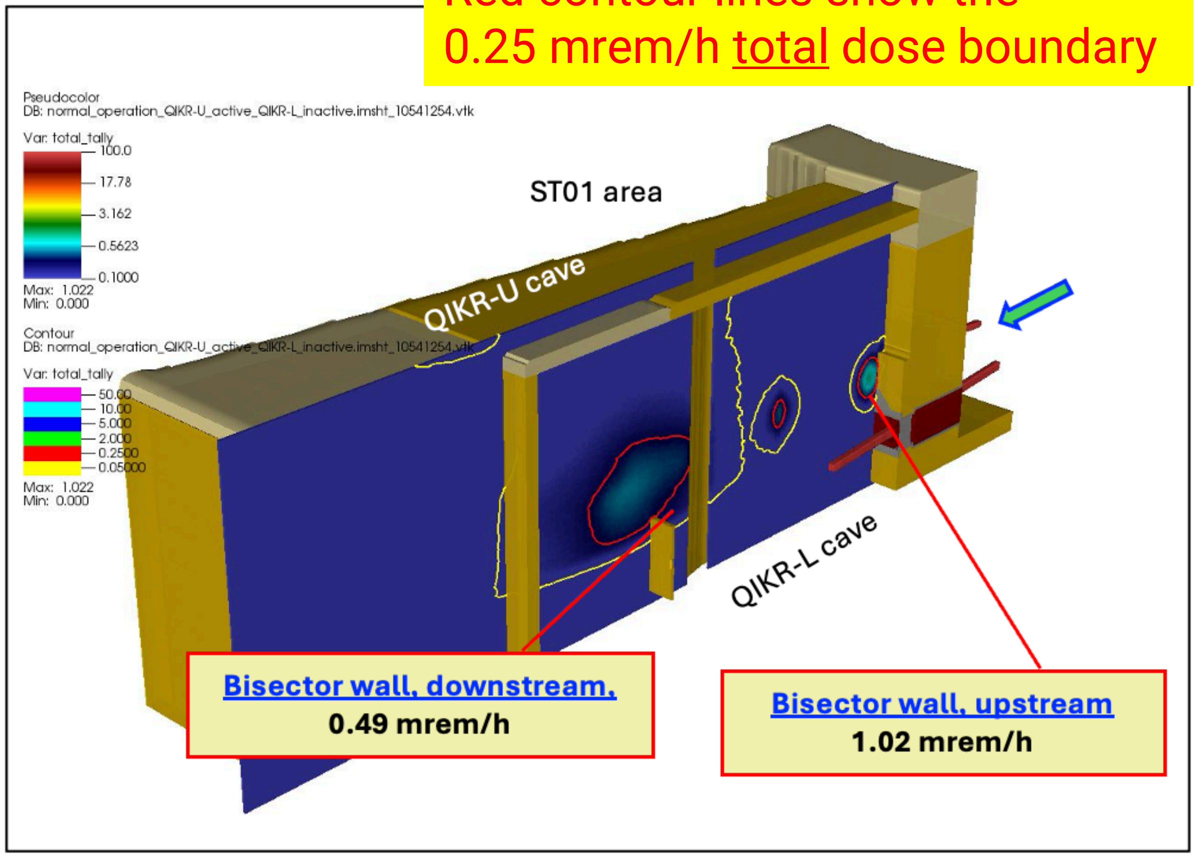
QIKR Cave Shielding Analysis: Normal Operation

Normal operation, One beamline is active, the other is inactive (used to estimate the dose rates inside the caves)
- White beam - **Water sample** - With Slits (full aperture)

Red contour lines show the 0.25 mrem/h total dose boundary



(a) Dose profile along the QIKR-U elevation
(QIKR-U is active, QIKR-L is inactive)



(b) Dose profile at 30 cm away from the bisector wall inside QIKR-L cave
(QIKR-U is active, QIKR-L is inactive)

Dose profiles when one beam is operating normally, and the other is inactive.

Summary: Normal Operation

No significant elevated dose rates inside/outside the QIKR instrument cave enclosure

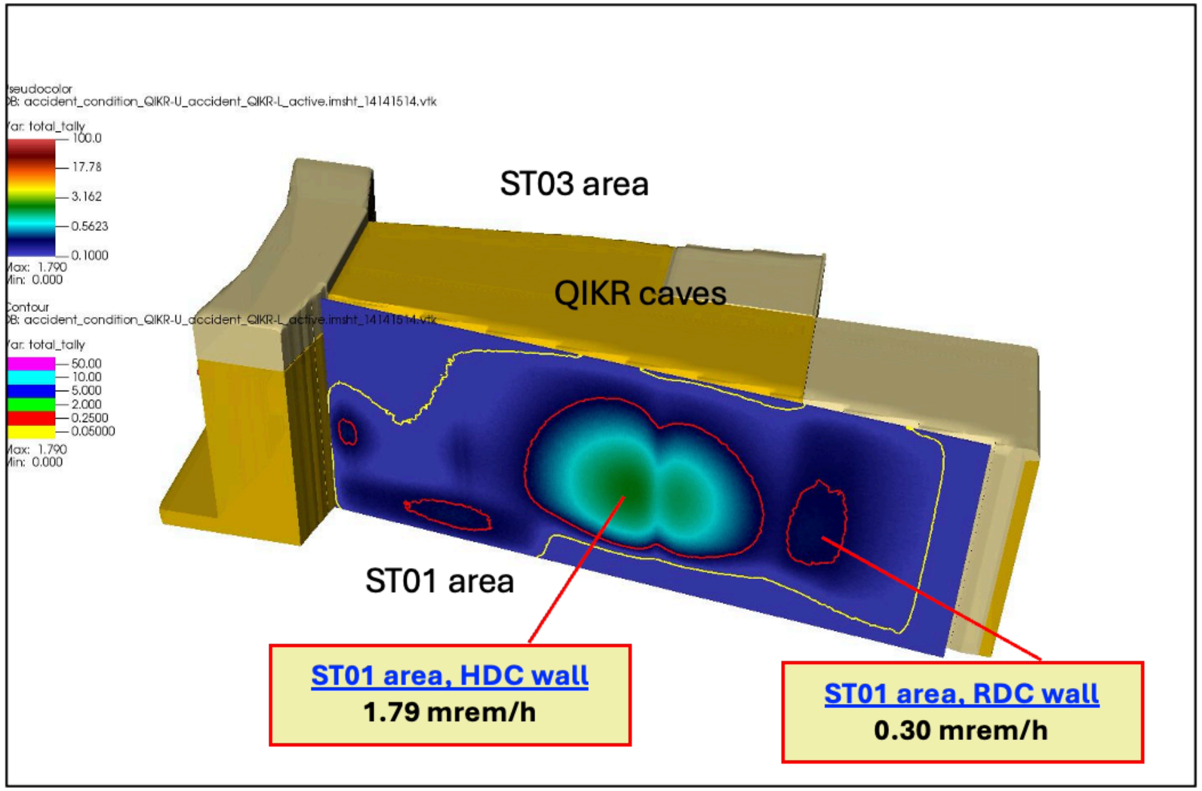
normal operation (QIKR-L active and QIKR-U active)			
Cave	Location		maximum total dose rate (mrem/h)
QIKR-L	Outer wall, ST03 side	Upstream (HDC)	0.72
		Downstream (RDC)	0.28
	Back Wall		< 0.25
	Roof	Upstream (HDC)	< 0.25
		Downstream (RDC)	0.43
QIKR-U	Outer wall, ST01 side	Upstream (HDC)	0.64
		Downstream (RDC)	0.34
	Back Wall		< 0.25
	Roof	Upstream (HDC)	0.31
		Downstream (RDC)	0.51
normal operation (only QIKR-U active)			
QIKR-L	in-beam		0.27
	bisector wall (inside cave)	Upstream (HDC)	1.02
		Downstream (RDC)	0.49
normal operation (only QIKR-L active)			
QIKR-U	in-beam		0.28
	bisector wall (inside cave)	Upstream (HDC)	0.71
		Downstream (RDC)	0.29

QIKR Cave Shielding Analysis: Accident Conditions

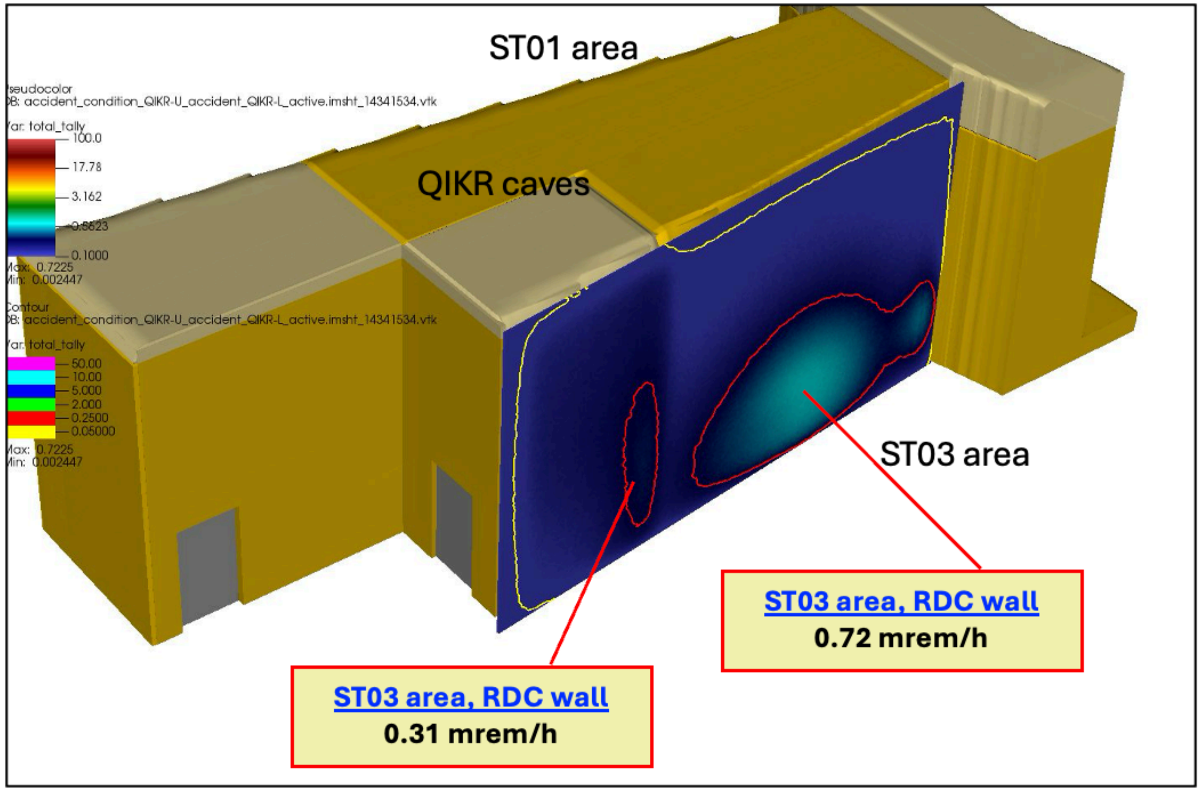
Accident condition
White beam, **Steel sample**, With Slits (full aperture)

QIKR-U is in accident
QIKR-L is operating normally

Red contour lines show the
0.25 mrem/h total dose boundary



(a) Dose profiles along the outer wall of the QIKR enclosure on the ST01 side



(b) Dose profiles along the outer wall of the QIKR enclosure on the ST03 side

Dose profiles calculated at 30 cm away from the cave outer walls when QIKR-U is in accident and QIKR-L is operating normally.

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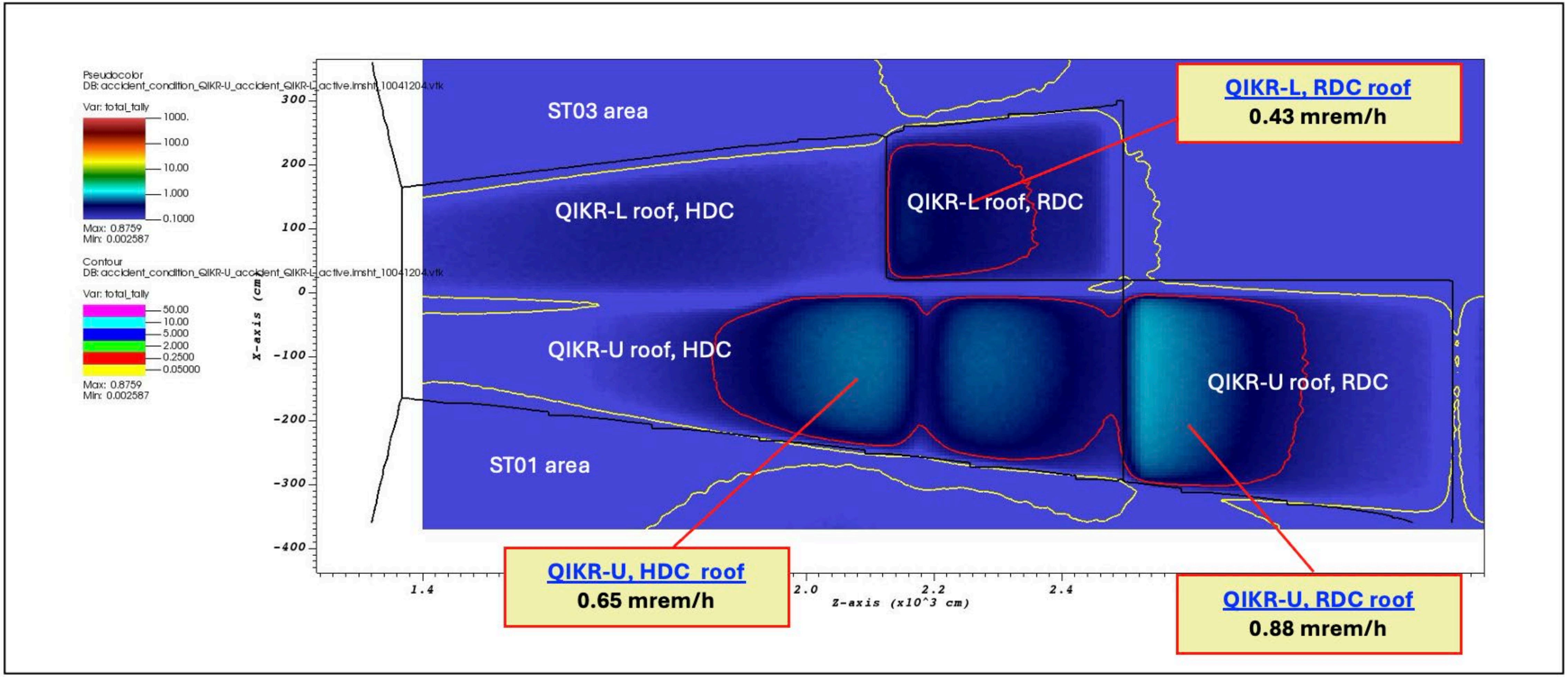
QIKR Cave Shielding Analysis: Accident Conditions

Accident condition
White beam, **Steel sample**, With Slits (full aperture)

QIKR-U is in accident
QIKR-L is operating normally

Red contour lines show the
0.25 mrem/h total dose boundary



Dose profiles at 30 cm above the QIKR instrument caves' roof (plan-view) when QIKR-U is in accident and QIKR-L is operating normally.

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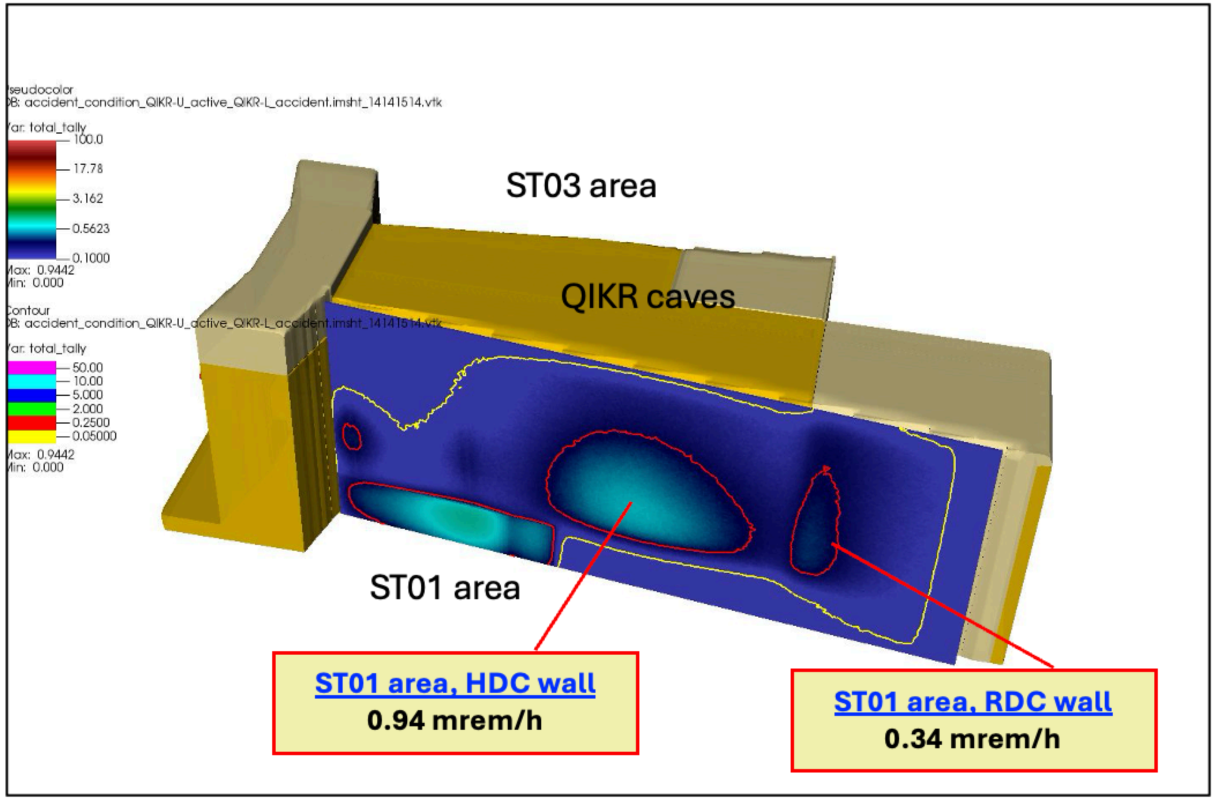
QIKR Cave Shielding Analysis: Accident Conditions

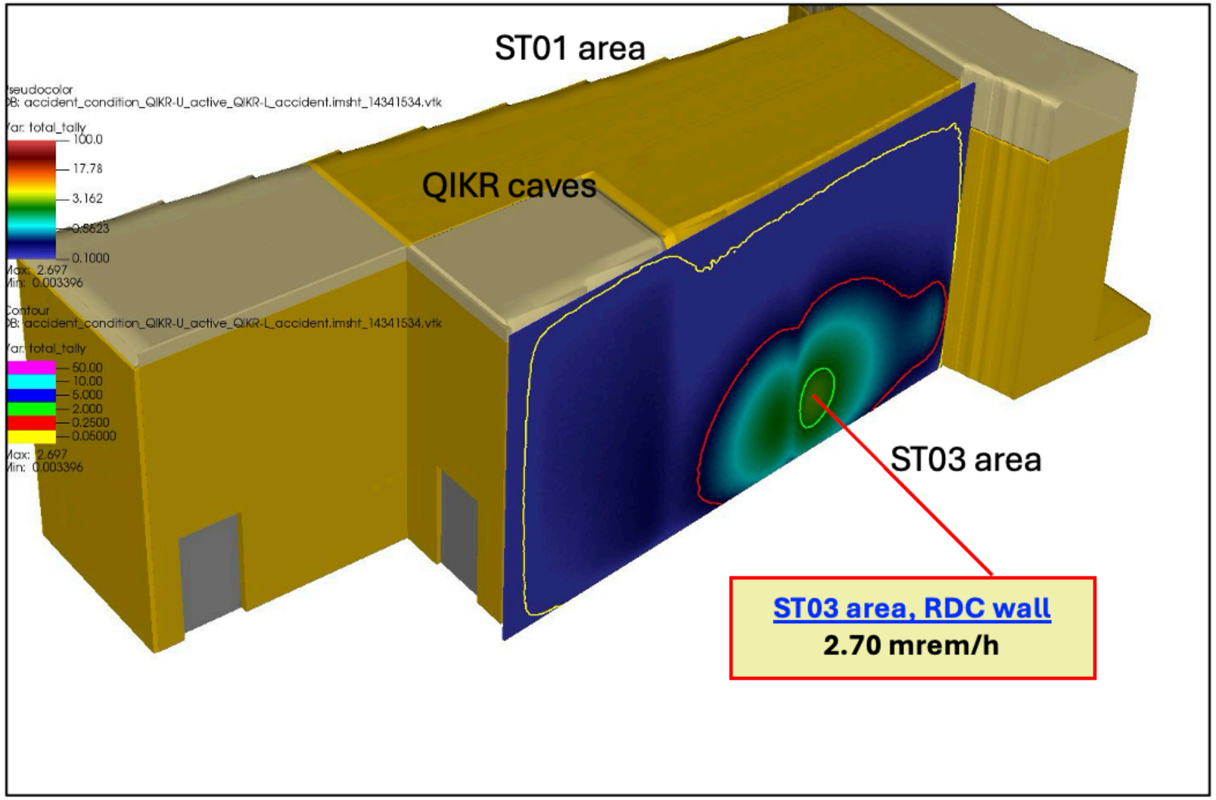
Accident condition
White beam, **Steel sample**, With Slits (full aperture)

QIKR-U is operating normally
QIKR-L is in accident

Red contour lines show the
0.25 mrem/h total dose boundary



(a) Dose profiles along the outer wall of the QIKR enclosure on the ST01 side



(b) Dose profiles along the outer wall of the QIKR enclosure on the ST03 side

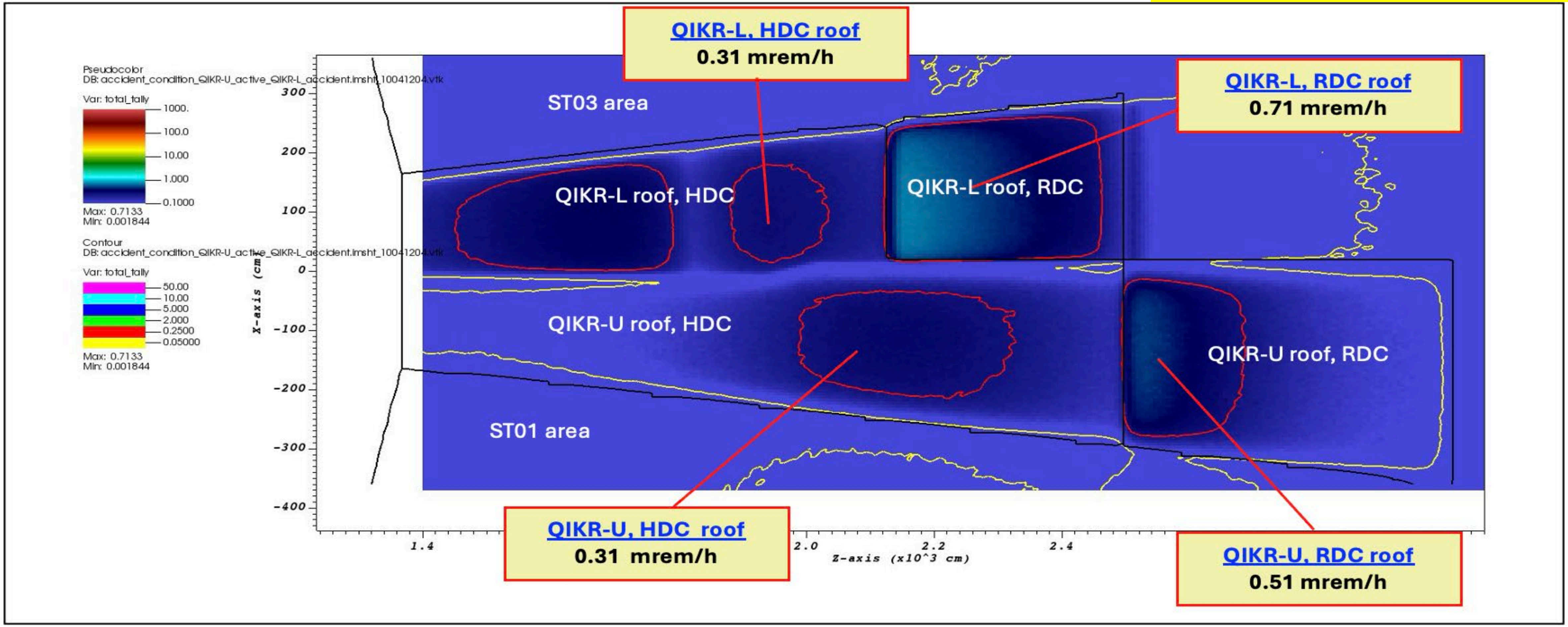
Dose profiles calculated at 30 cm away from the cave outer walls when QIKR-L is in accident and QIKR-U is operating normally.

QIKR Cave Shielding Analysis: Accident Conditions

Accident condition
White beam, **Steel sample**, With Slits (full aperture)

QIKR-U is operating normally
QIKR-L is in accident

Red contour lines show the 0.25 mrem/h total dose boundary



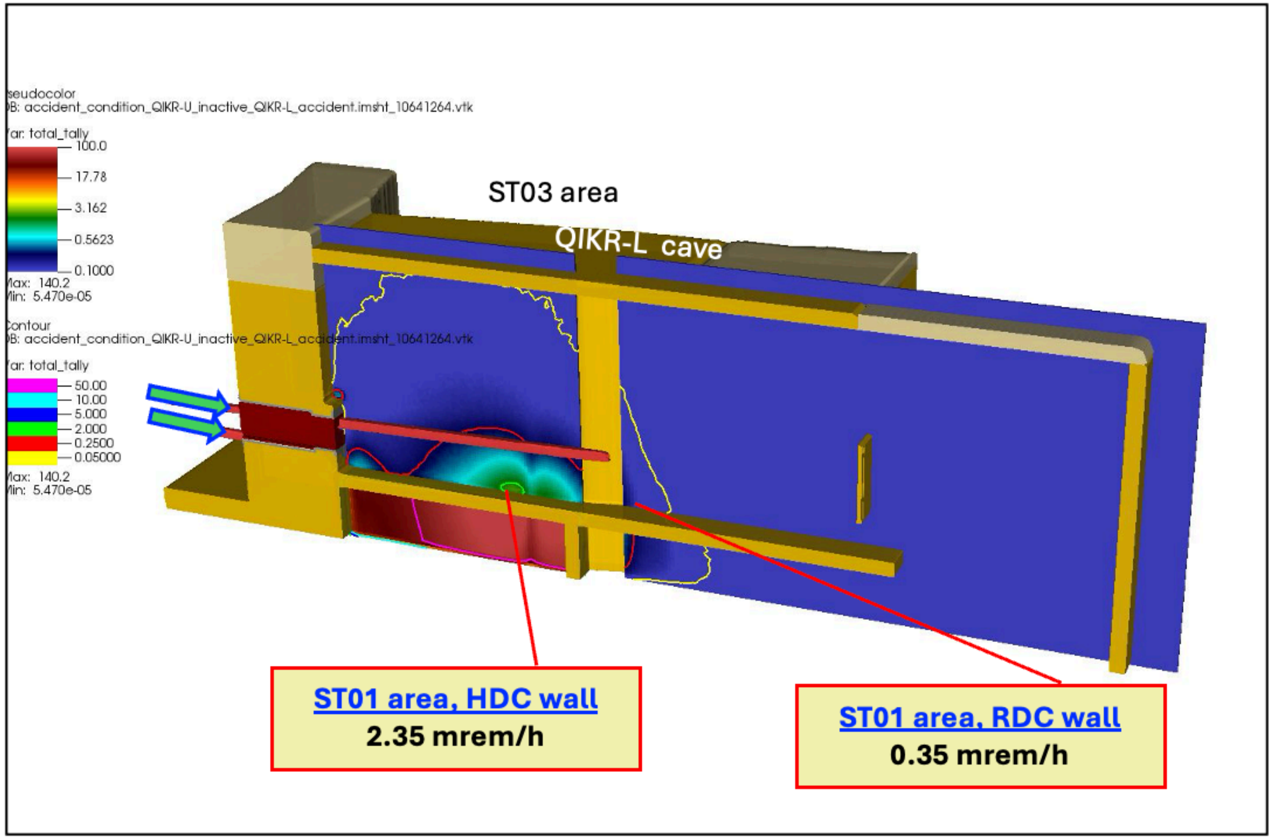
Dose profiles at 30 cm above the QIKR instrument caves' roof (plan-view) when QIKR-L is in accident and QIKR-U is operating normally.

QIKR Cave Shielding Analysis: Accident Conditions

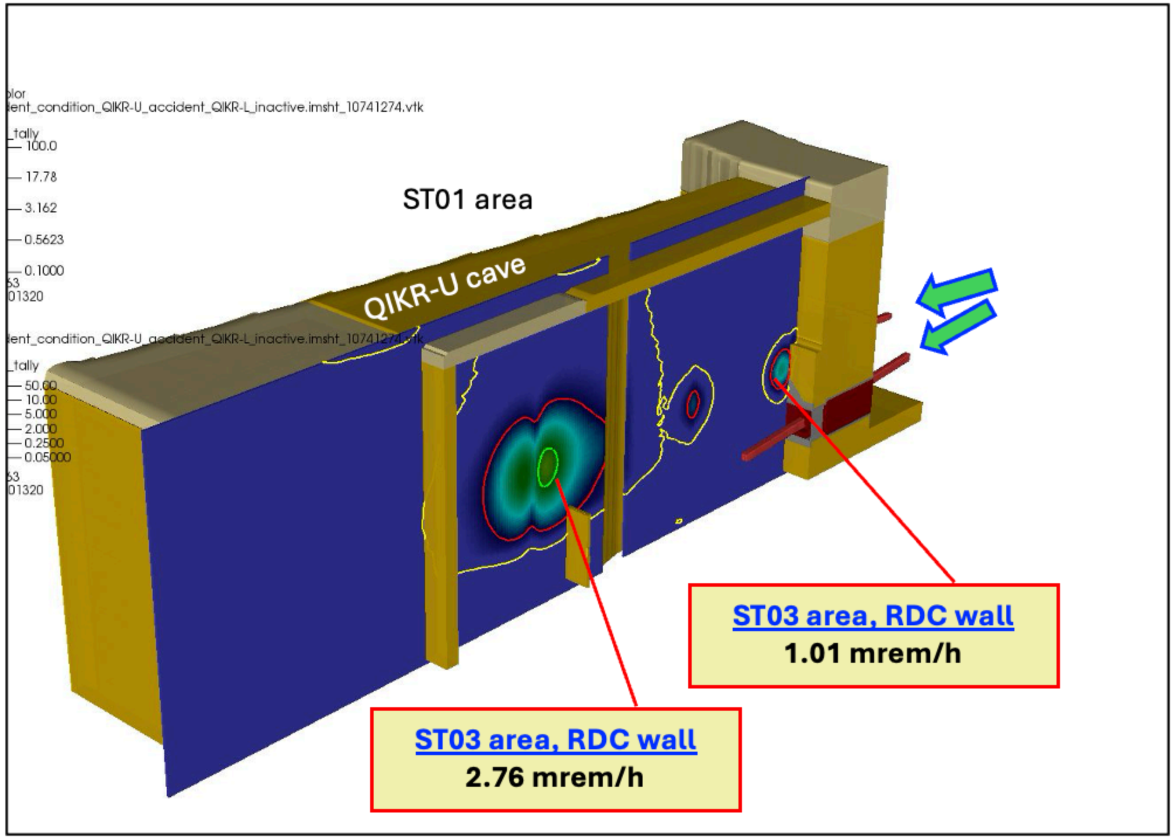
Accident condition
White beam, **Steel sample**, With Slits (full aperture)

One beamline is in accident, the other is inactive

Red contour lines show the 0.25 mrem/h total dose boundary



(a) Dose profiles along the inner wall inside QIKR-U cave
(QIKR-U is inactive, QIKR-L is in accident)



(b) Dose profiles along the inner wall inside QIKR-L cave
(QIKR-U is in accident, QIKR-L is inactive)

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Dose profiles in the inactive beam cave when the other beamline is in accident.

Summary: Accident Conditions

Some elevated dose rates above 2mrem/h inside/outside the QIKR instrument cave enclosure when one QIKR beam line is in accident… something to address?

Cave	Location		maximum total dose rate (mrem/h)
accident condition (QIKR-L normal operating and QIKR-U accident)			
QIKR-L	Outer wall, ST03 side	Upstream (HDC)	0.72
		Downstream (RDC)	0.31
	Back Wall		< 0.25
	Roof	Upstream (HDC)	< 0.25
		Downstream (RDC)	0.43
QIKR-U	Outer wall, ST01 side	Upstream (HDC)	1.79
		Downstream (RDC)	0.30
	Back Wall		< 0.25
	Roof	Upstream (HDC)	0.65
		Downstream (RDC)	0.88
accident condition (QIKR-L accident and QIKR-U normal operating)			
QIKR-L	Outer wall, ST03 side	Upstream (HDC)	2.70
		Downstream (RDC)	< 0.25
	Back Wall		0.31
	Roof	Upstream (HDC)	0.38
		Downstream (RDC)	0.71
QIKR-U	Outer wall, ST01 side	Upstream (HDC)	0.94
		Downstream (RDC)	0.34
	Back Wall		< 0.25
	Roof	Upstream (HDC)	0.31
		Downstream (RDC)	0.51
accident condition (QIKR-L inactive and QIKR-U accident)			
QIKR-L	in beam		0.28
	bisector wall	Upstream (HDC)	1.01
		Downstream (HDC)	2.76
accident condition (QIKR-L accident and QIKR-U inactive)			
QIKR-U	in beam		0.27
	bisector wall	Upstream (HDC)	2.35
		Downstream (HDC)	0.35

Questions??