Radiation environment around IBA systems

RADSUM workshop – January 2025

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Introduction

Global leader in particle beam technology

Proton Therapy > proton beam cancer radiotherapy equipment & services

75 PT solutions sold

RadioPharma Solutions > radiopharmaceuticals & radiochemistry solutions

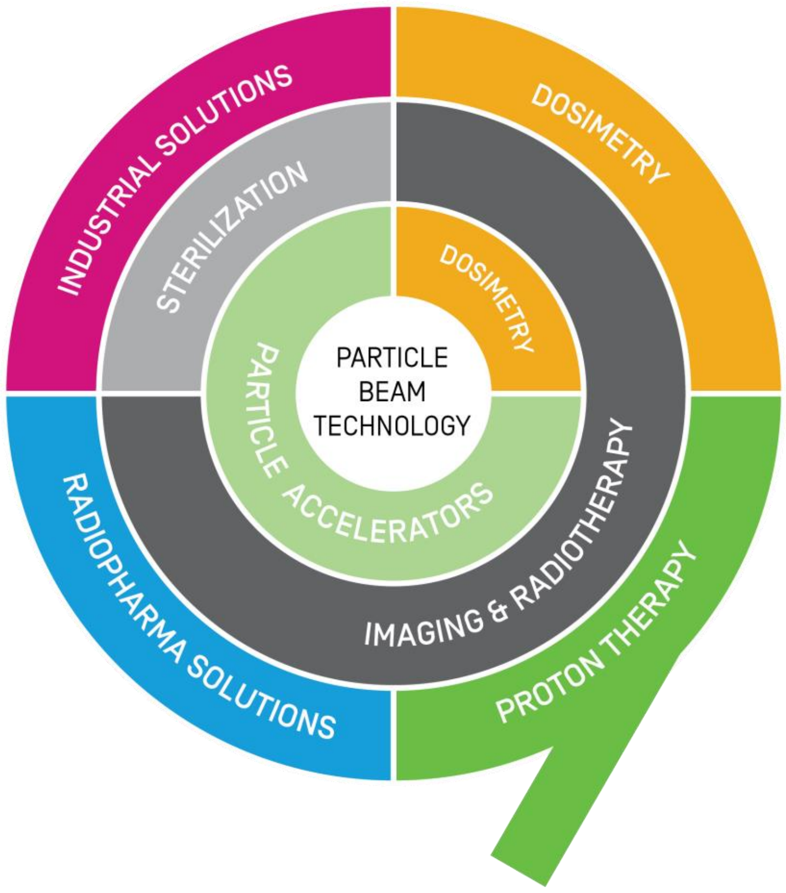
300+ cyclotrons sold

Industrial Solutions > ion beam sterilization industry

250+ accelerators sold

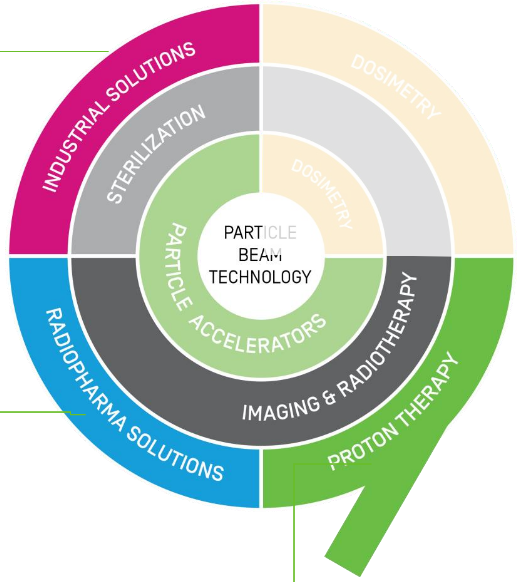
Dosimetry > quality assurance for medical imaging & radiotherapy

10K clients



Typical beams used for IBA applications

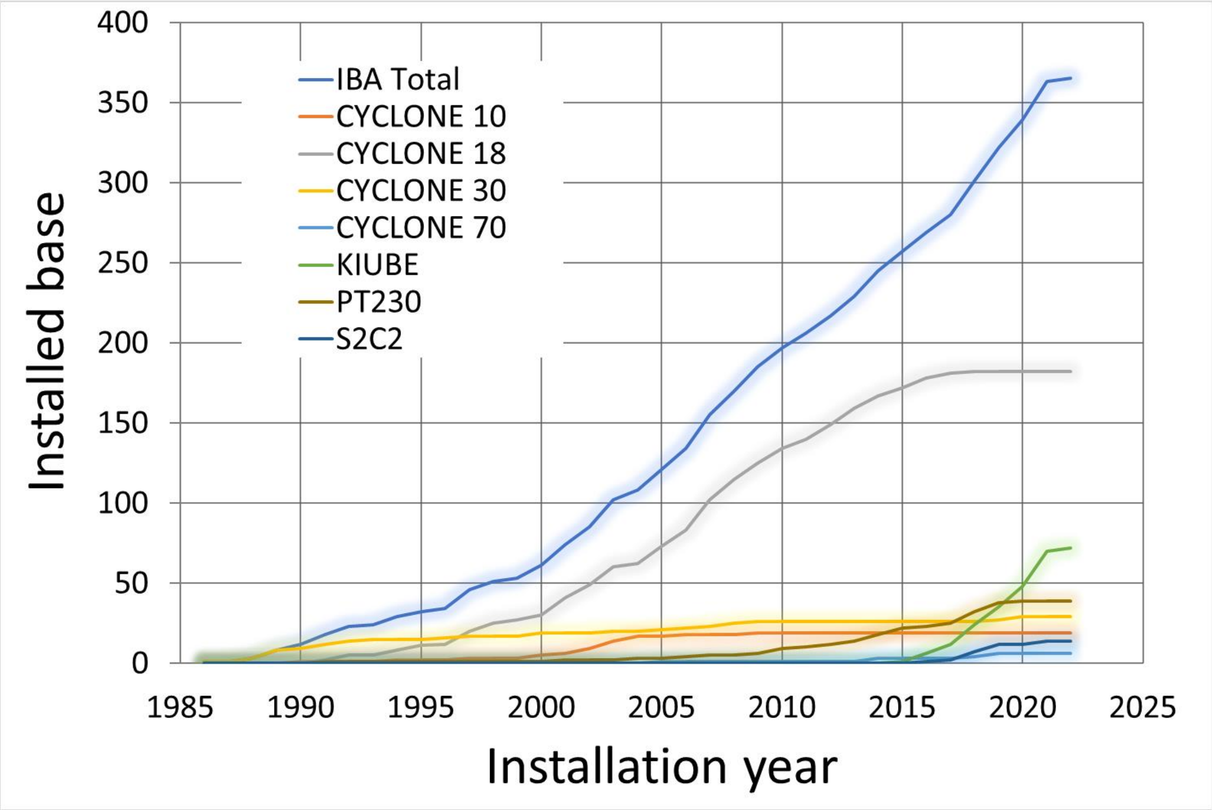
Application	Particle	Energy (MeV)	Typical beam current (on target)	Machine load (beam time)	IBA machine
Sterilization, food, material processing…	Electron (=>Xrays)	7-10	70 mA	24/7	Rhodotron
PET Radioisotopes	Protons	9-18	100-300 µA	3-12 h/day	Cyclone®Key Cyclone®Kiube
PET+SPECT (and theranostics) radioisotopes	Protons	30-70	300-1200 µA	3-12 h/day	Cyclone®Ikon, Cyclone®70
Theranostics	Electrons (=>Xrays)	40	3 mA	3-12 h/day	Rhodotron
Proton Therapy*	Protons	230	2-4 nA	~1 h/day**	ProteusPlus (C230) and Proteus One (S2C2)
Carbon Therapy	Carbon (and Helium)	4800 (920)	2-4 nA	~1 h/day**	C400 (NHa)



* non-flash – consider the total machine load to be similar ** a few minutes per patient, about 20 patients per room per day

(Synchro-)Cyclotron installed base

- IBA has more than 350 cyclotrons installed worldwide



RPS

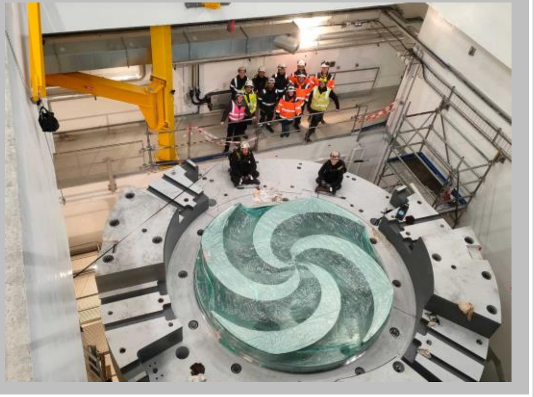
PT

Note about superconductivity

- Currently, IBA used Superconducting magnets only for its accelerators used in particle therapy
  - low beam time but magnet “always on” at stable magnetic field
  - high magnetic field for compact systems
- Elsewhere…?
  - Proton Therapy beam lines have varying magnetic fields and have field off most of the time
  - Internal studies have shown that SC technology was too expensive for the production of radioisotopes*.

CYCLOTRON
S2C2<
(ProteusOne)
200 kW => ~40 kW

CYCLOTRON
C400<
(NHa)



But there is definitely an ongoing discussion and tech watch on this topic and IBA will definitely switch to SC technology anywhere it proves to bring a functional or economical advantage

* not enough gain/savings on the long-term to justify initial investment

Typical beams used for IBA applications

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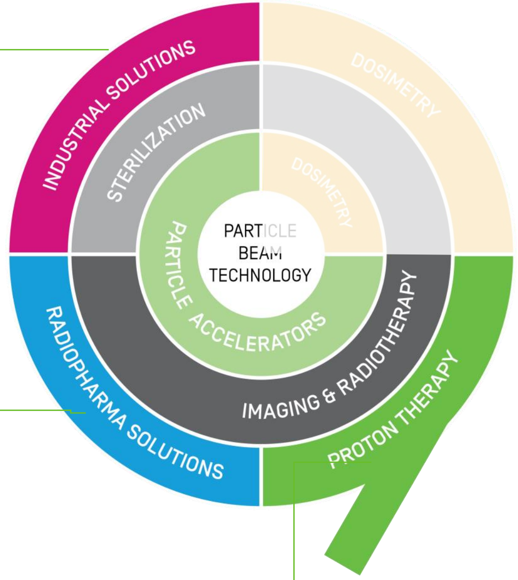


Superconducting coils

* non-flash – consider the total machine load to be similar ** a few minutes per patient, about 20 patients per room per day

Radiation backgrounds

Not limited to Particle Therapy…

How we usually proceed for radiation background modelling

Primary beam interactions
- losses & target
- Identification of materials

Simple target modelling
- Primary beam on various materials
- Tally (& benchmark) the resulting secondary radiations
- Prepare source cards for further modelling

Several "full model" MC runs
- Implementation of full geometry
- Run relevant source card on every primary beam interaction location

Merge results
- Weighted average of the MC runs according to actual machine use (energy, time, beam line configuration…)

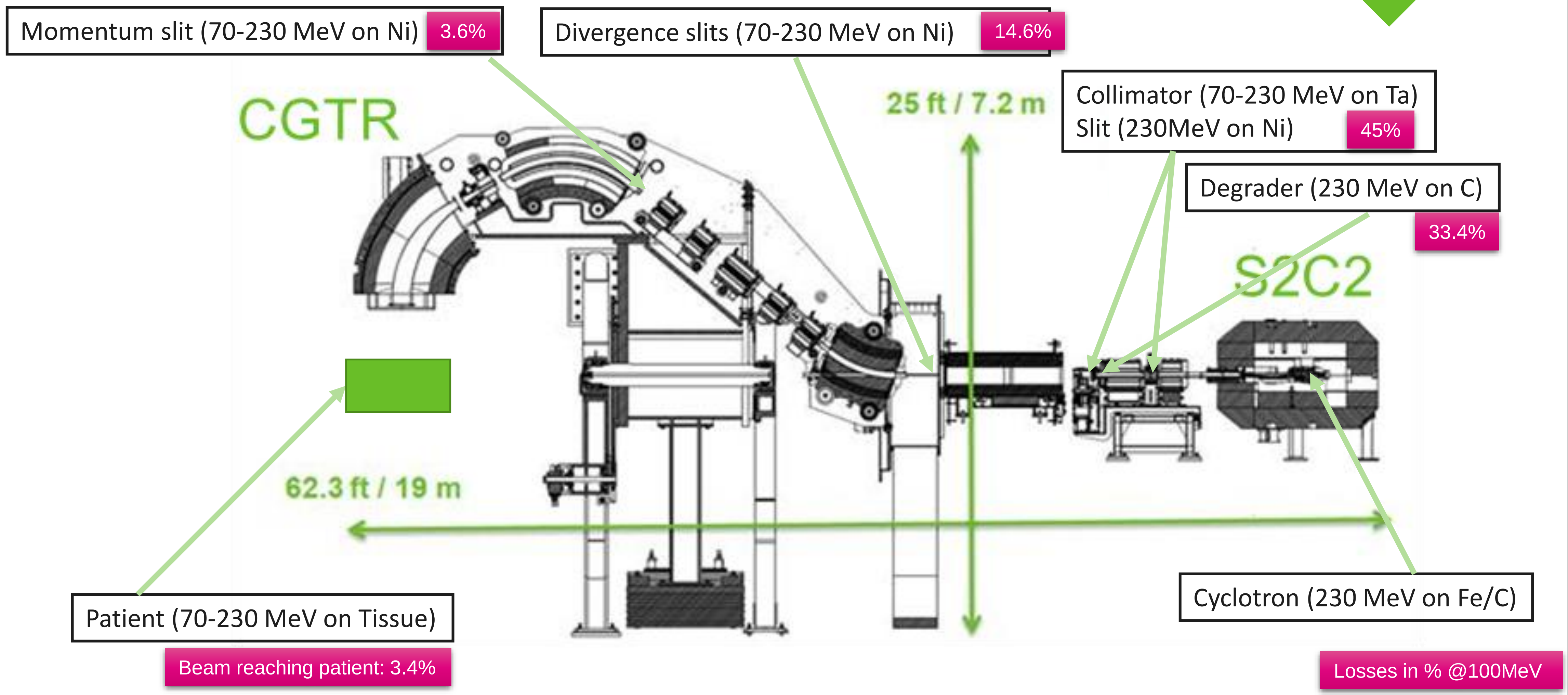
Benchmark
- MC studies are oftentimes benchmarked with on-site measurements using standard Radiation protection tools like ionization chambers (FH40) or neutron detectors (WENDI-II)

At our energies and after comparison, IBA mostly uses MCNP and sometimes PHITS for MonteCarlo modeling of beam-matter interactions.

We couple MCNP with FISPACT-II for in-depth activation studies when needed.

Example: Radiation Sources in ProteusONE

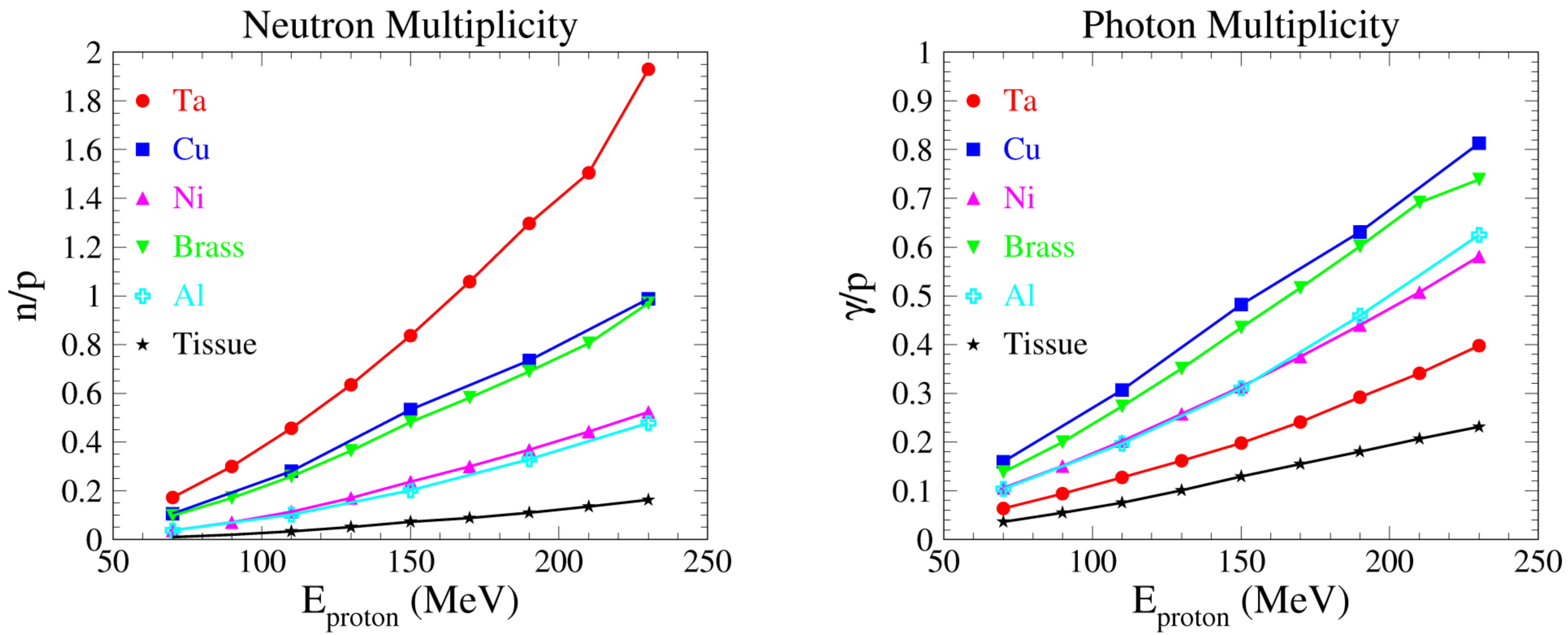
Primary beam interactions



Example: Radiation Sources in ProteusONE

Simple target modelling

Yields of secondary particles depend on beam energy and target materials

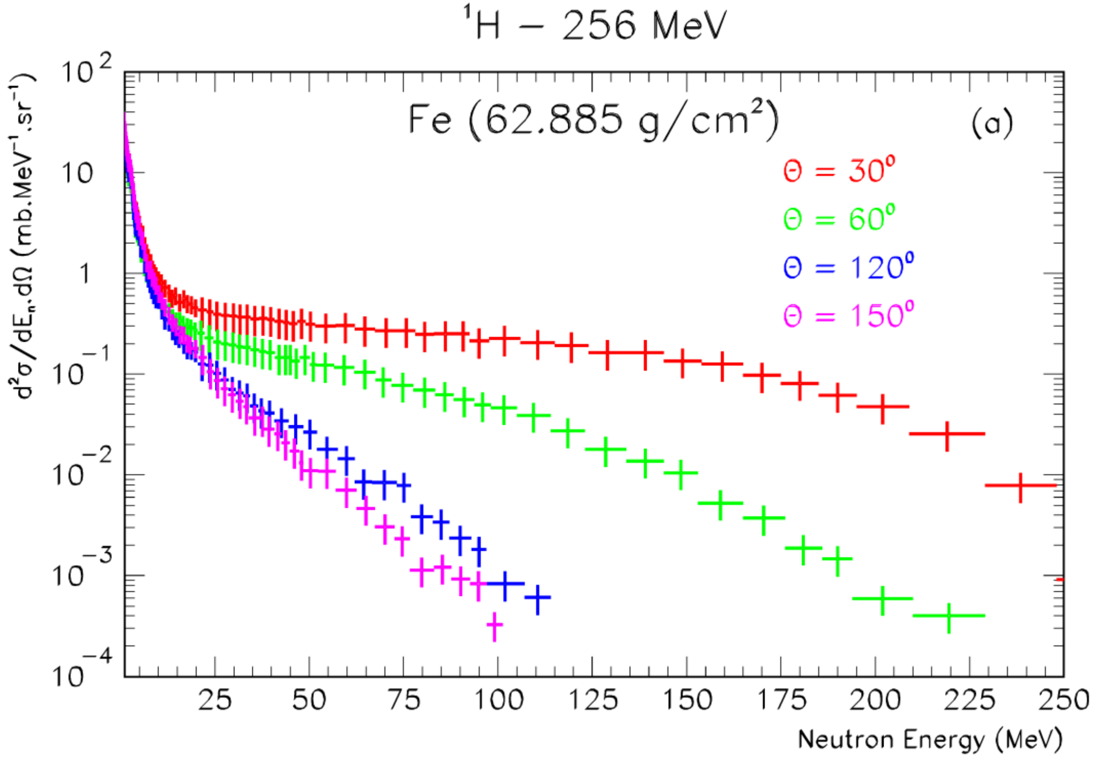


Example: Radiation Sources in ProteusONE

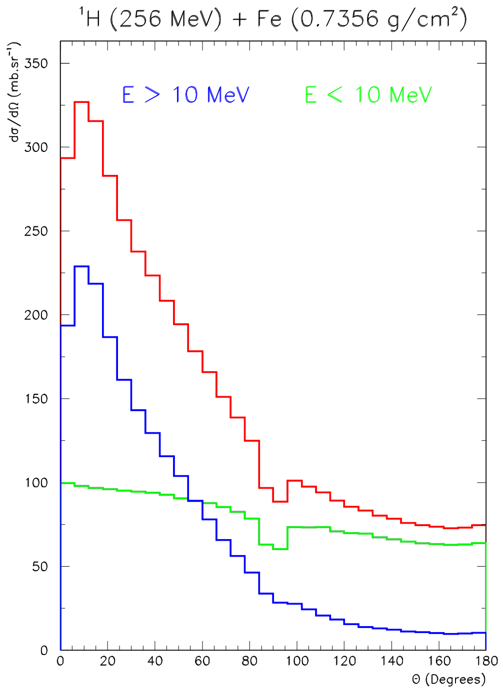
Simple target modelling

Production of secondary neutrons:

- Intranuclear cascade ➔ high-energy neutrons, mostly forward emission
- Target nuclei evaporation ➔ neutrons < 10 MeV, isotropic emission



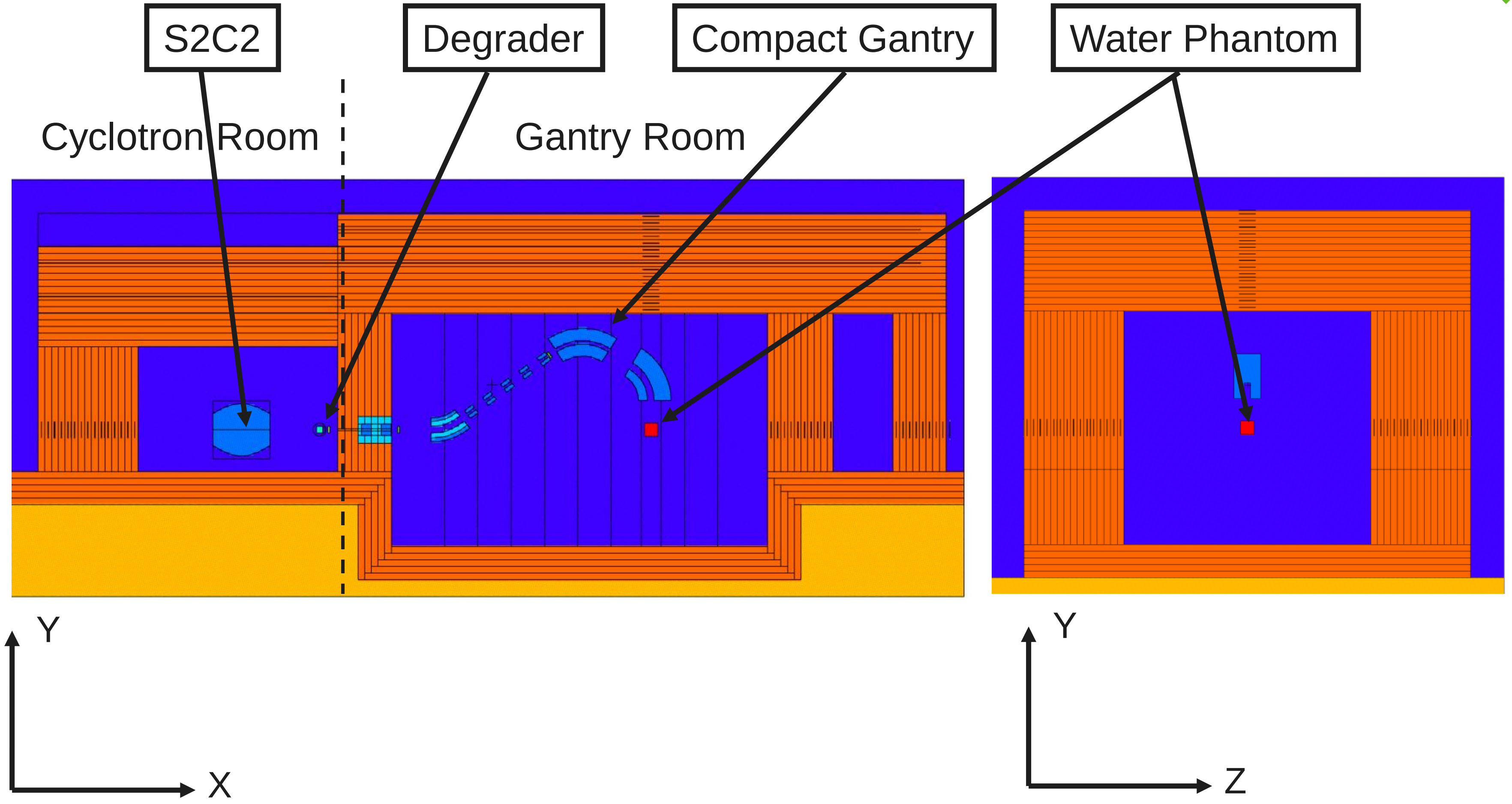
M.M. Meier et al, Nucl. Sci. Eng. **104**, 339 (1990)



MCNPX simulation

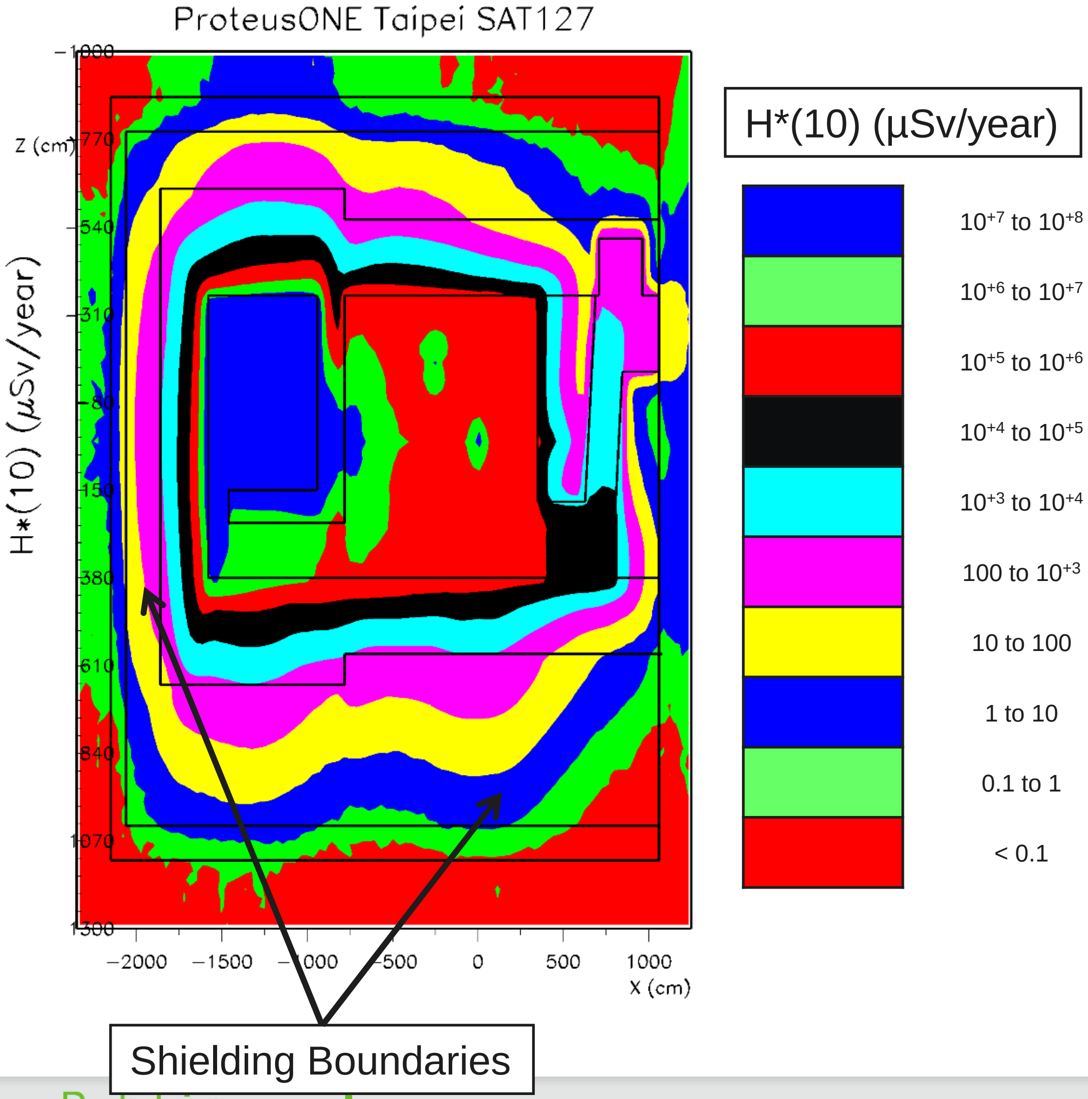
Example: Radiation Sources in ProteusONE

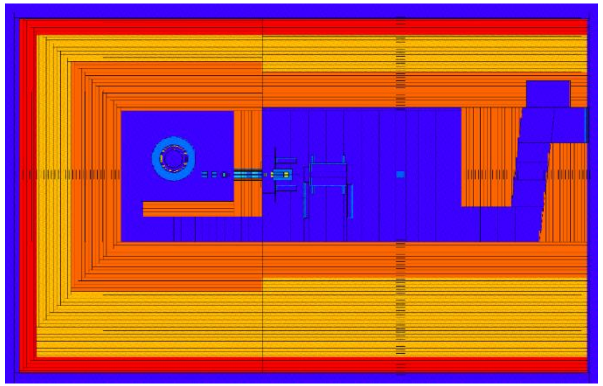
Several "full model" MC runs



Example: Radiation Sources in ProteusONE

Merge results





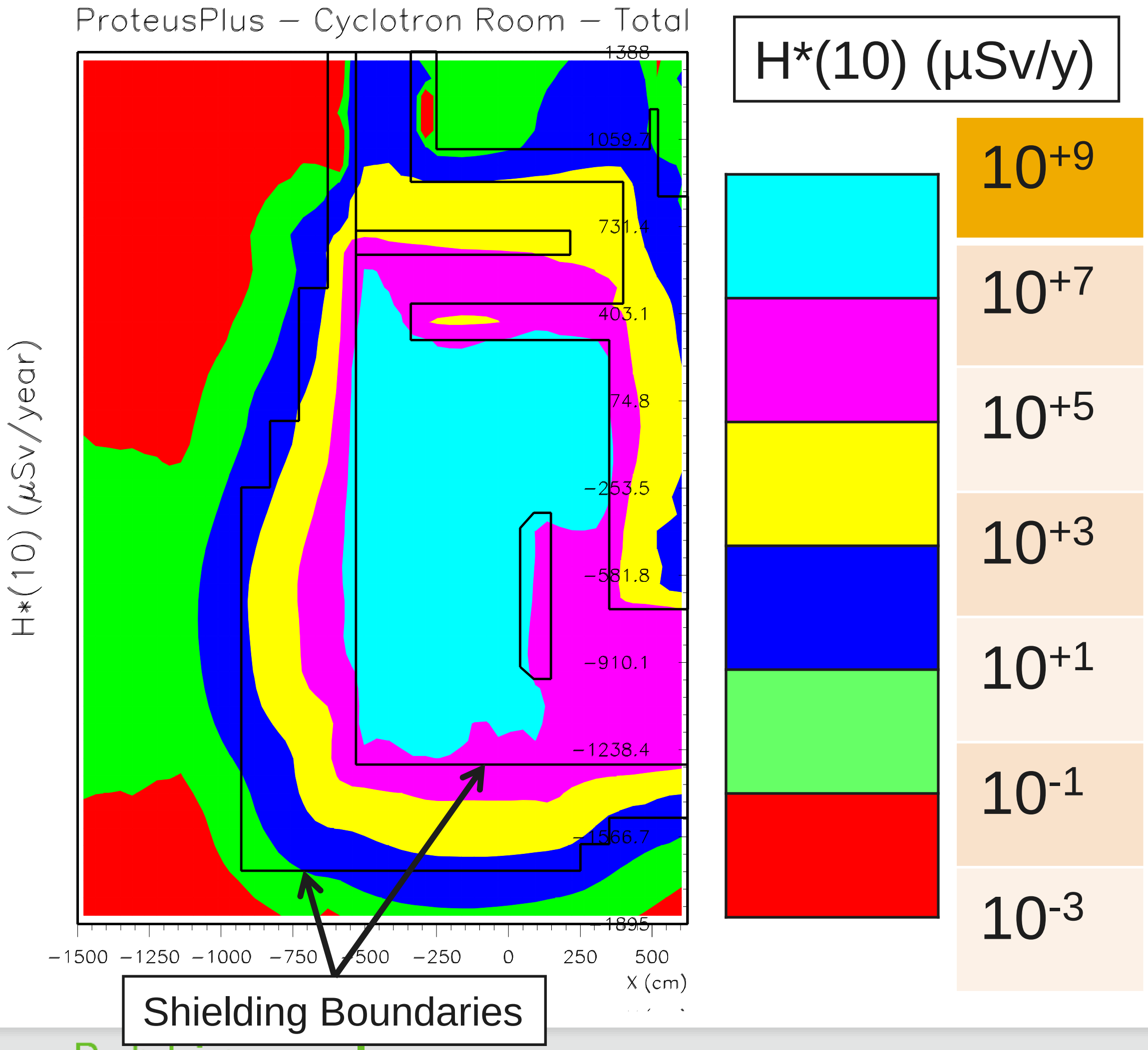
- Note that this is in µSv/y…
- But as the radiation background is dominated by neutrons in the accelerator room…
- … And considering a neutron quality factor of ~10…

=> The annual dose to the equipment in the accelerator room is about 10 Gy/y

Example: Radiation Sources in ProteusPLUS

Merge results

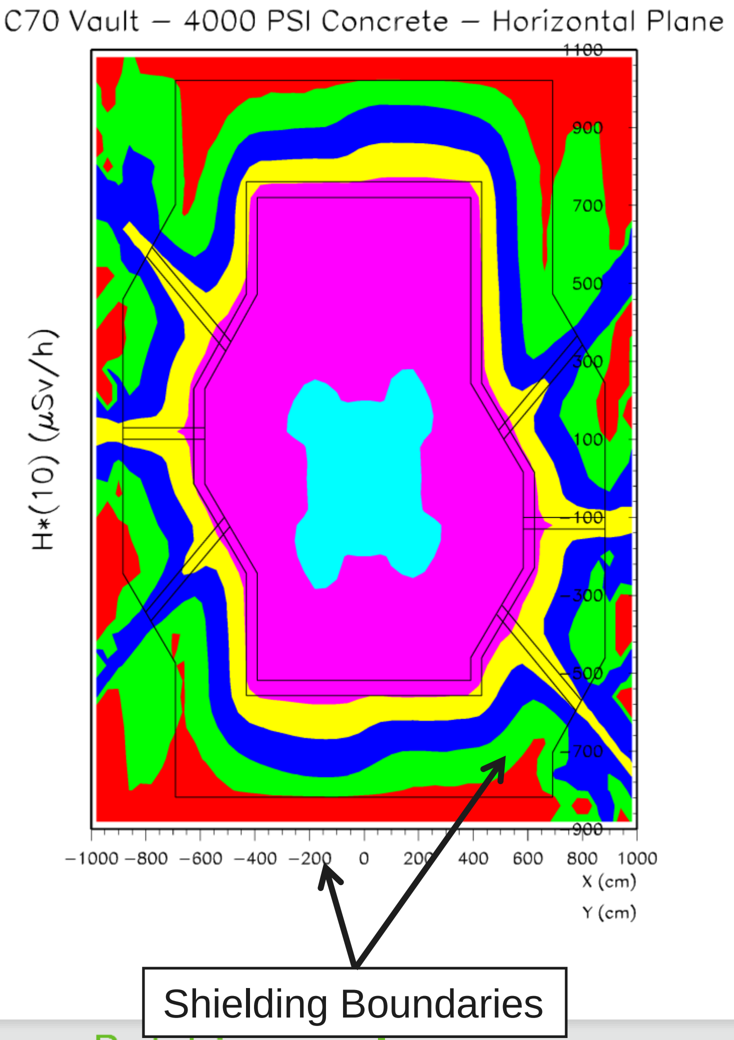
Multi-room system

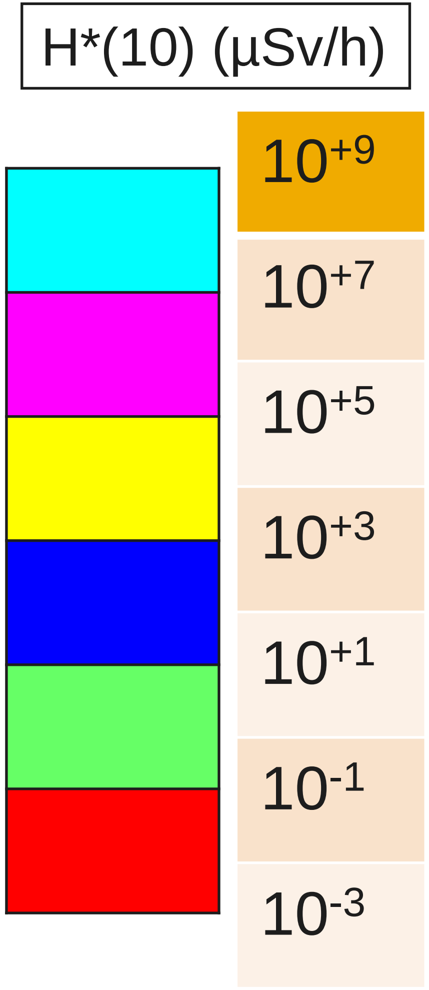


- Note that this is in μSv/y…
- But as the radiation background is dominated by neutrons in the accelerator room…
- … And considering a neutron quality factor of ~10…

=> The annual dose to the equipment in the accelerator room is about 100 Gy/y

Radiation background around a Cyclone®70 (PET/SPECT)

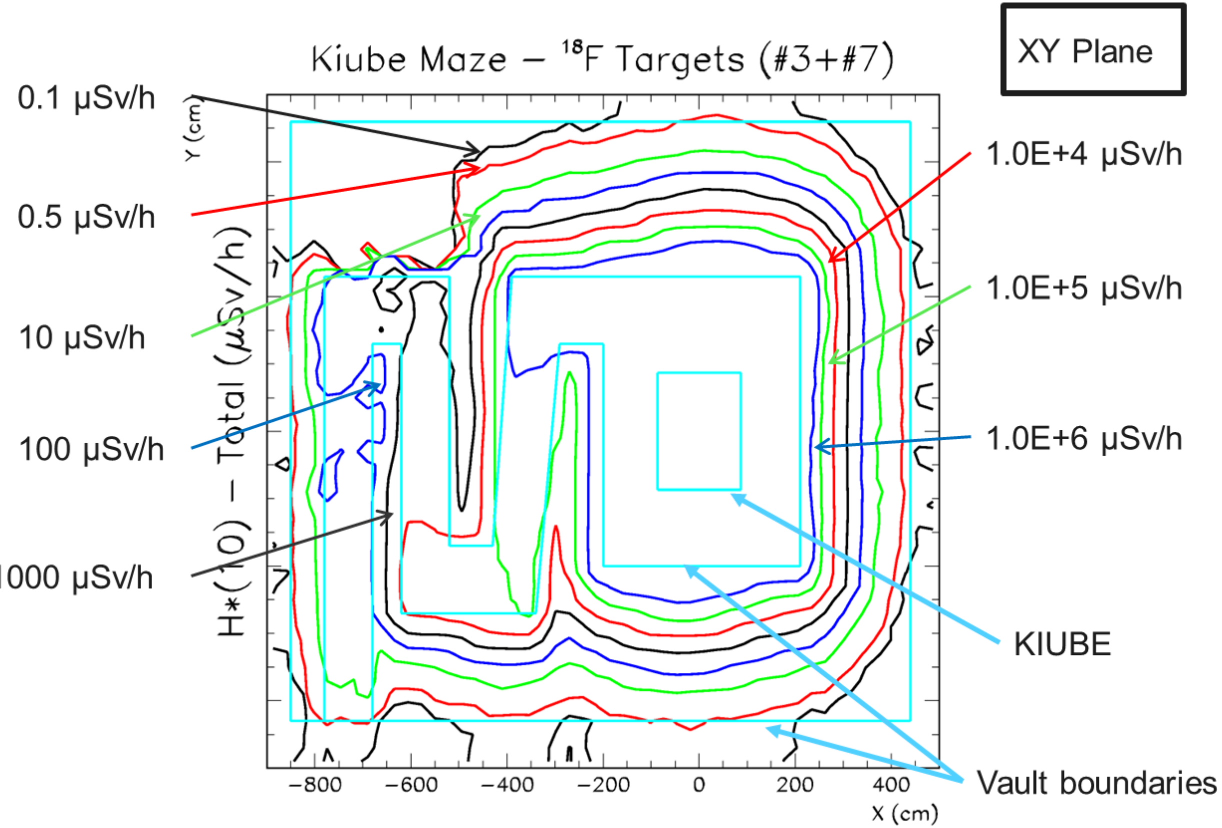




- Note that this is in µSv/h…
- Considering again a neutron quality factor of ~10…
- … And assuming 12h of beam time per day (worst/best case scenario)

=> The annual dose to the equipment in the accelerator room is about 250 kGy/y

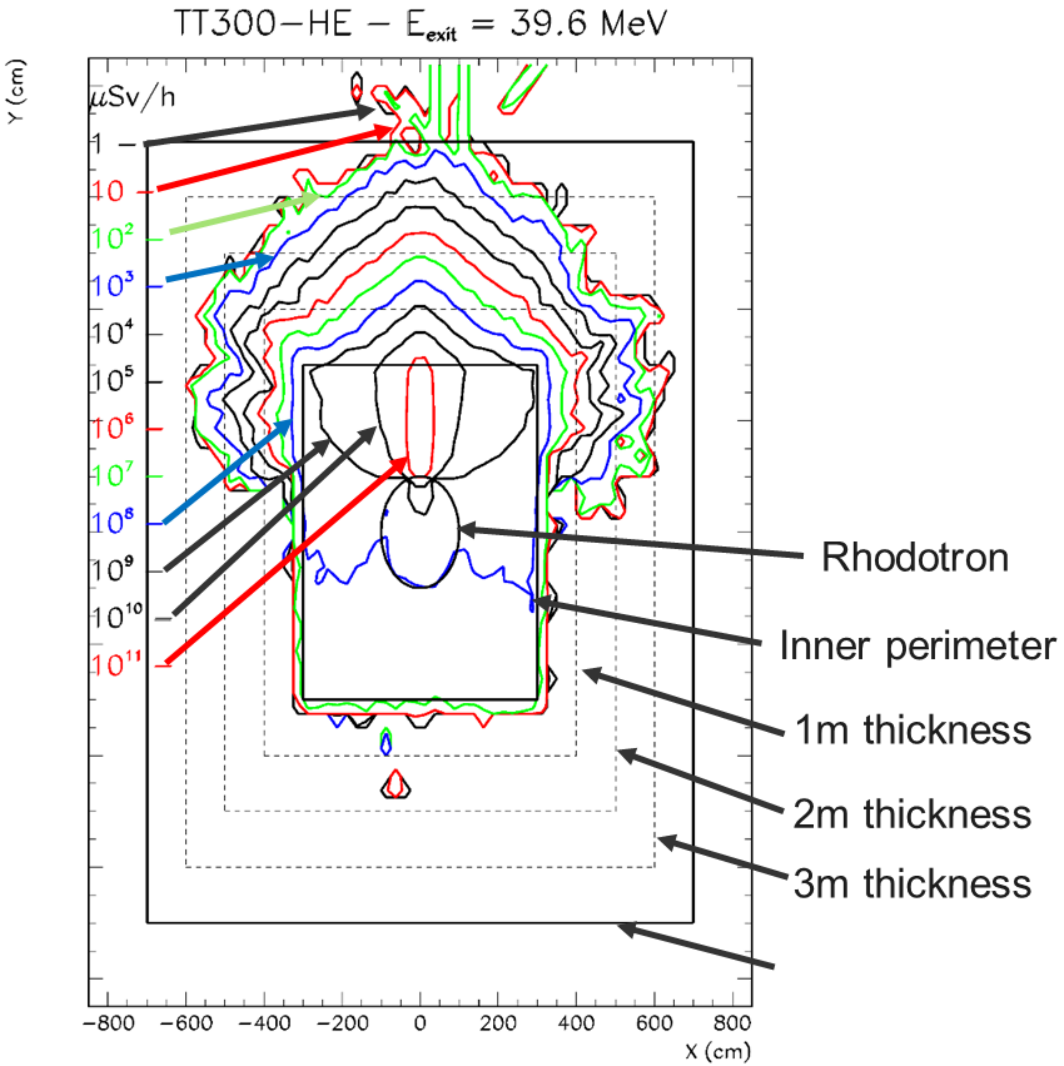
Radiation background around a Cyclone®Kiube (18 MeV for PET)



- Note that this is in µSv/h…
- Considering again a neutron quality factor of ~10 (a strong assumption here)…
- … And assuming 12h of beam time per day (worst/best case scenario)

=> The annual dose to the equipment in the accelerator room is about 250 Gy/y

Radiation background around a TT300HE (40 MeV e- for theranostics)



- Note that this is in µSv/h…
- Considering again a neutron quality factor of ~10…
- … And assuming 12h of beam time per day (worst/best case scenario)

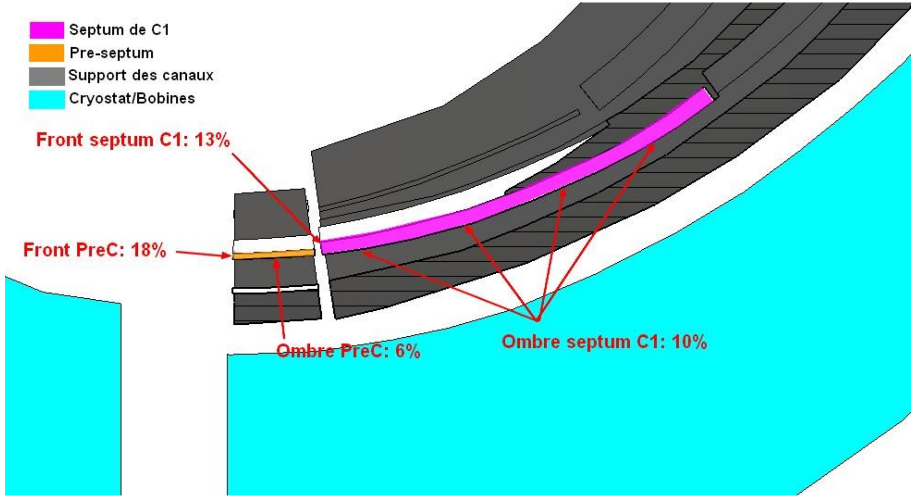
=> The annual dose to the equipment in the accelerator room is about 2,5 MGy/y and up to ~25 MGy/y

Focus on SC coils…

Heat loads, activation

Beam Losses inside a cyclotron result in locally higher dose and heat load

- **Beam losses inside the S2C2 are distributed at 4 locations:**
  - On the pre-septum and septum front: 31%
  - Along the septum: 16%
  - Vertical losses around the machine: 8.5%
  - Horizontal losses on the vacuum chamber: 16.5%

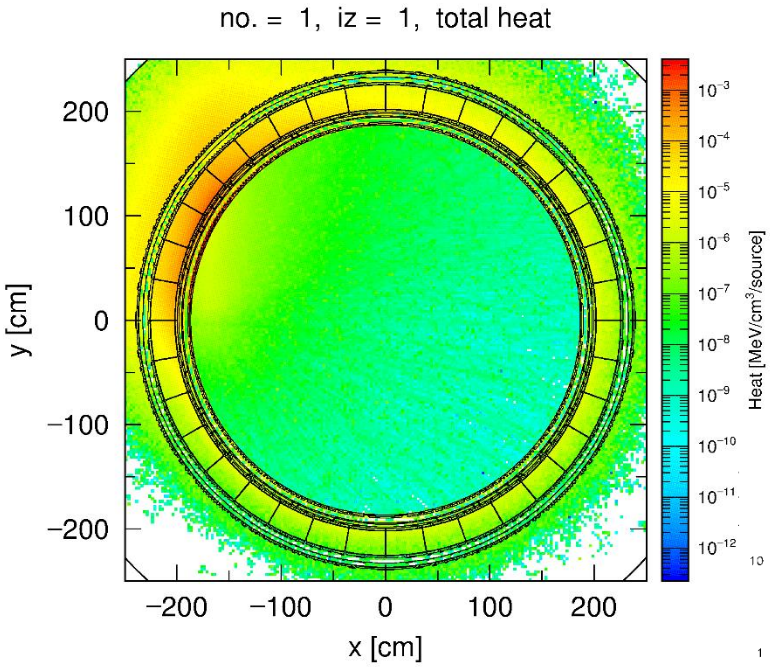


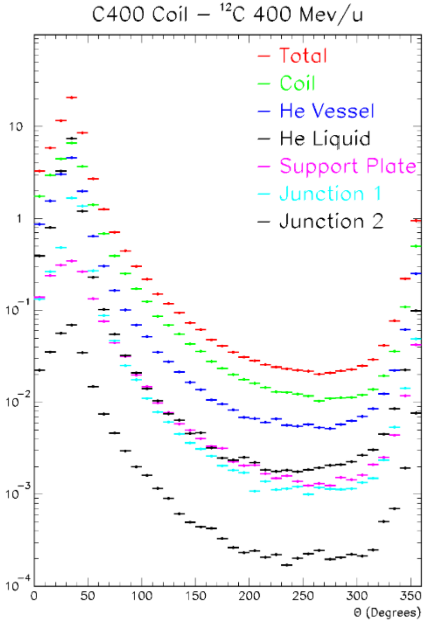
		Coil (W)	Al Structure (W)
Septum local losses	n	0.211	0.070
	γ	0.013	0.010
Septum spread losses	n	0.109	0.036
	γ	0.0067	0.0054
Vertical losses	n	0.0609	0.0164
	γ	0.0027	0.0013
Vacuum chamber losses	n	0.128	0.045
	γ	0.0101	0.0074
Total		0.5415	0.1915

The annual, average dose to the coil is about 1.8 kGy/y

(~55 kGy over 30 years)

The C400* has been modeled as well**





mW/pnA	^{12}C 400 MeV/u	^{4}He 400 MeV/u
Coil	47.31	26.44
Helium Vessel	27.78	12.29
Liquid Helium	0.54	0.25
Support plate	3.48	2.00
Junction 1 (outer)	8.98	3.56
Junction 2 (inner)	27.48	6.34
Total	115.57	50.88

The annual, average dose to the coil is about 122 Gy/y

(~4.7 kGy over 30 years)

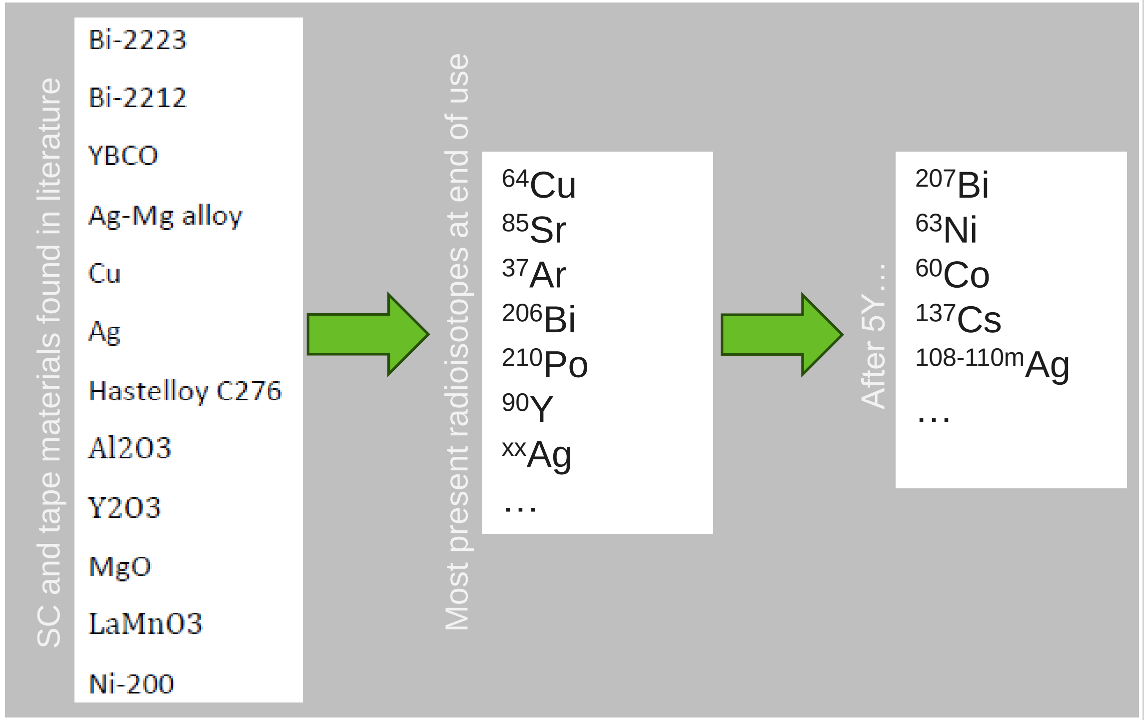
* NHa carbon therapy project

** Using PHITS, whose results have been benchmarked with available literature

Activation

Activation

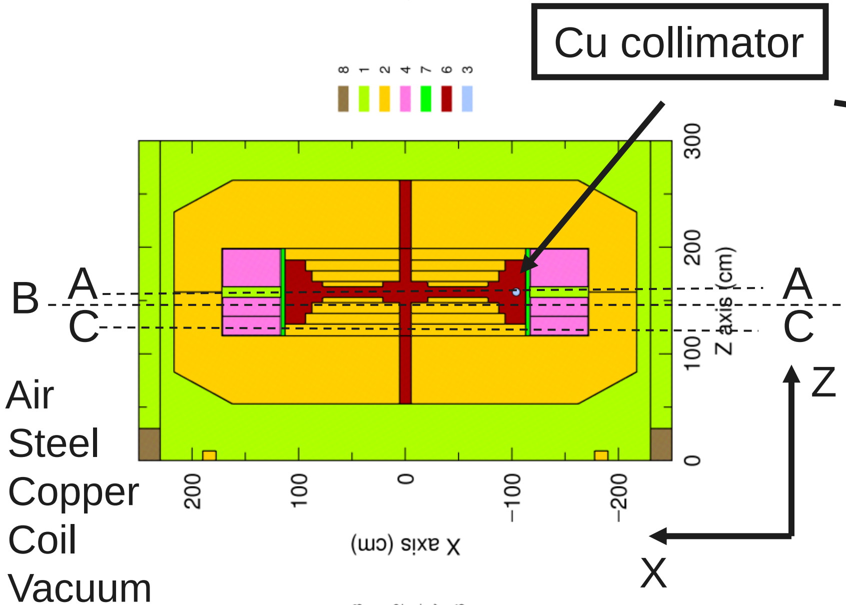
- IBA started the TAPIR project, with “The Binding Energy”*. This project targets to automate the simulation chain that yields detailed activation studies
- Preliminary results should be taken with utmost care
  - no validation yet,
  - Results to be presented according to clearance levels (for which we will have to know better the actual initial content of HTS conductors)
- … but HTS should present significant (=above clearance levels) activation



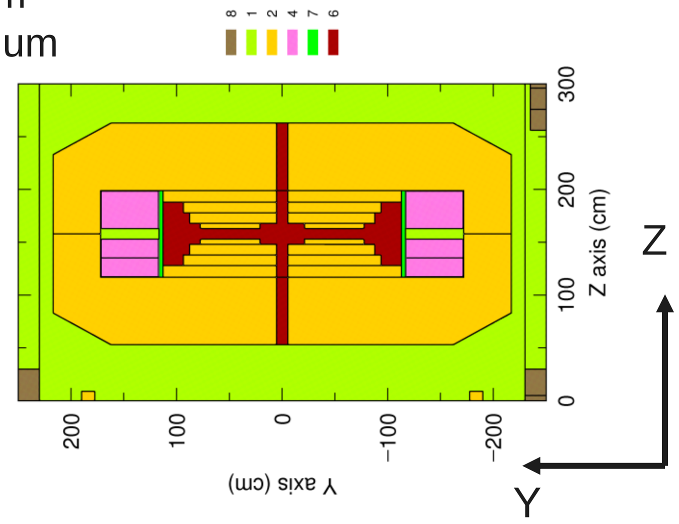
- The following slides show indeed that activation of Copper in a Proton Therapy cyclotron, presents some isotopes being indeed above clearance levels

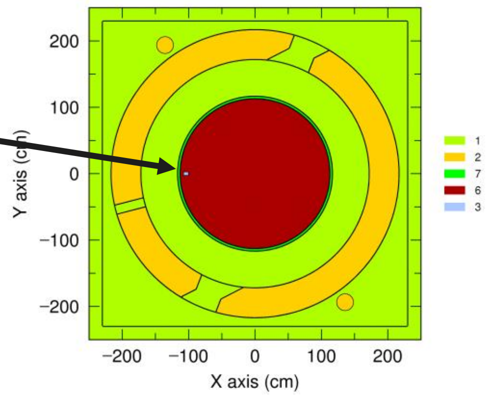
* a Belgian SME based in Gent and Brussels

Cyclone®230 Modelling (2)

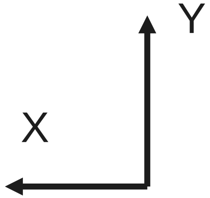


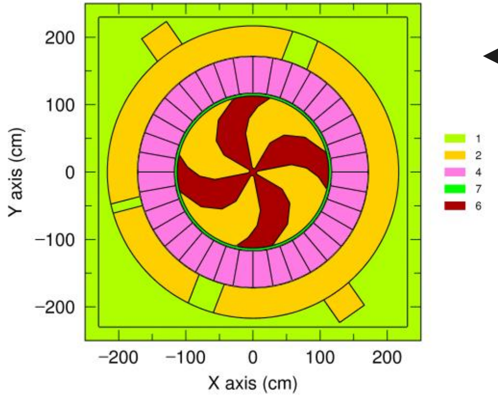
1 = Air
2 = Steel
3 = Copper
4 = Coil
6 = Vacuum
7 = Aluminum



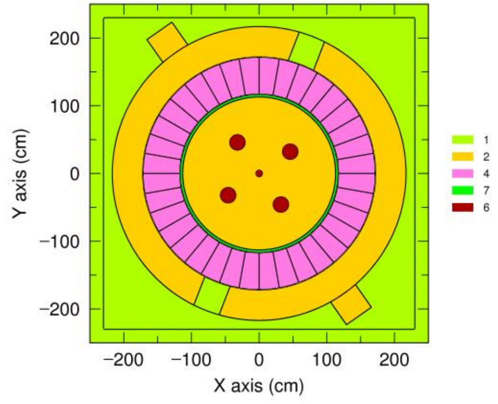


A-A
(median plane)



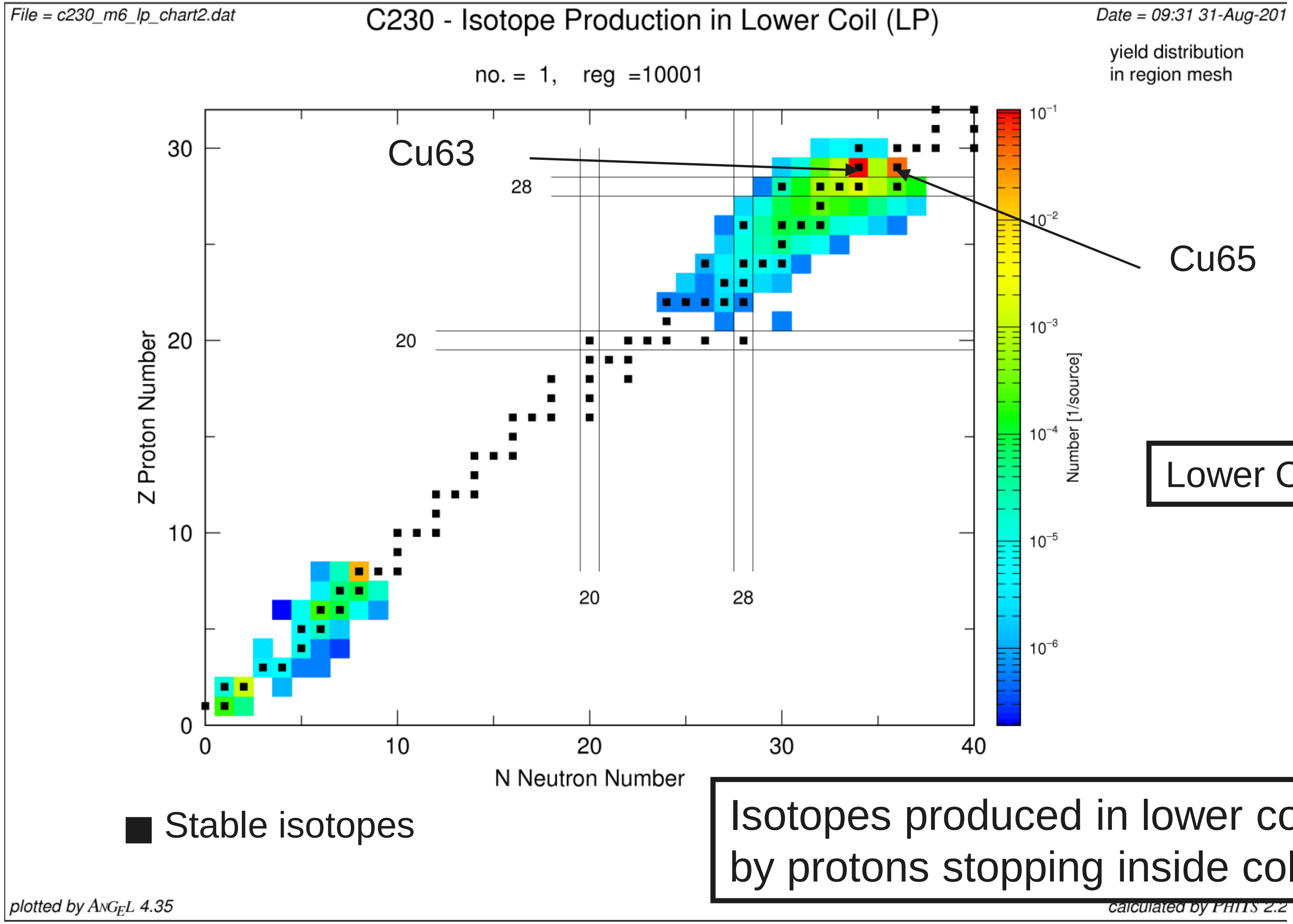


B-B
(upper coil)



C-C
(lower coil)

Generated Isotopes



Isotopes produced in lower coil by protons stopping inside collimator

Results for Upper Coil

Isotope	A_{total} (Bq)	$A_{specific}$ (Bq/g)	A/CL
^{7}Be	$0.110\ 10^{6}$	$0.192\ 10^{-1}$	$0.192\ 10^{-2}$
^{51}Cr	$0.268\ 10^{6}$	$0.466\ 10^{-1}$	$0.466\ 10^{-3}$
^{54}Mn	$0.114\ 10^{7}$	0.199	1.99
^{55}Fe	$0.737\ 10^{6}$	0.128	$0.128\ 10^{-3}$
^{56}Co	$0.605\ 10^{6}$	0.105	1.05
^{57}Co	$0.352\ 10^{7}$	0.614	0.614
^{58}Co	$0.838\ 10^{7}$	1.46	1.46
^{60}Co	$0.200\ 10^{6}$	0.348	3.48
^{59}Ni	108.0	$0.188\ 10^{-4}$	$0.188\ 10^{-6}$
^{63}Ni	$0.579\ 10^{6}$	0.101	$0.101\ 10^{-2}$
^{65}Zn	$0.619\ 10^{5}$	$0.108\ 10^{-1}$	0.108

Σ A/CL = 8.70 +- 1.96

Summary

Summary: heat load and activation may be a problem, degradation of perf. not

Application	Particle	Energy (MeV)	Typical beam current (on target)	Machine load (beam time)	IBA machine	Typical annual dose to equipment	Typical dose on (SC) coils	Activation
Sterilization, food, material processing…	Electron (=>Xrays)	7-10	70 mA	24/7	Rhodotron			
PET Radioisotopes	Protons	9-18	100-300 µA	3-12 h/day	Cyclone®Key Cyclone®Kiube	~250 Gy/y (at least)		
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Theranostics	Electrons (=>Xrays)	40	3 mA	3-12 h/day	Rhodotron	25 kGy/y 25 MGy/y		
Proton Therapy*	Protons	230	2-4 nA	~1 h/day**	ProteusPlus (C230) and Proteus One (S2C2)	10-100 Gy/y	1.8 kGy/y (55 kGy - 30 years)	^{207}Bi - ^{63}Ni ^{60}Co - ^{137}Cs $^{108\text{-}110m}$Ag …??
Carbon Therapy	Carbon (and Helium)	4800 (920)	2-4 nA	~1 h/day**	C400 (NHa)		122 Gy/y (4.7 kGy - 30 years)	

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Thank you!

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