

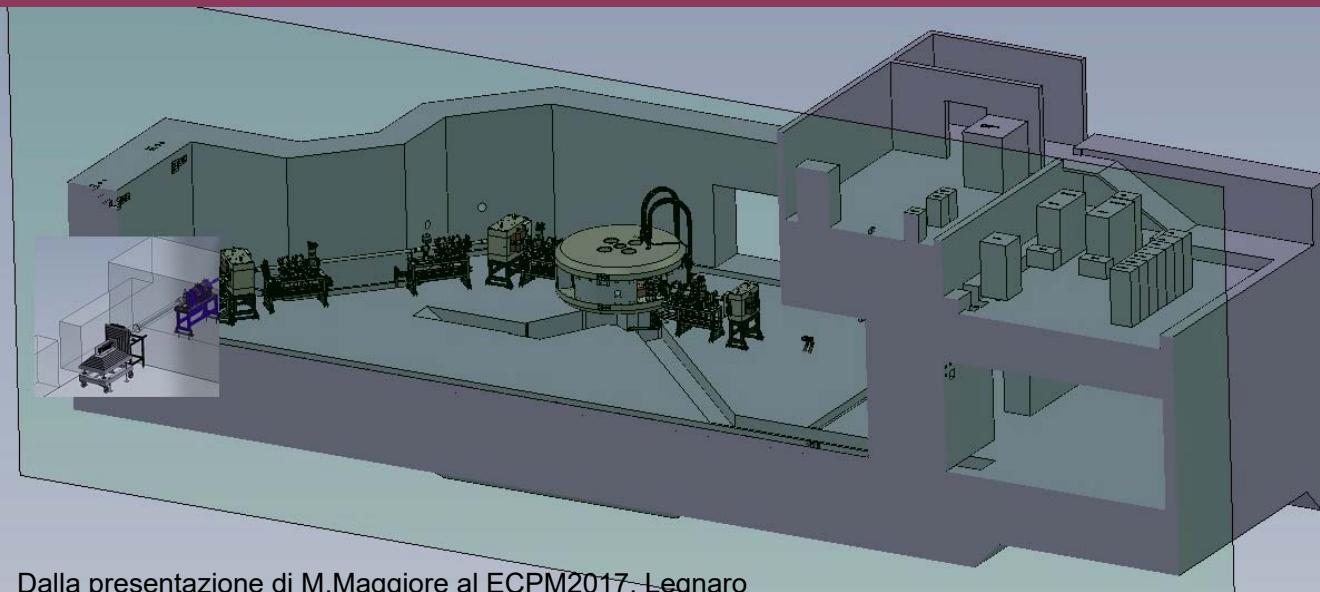
A photograph of a large, complex scientific instrument, specifically a cyclotron, housed within a massive metal vacuum chamber. The chamber is supported by a network of steel beams and has a thick, dark grey or black exterior. In the foreground, a bright yellow safety barrier or walkway is visible, along with a person's arm and hand reaching towards the machine. The background shows more of the cyclotron's internal structure, including copper-coated accelerating tubes and various mechanical components.

# Radiation Protection at LNL's 70 MeV cyclotron

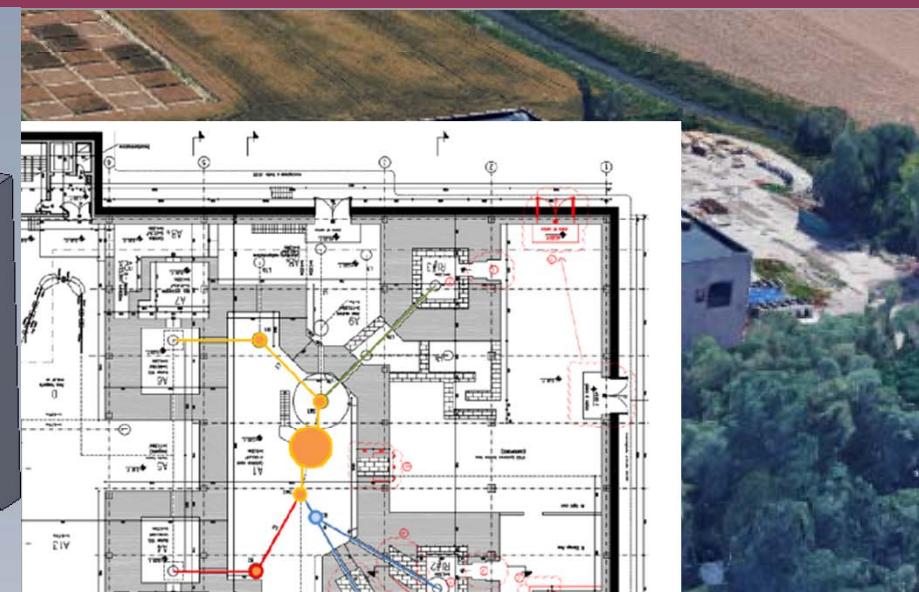
# *Summary*

- SPES Project at LNL
- New proton cyclotron of 70 MeV energy and 750 microA current
- Nuclear safety aspects
- Aspects preliminary evaluated:
  - Doses in different cyclotron irradiation areas
  - Cyclotron and beam line induced radioactivity
  - Environmental impact
- Commissioning of the cyclotron: measurement campaign

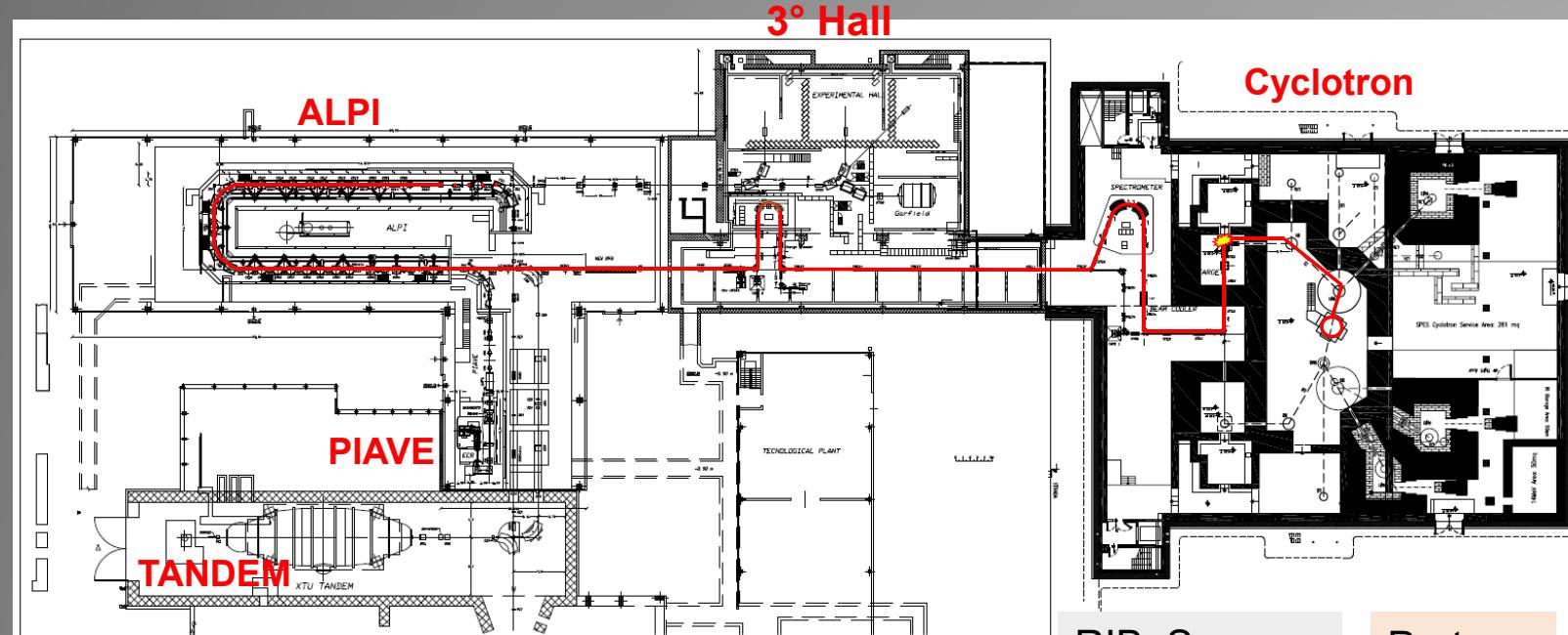
# SPES Project



Dalla presentazione di M.Maggiore al ECPM2017, Legnaro



# The SPES Project and the Cyclotron



RIB: Sn-  
132<sup>+n</sup>, I-  
135<sup>+n</sup>, 9  
MeV/amu

RIB: Sn-132<sup>+n</sup>,  
I-135<sup>+n</sup>, ...  
up to 40 kV

RIB: Sn-  
132<sup>+1</sup>, I-  
135<sup>+1</sup>, ...  
up to 40 kV  
according to  
mass

Protons  
, 40  
MeV  
200  $\mu$ A

# *Stages of the SPES Project*



Proton beam of 40 MeV and 200 uA

Direct fission on  $\text{Uc}_x$  target

Ionization of the fission products

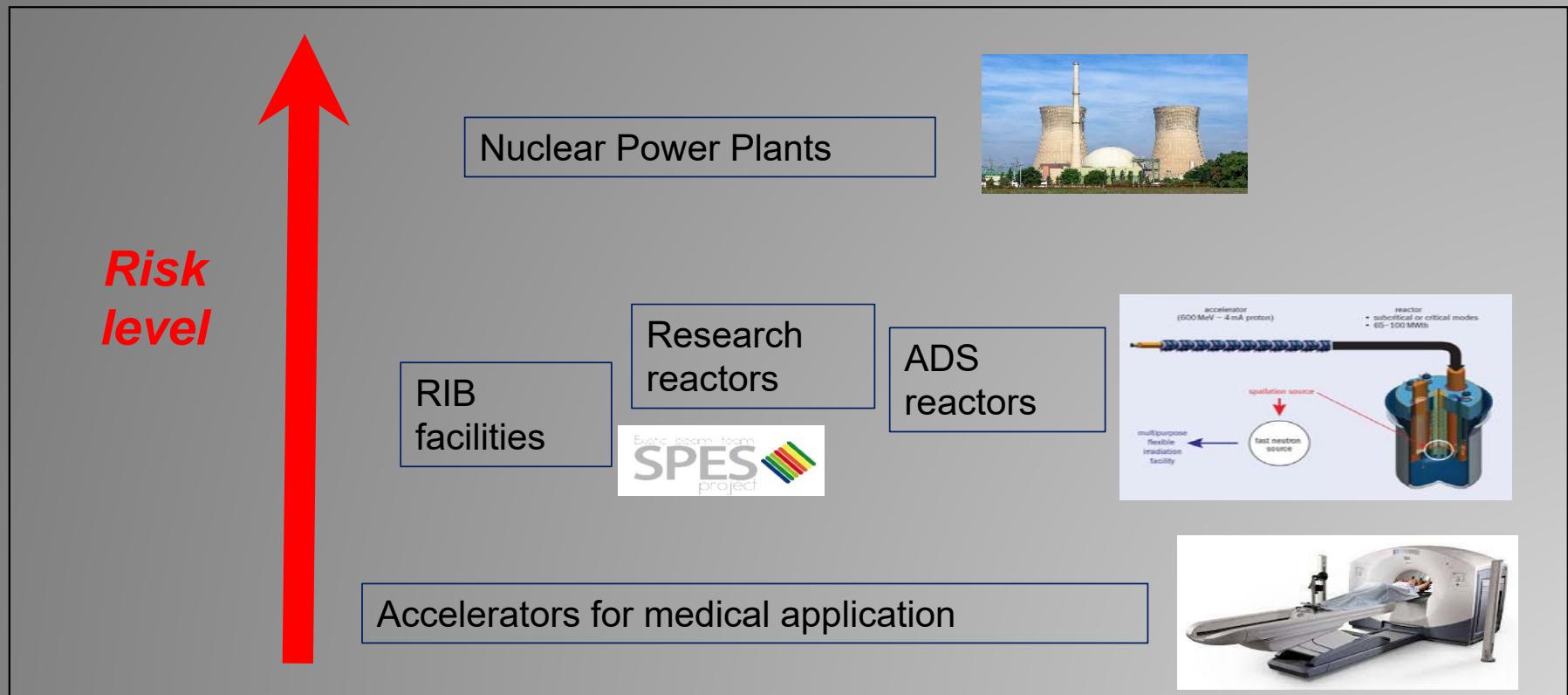
Selection of the beam of interest and increase of his charge

Ri-acceleration of the RIB

# Nuclear safety for accelerator facilities

# *Nuclear safety and SPES*

*Deterministic and probabilistic analysis of safety in particle accelerators - Sakar*



## *Why nuclear safety?*

ADS and RIB facilities are based on medium (or high) energy, high intensity particle accelerators producing large fluence of neutrons and gammas. The major radiation safety considerations for these facilities can be broadly classified in two parts:

1. To protect the public from radiation hazards (for which we have to take into consideration skyshine, release of toxic gases in the environment, soil and groundwater activation)
2. To maintain hazards within limits for radiation workers (for this we have to consider bulk shielding, streaming of radiation through ducts and penetrations, induced activity in target, air, cooling water, walls and accelerator structures).

## *Why nuclear safety?*

The radioactive ion production target is hot from radiological point of view and shows out gassing, but at the same time ionized species, in particular fission products are extracted. To safely confine and control the radioactive inventory of this open source special efforts are required.



### **NUCLEAR SAFETY**

- Analysis techniques
- Technical solutions

# **Nuclear safety objective**

“Readjusted from INSAG – 12”

**General Safety Objective:** To protect individuals, society and the environment by establishing and maintaining in nuclear facilities an effective defence against radiological hazard.

## **Radiation Protection Objective:**

- to ensure in normal operation that radiation exposure within the plant and due to any release of radioactive material from the plant is kept **as low as reasonably achievable** and below prescribed limits
- to ensure **mitigation** of the extent of radiation exposures due to accident

## **Technical Safety Objective:**

- to prevent with high confidence accidents in nuclear facilities;
- to ensure that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor;
- to ensure that the likelihood of **severe accidents** with serious radiological consequences is extremely small

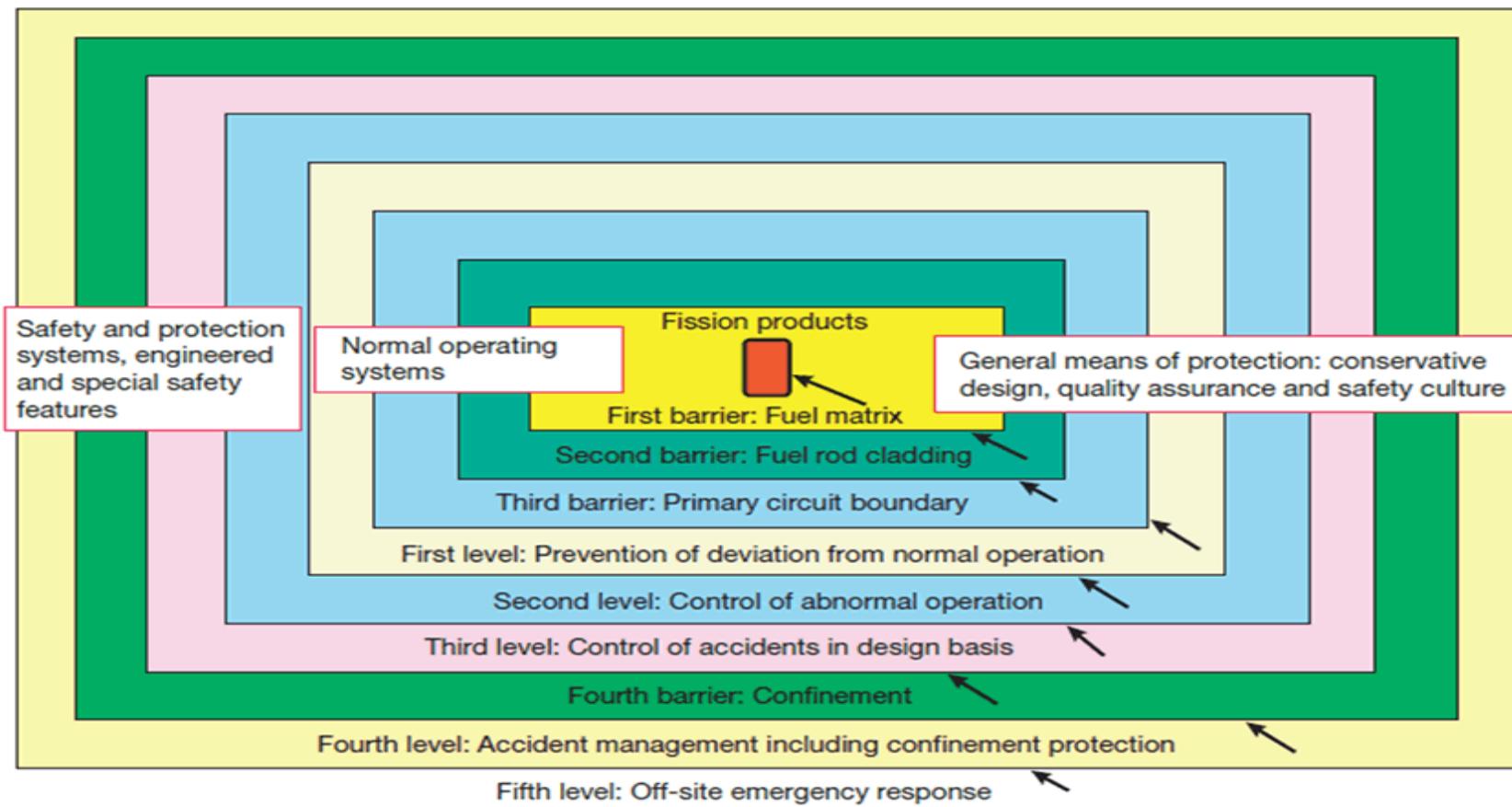
## *How to implement it?*

Nuclear safety golden rule: the **defence in depth**

- Def: to provide multiple independent protections, against the occurrence of accidents and their progression, in such a way that, should one of them fail, at least another is present and its failure is independent from the operation of the first.

It is implemented through design and operation provisions in a way to provide a “graded” protection against a vast variety of transients, abnormal events and accidents, including the malfunction of components, human errors.

# *Defence in depth*



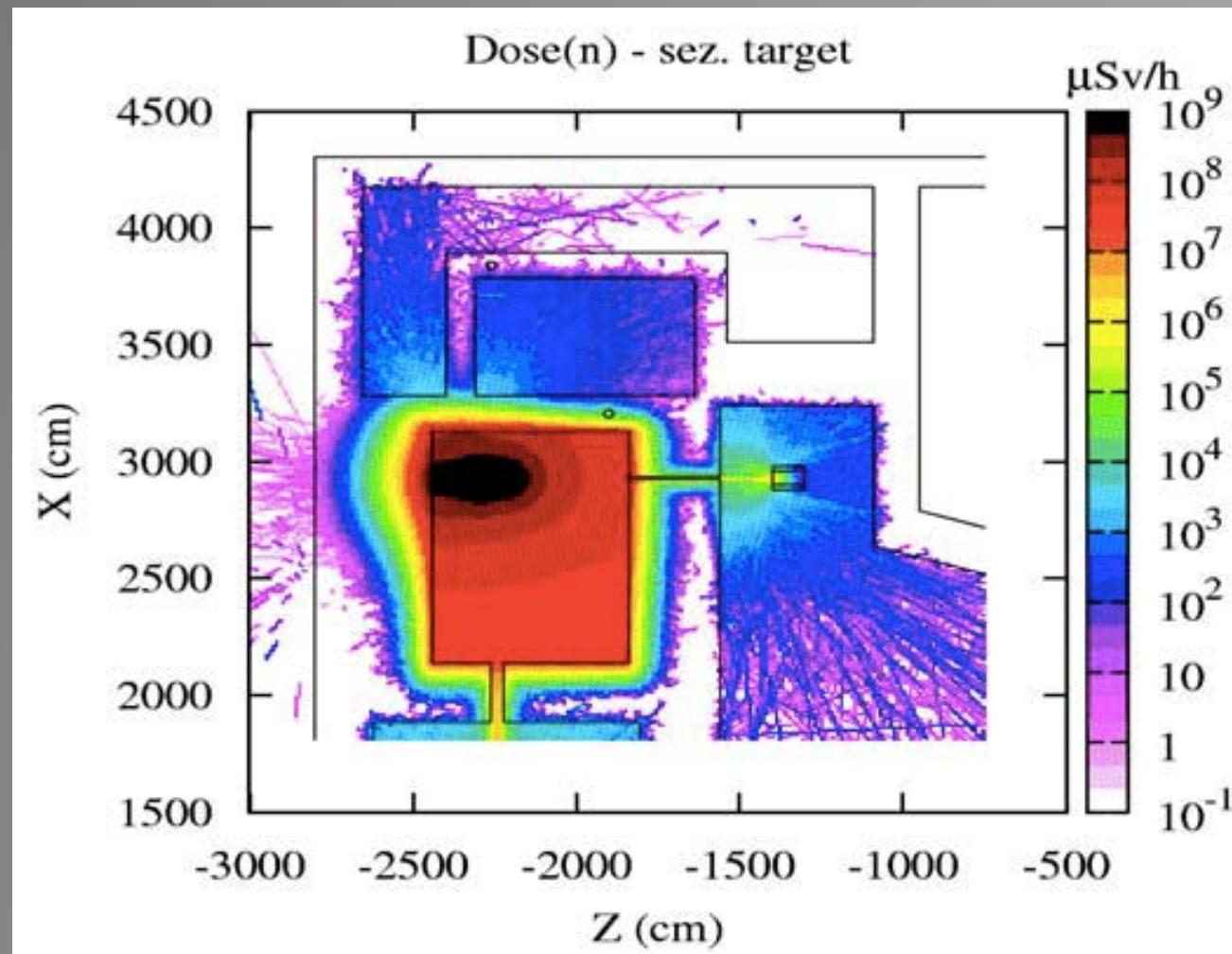
## **Defence level**

Defence level	objective	how
<b>Level 1</b>	Prevention of abnormal operation and of malfunctions (Defense level)	Conservative design and high quality of construction and of operation
<b>Level 2</b>	Control of abnormal operation and detection of malfunctions (Defense level)	Control, limitation and protection systems and other surveillance characteristics
<b>Level 3</b>	Control of accidents included in the Design Basis Accident	Engineered safety systems and accident procedures
<b>Level 4</b>	Control of the severe accident conditions of the plant, including the prevention of accident progression and mitigation of consequences.	Additional measures and accident management in site
<b>Level 5</b>	Mitigation of the radiological consequences of significant releases of radioactive products	External site emergency plan

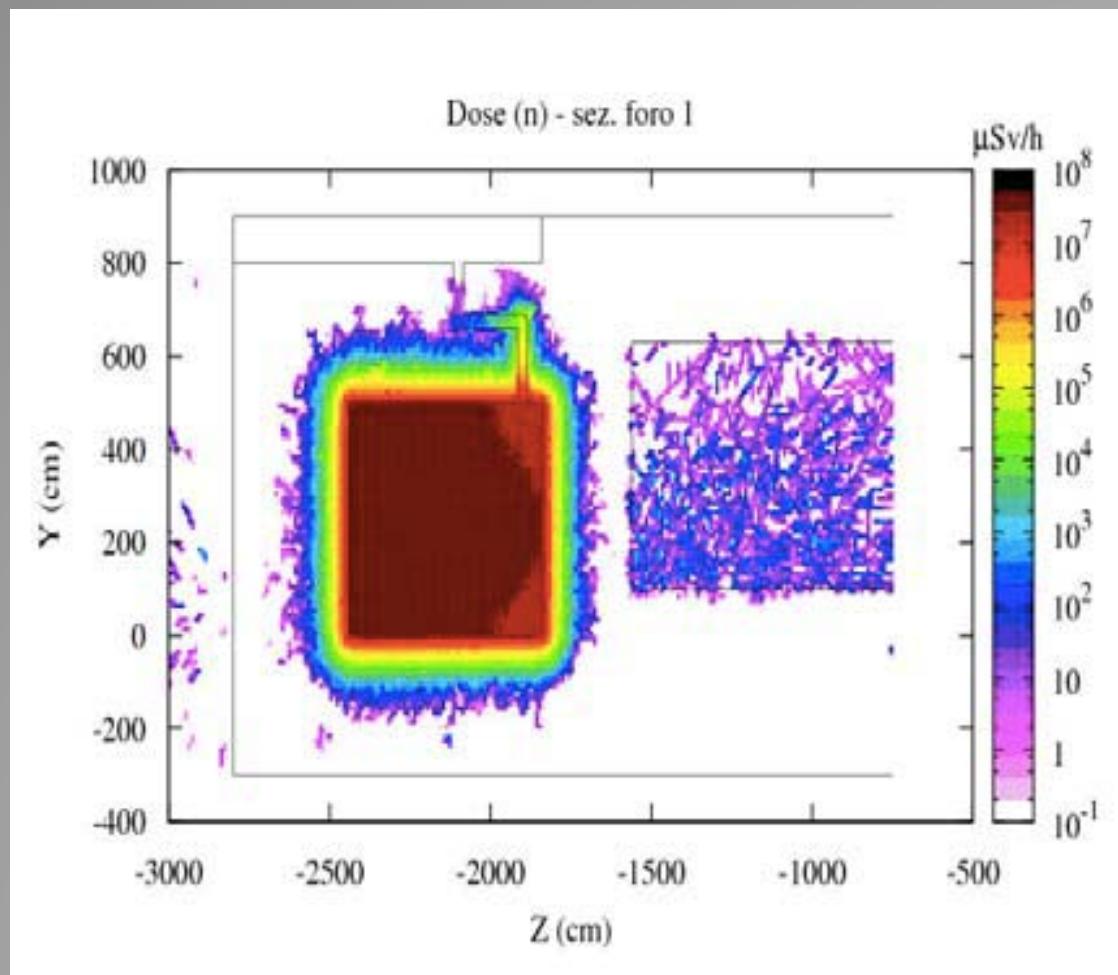
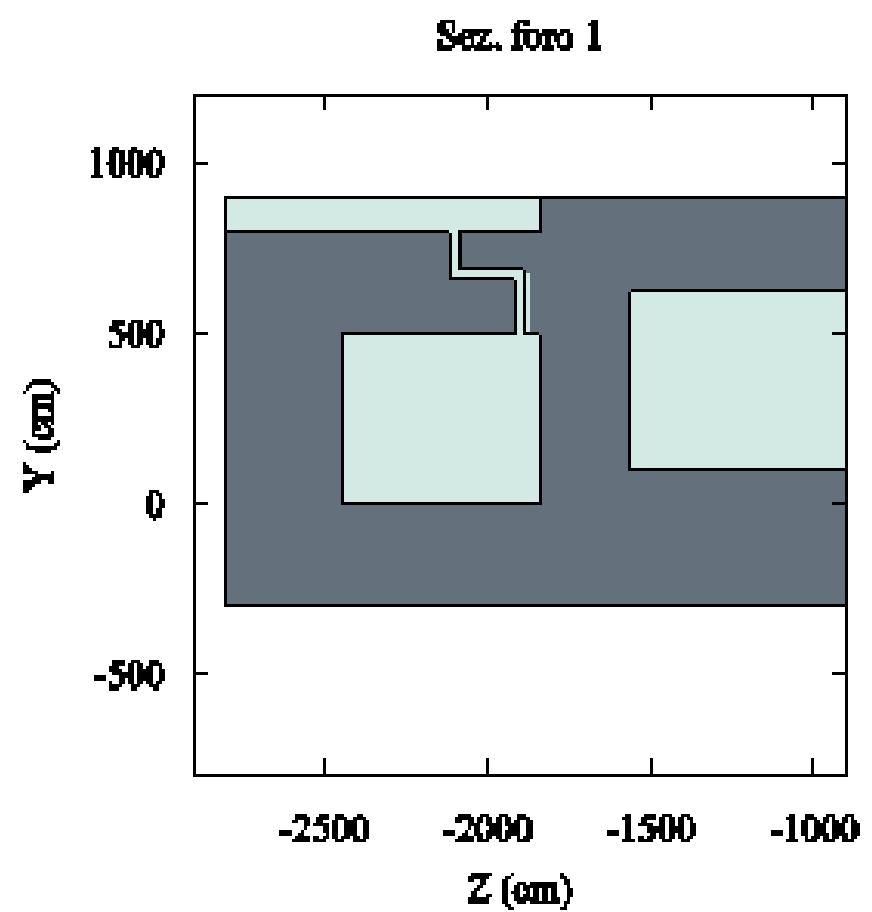
# TOOLS AND INSTRUMENTATION USED FOR SHIELDING CALCULATIONS AND CYCLOTRON COMMISSIONING

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# FLUKA MONTE CARLO CODE



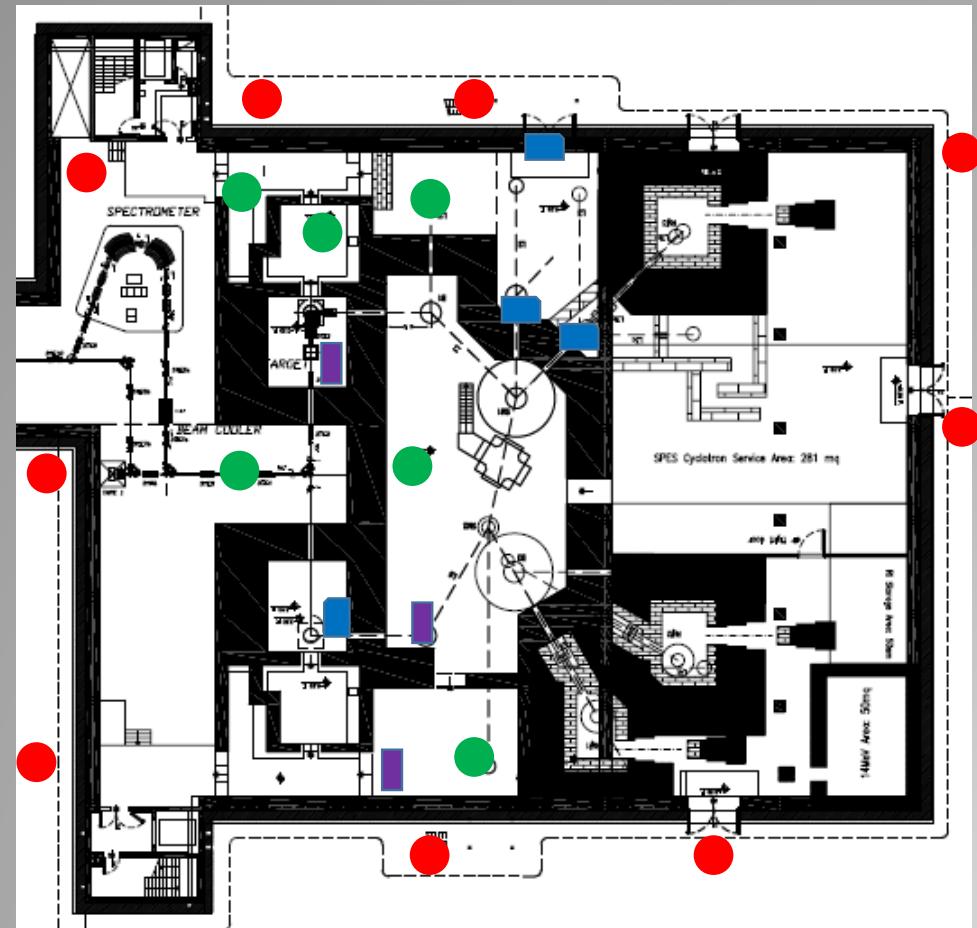
# FLUKA MONTE CARLO CODE



# *Monitoring plan and instrumentation*

Environmental monitoring: n-gamma mobile stations inside the building and passive neutron-gamma dosimeters on the building external perimeter

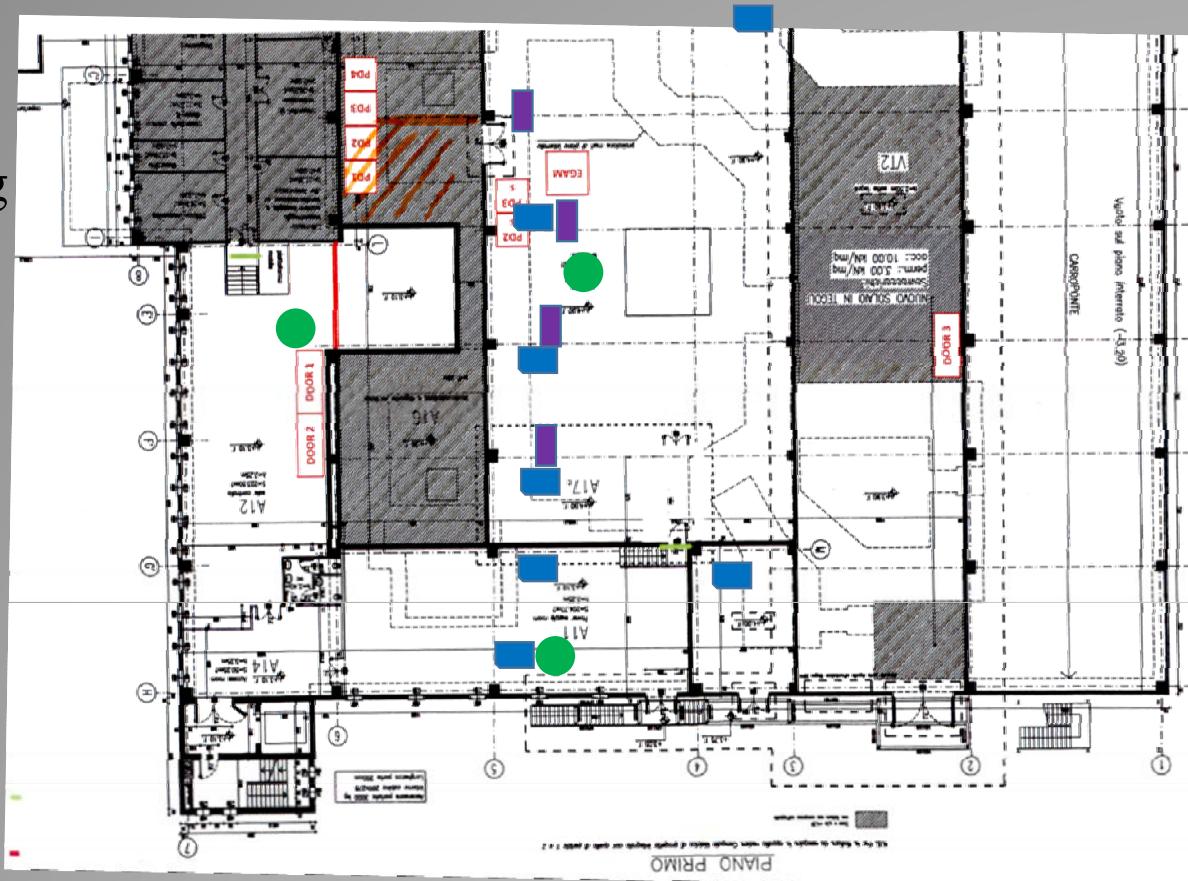
- Active n-gamma monitoring
- Passive neutron monitoring
- Passive n-gamma monitoring
- Active gamma monitoring



# *Monitoring plan and instrumentation*

Environmental monitoring: n-gamma stations inside the building and passive neutron-gamma dosimeters on the building external perimeter

- Active n-gamma monitoring
- Passive neutron monitoring
- Passive n-gamma monitoring
- Active gamma monitoring



# *Monitoring plan and instrumentation*



**Ionization chamber**

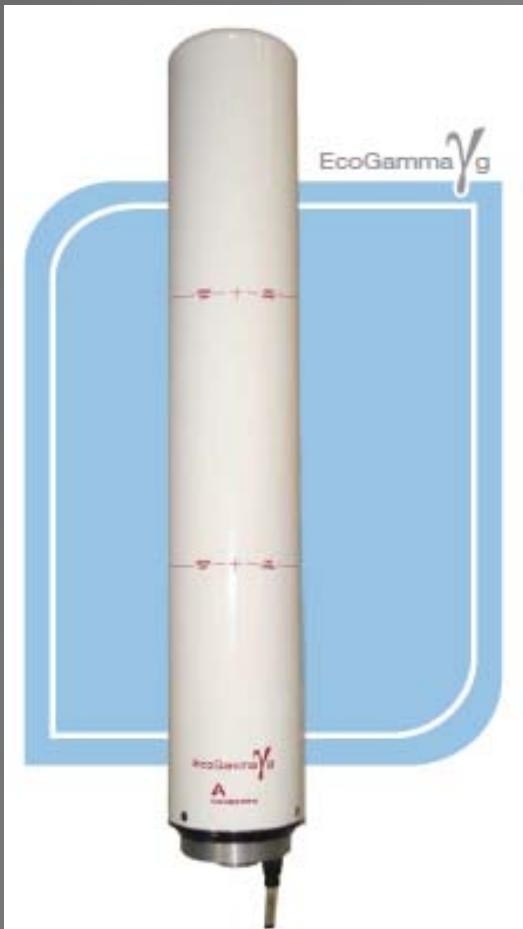
Measuring range 100 nSv/h– 1 Sv/h  
Energy range 30 keV – 7 MeV



**Wide Extended Neutron  
Detector Instrument**

Measuring range 1 nSv/h –  
100 mSv/h  
Energy range 25 meV – 5

# *Monitoring plan and instrumentation*



## Ecogamma

10 nSv/h – 10 Sv/h

High range and Low range Geiger Mueller  
detectors

30 keV – 5 MeV

Used in high radiation environments, such as  
target irradiation bunkers for eob information

## *Monitoring plan and instrumentation*

Passive and active (electronic) personal dosimeters. Finger dosimeters provided for “hands on” intervention



28 uSv in 4 months

operations (6 operators)



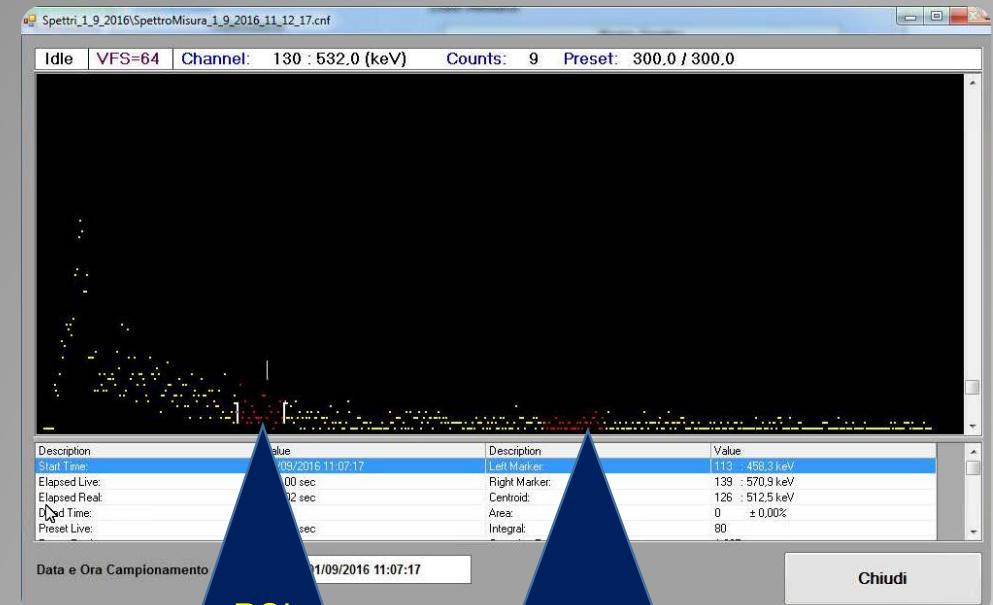
MIRION Technologies:  
immediate reading, only  
gamma dose at the moment



Thermoluminescent  
Dosimeter: provided for  
maintenance on activated  
parts of the cyclotron and  
beam line

# *Monitoring plan and instrumentation*

Spectrometric system for radioactivity concentration detection in air

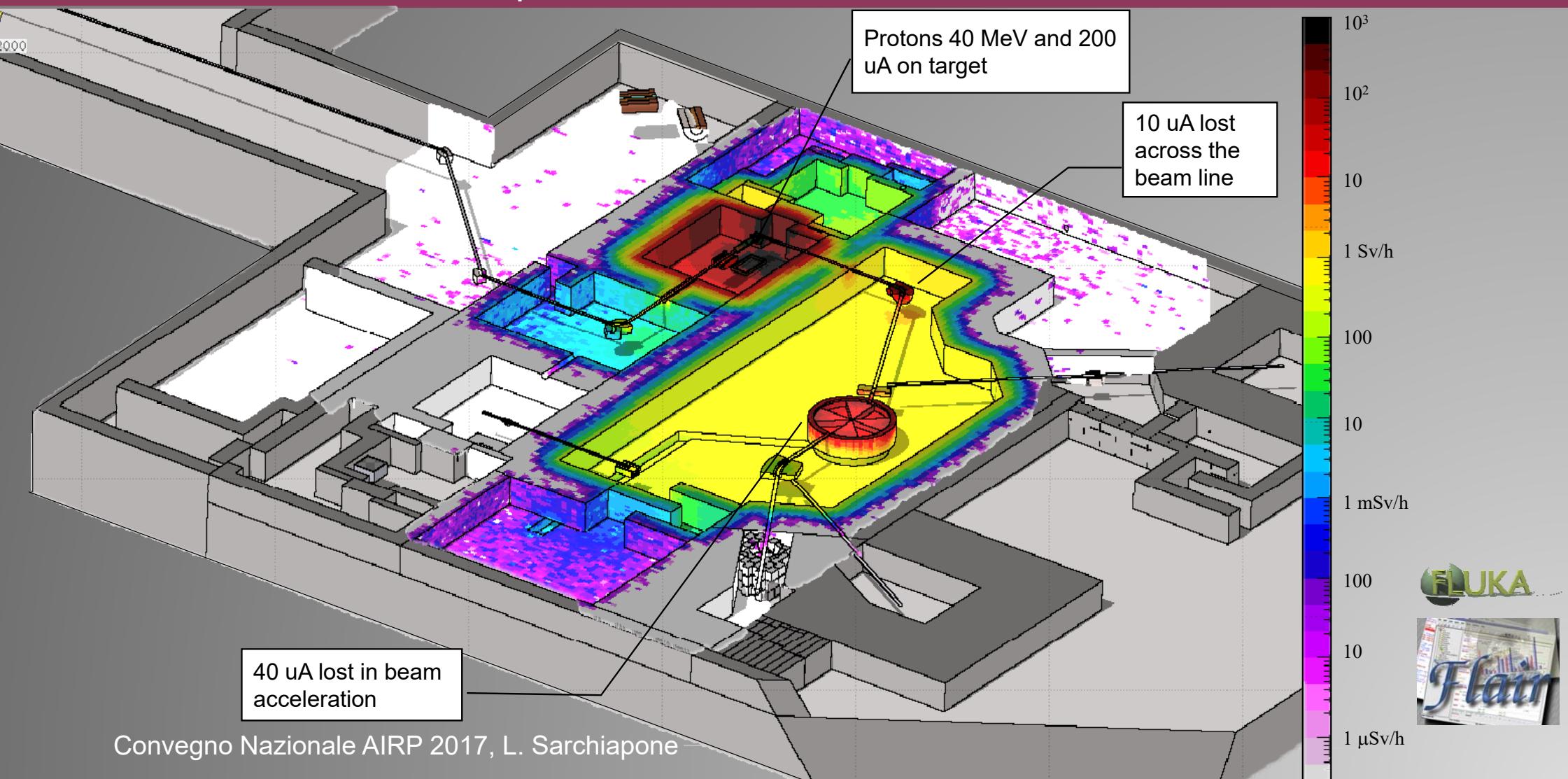


ROI  
1  
511  
keV

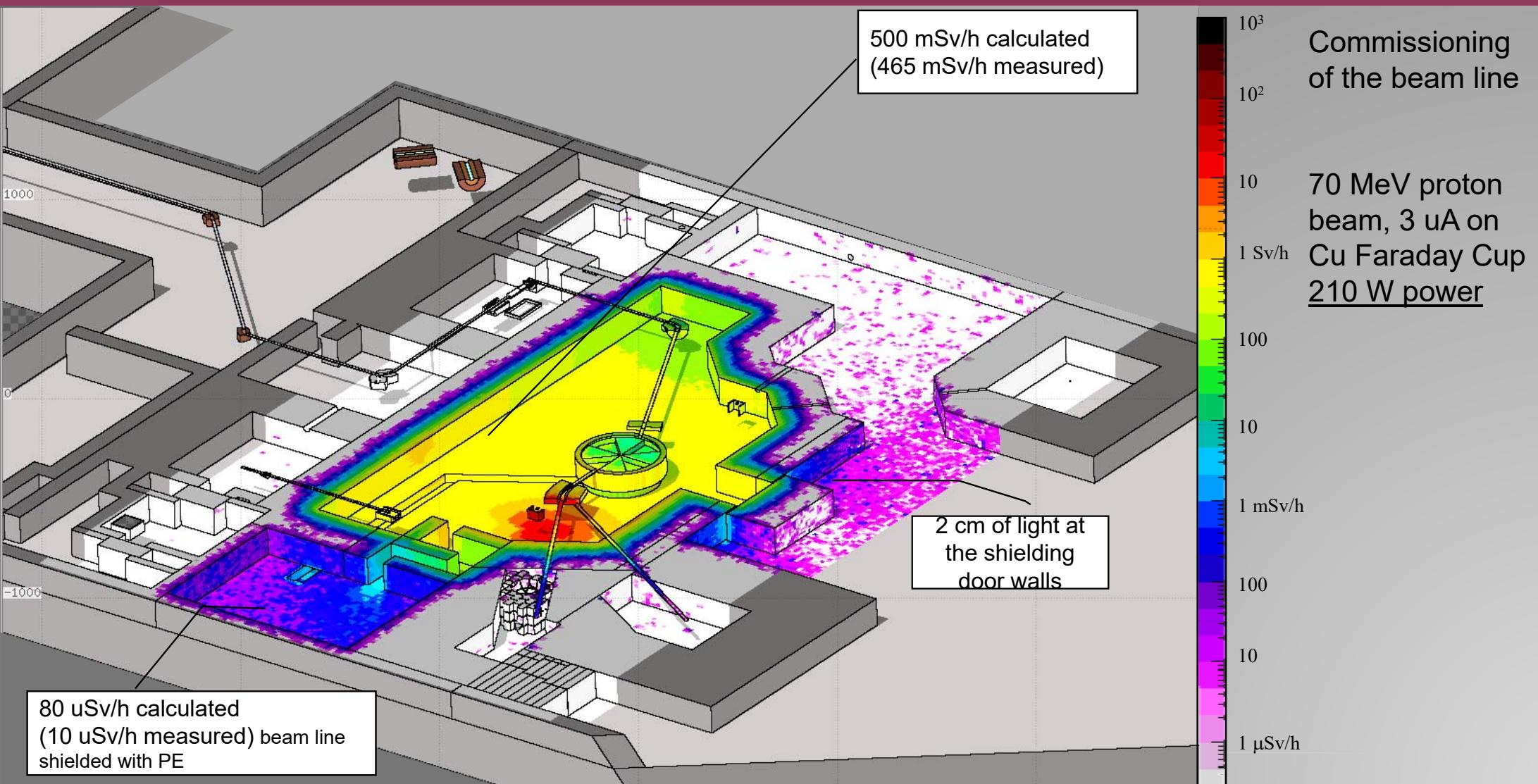
ROI 2  
1294  
keV

# Preliminary evaluations

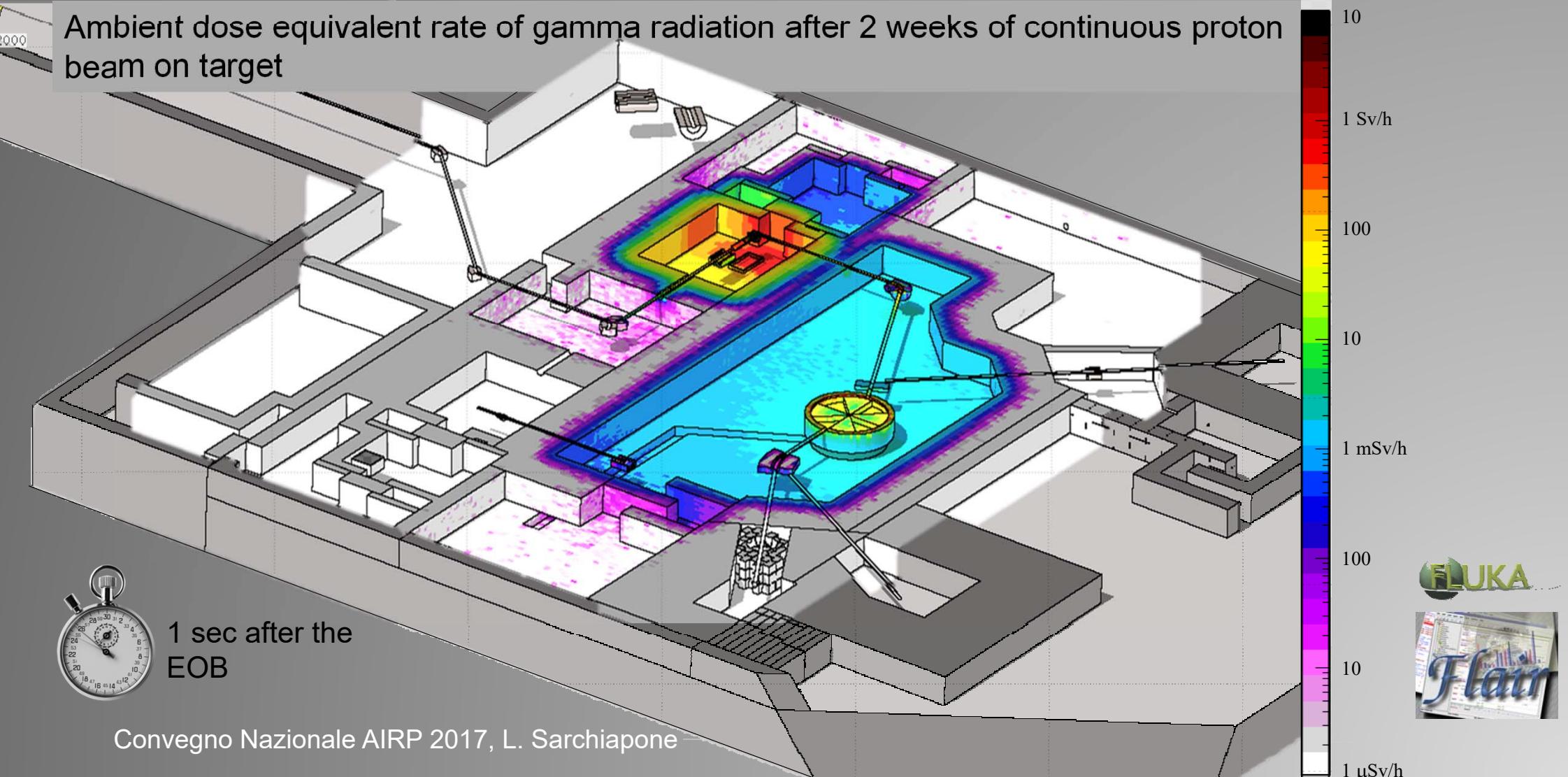
## Neutron ambient dose equivalent rate

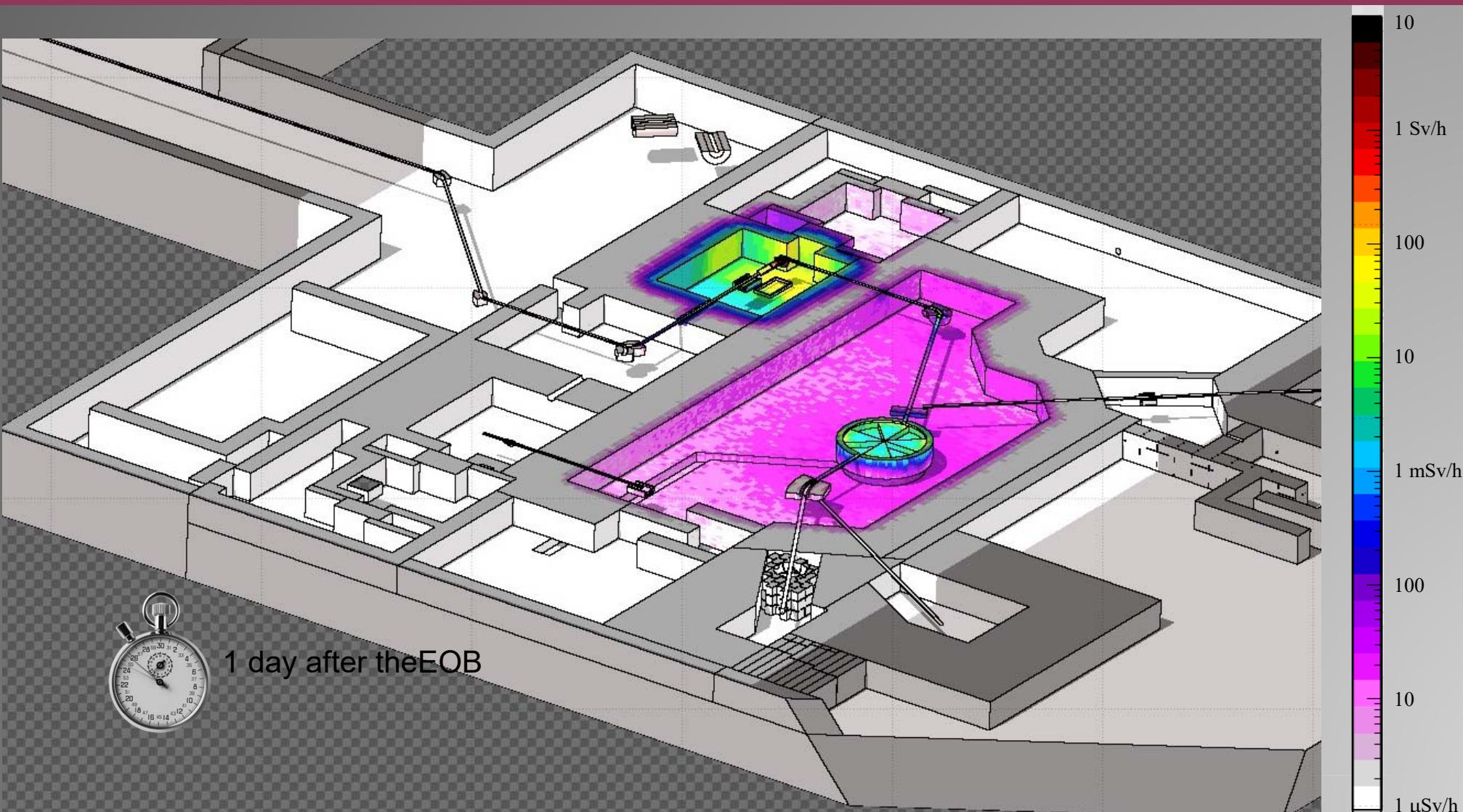


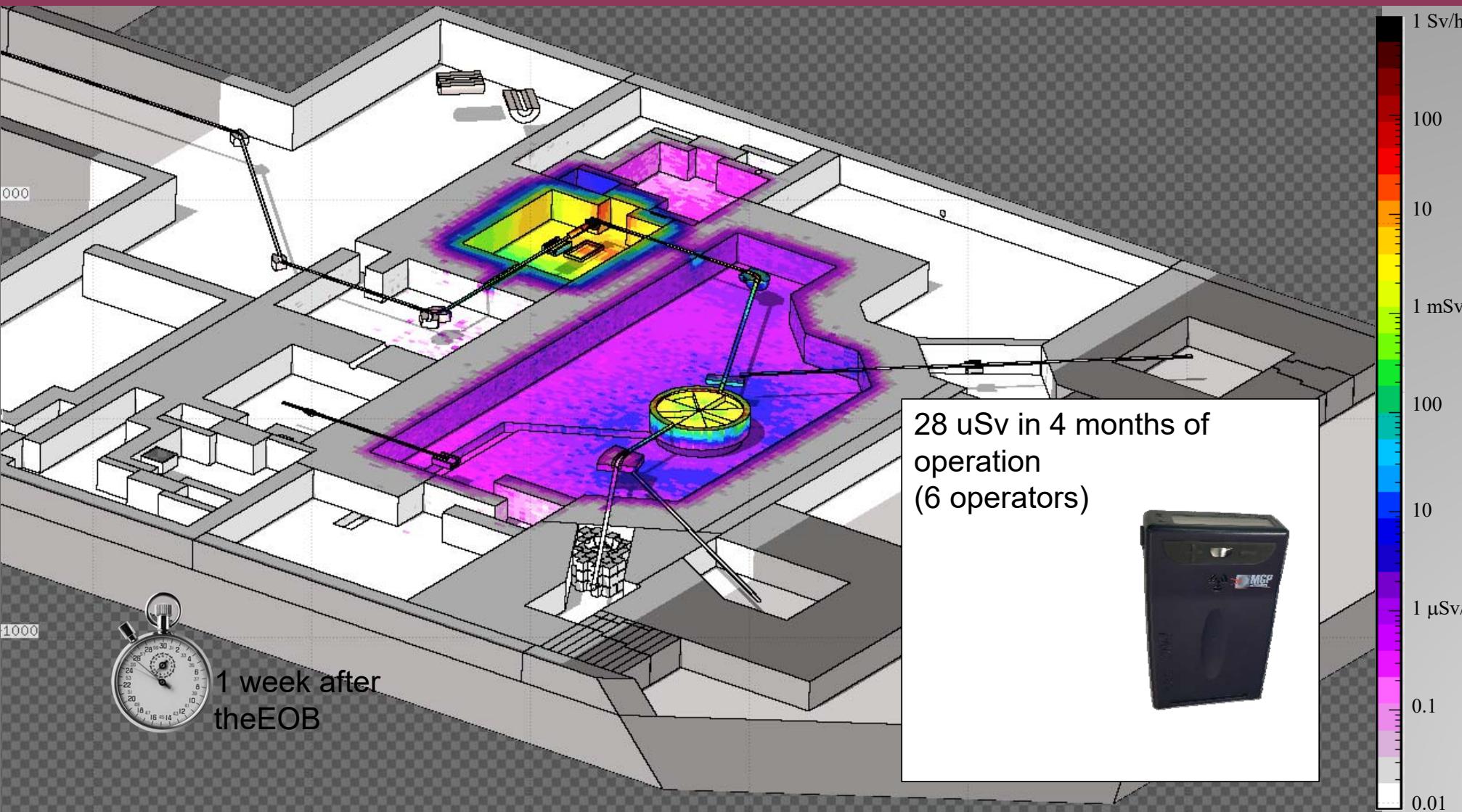
# Misure in fase di commissioning



Ambient dose equivalent rate of gamma radiation after 2 weeks of continuous proton beam on target







## *Air activation*



## Continuous air sampling and spectrometric analysis.

### Products of direct air activation detected

$\beta^+$  (511 keV),  $^{41}\text{Ar}$  (1293.64 keV)

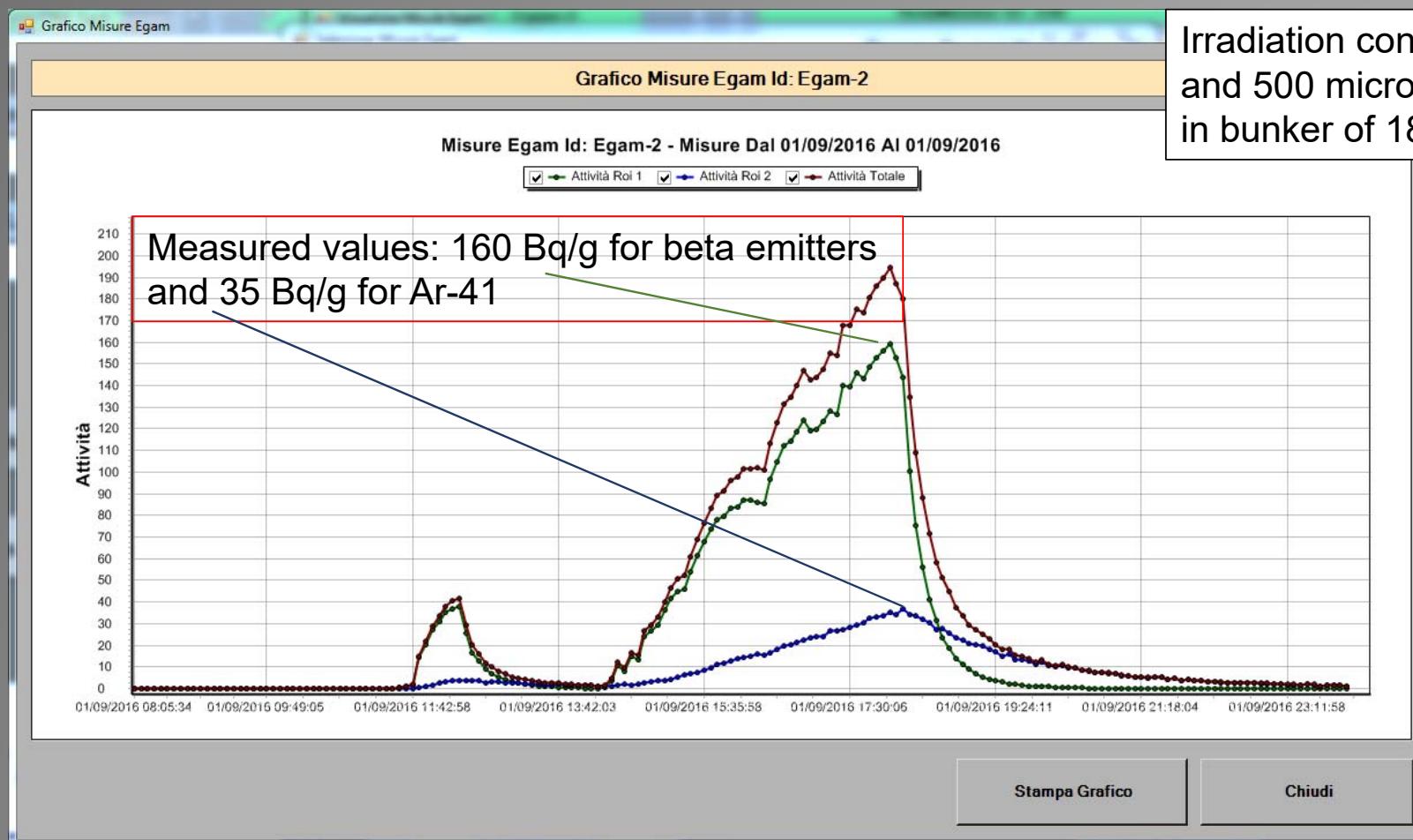
Sensitivity,  $f_z(t_{\text{sampling}})$ : 0.1-0.5 Bq/g<sub>air</sub>



Due instruments present at the site:

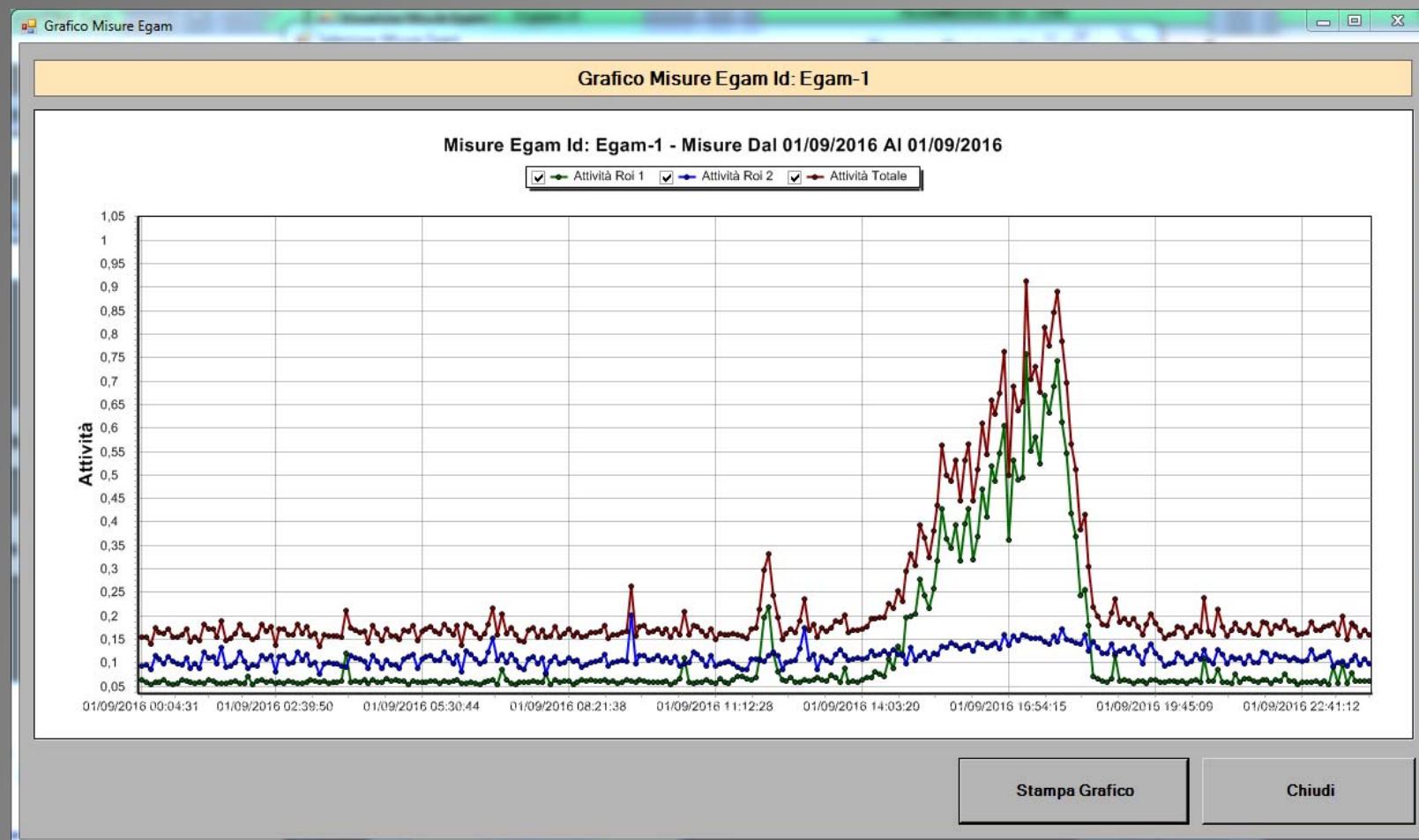
- One measure the emission in environment of the air coming from the facility
- The other measure directly the concentration of the radioactive gases produced in the irradiation bunker

# Air activation: data inside the irradiation bunker

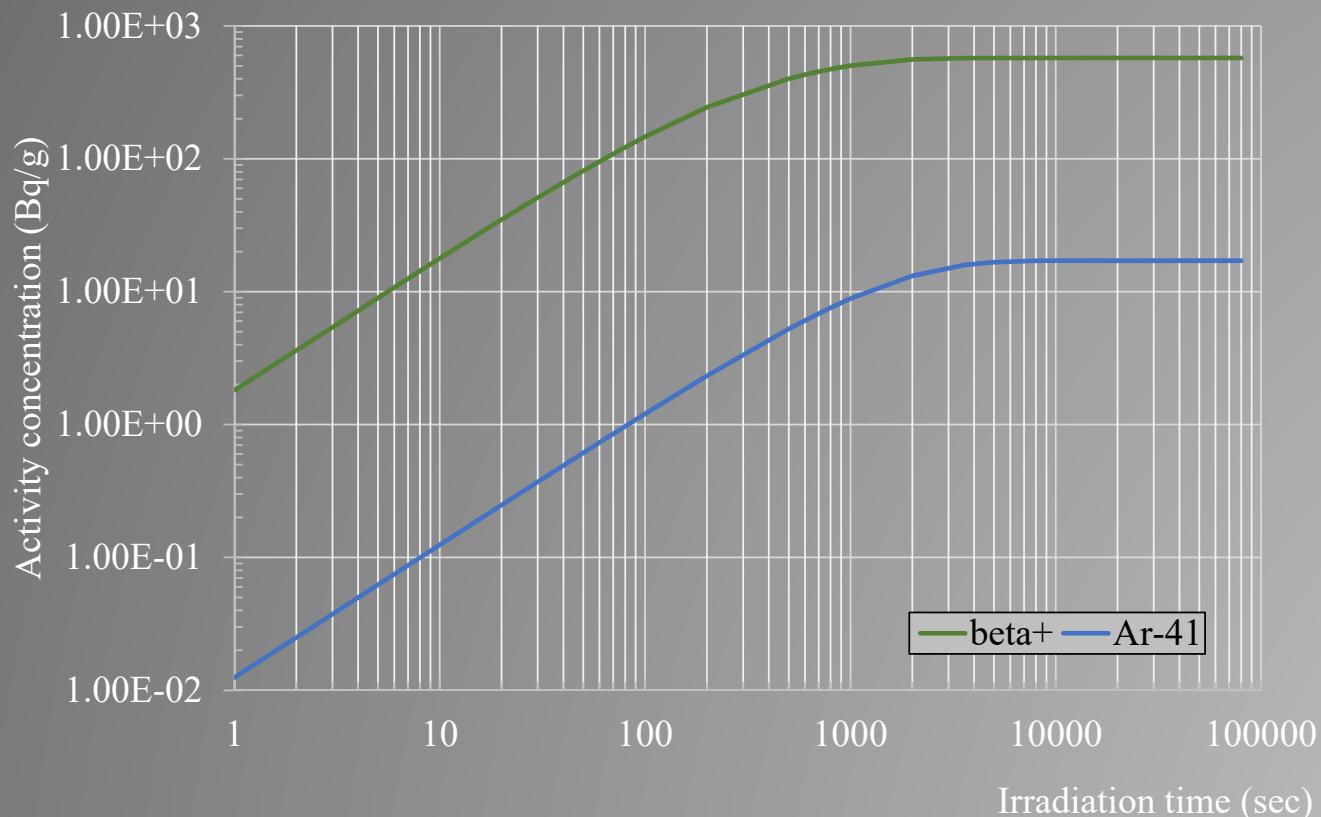


Irradiation conditions: 70 MeV and 500 microA, in BD located in bunker of 180 m<sup>3</sup> volume.

# *Air activation: data at the chimney*



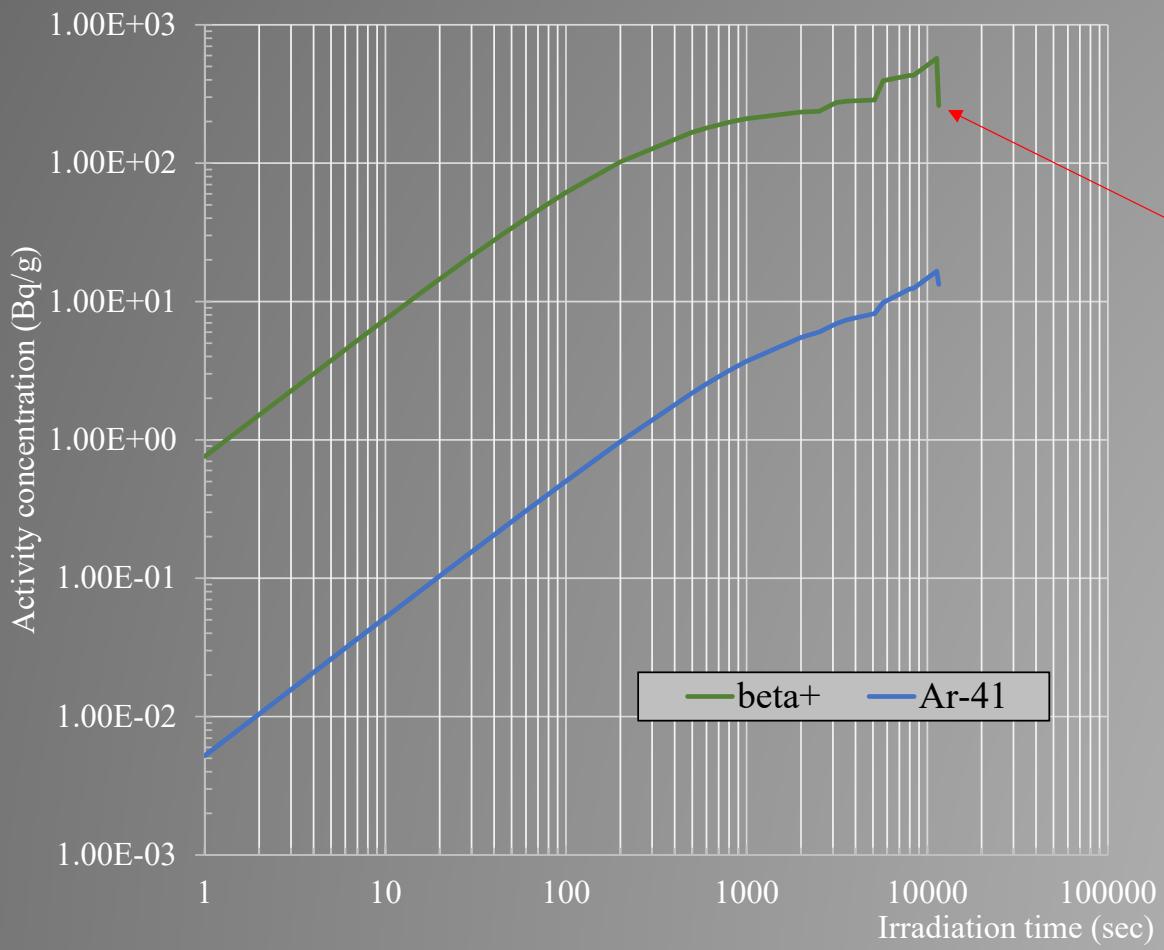
# Air activation: comparison of calculated data and measured ones



Irradiation conditions: 70 MeV  
and 500 microA, in BD located  
in bunker of 180 m<sup>3</sup> volume.

After 3 hours:  
Beta+: 705 Bq/g  
Ar-41: 21 Bq/g  
Calculated

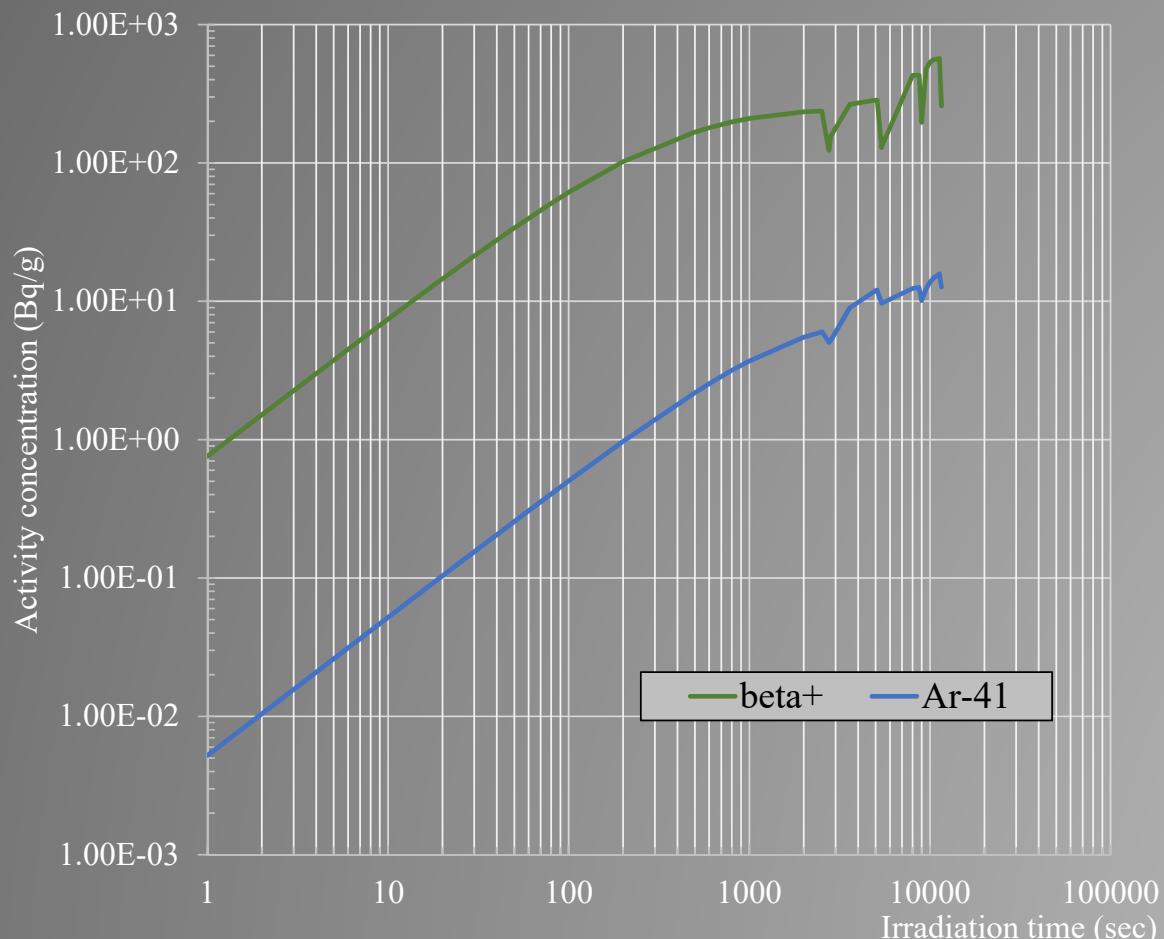
Measured: 160 Bq/g for beta and 35 Bq/g per Ar-41  
MORE INFO WE ADD MORE WE GO CLOSE TO THE  
MEASURED VALUES



Measured: 160 Bq/g for beta and 35 Bq/g per Ar-41

Continuous radiation with current ramp, 70 MeV and current from 170 to 407 microA (with 5 minutes decay to take into account the sampling time)

After 3 hours:  
Beta+: 261 Bq/g  
Ar-41: 13 Bq/g  
Calculated



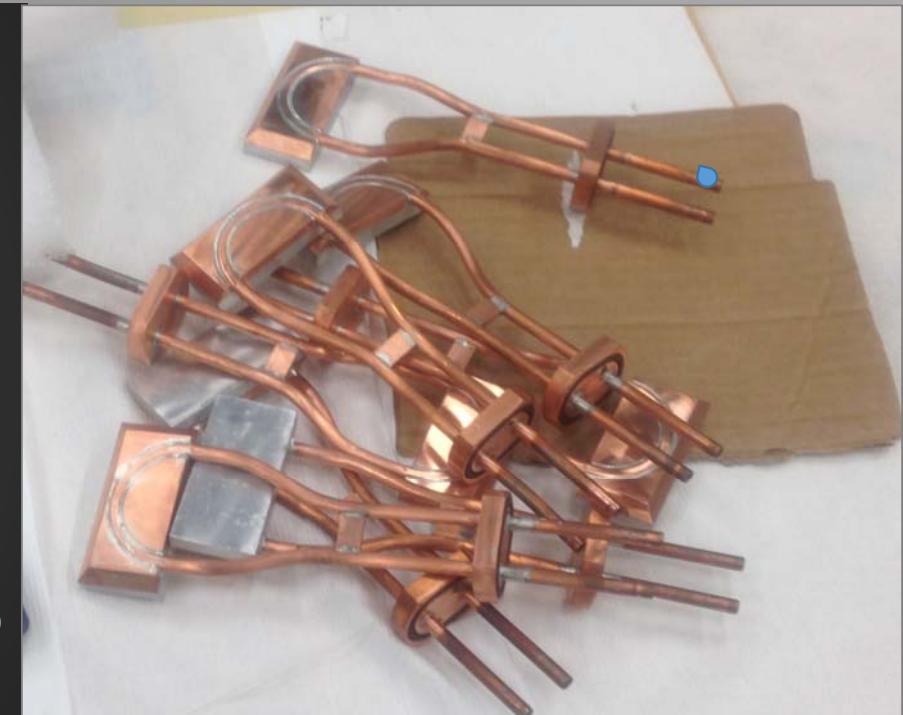
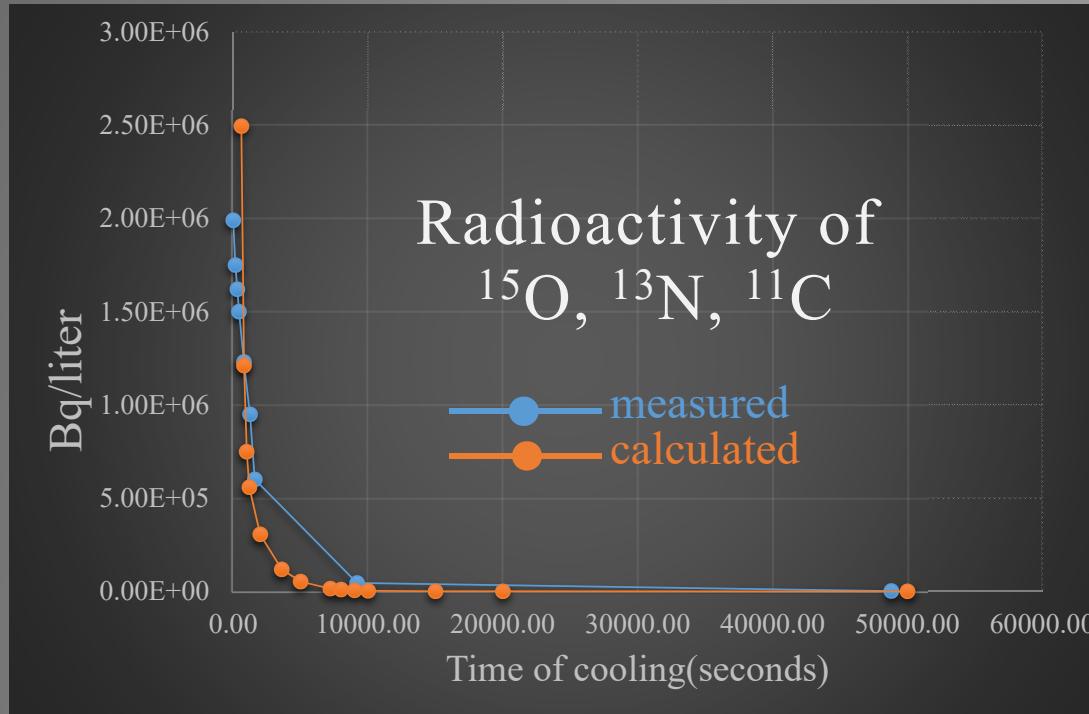
Measured: 160 Bq/g for beta and 35 Bq/g per Ar-41

Continuous radiation with current ramp, 70 MeV, current from 170 to 407 microA and 5 min stop beam at each current change (with 5-minute decay to account for sampling)

AFTER 3 hours:  
Beta+: 259 Bq/g  
Ar-41: 12.7 Bq/g

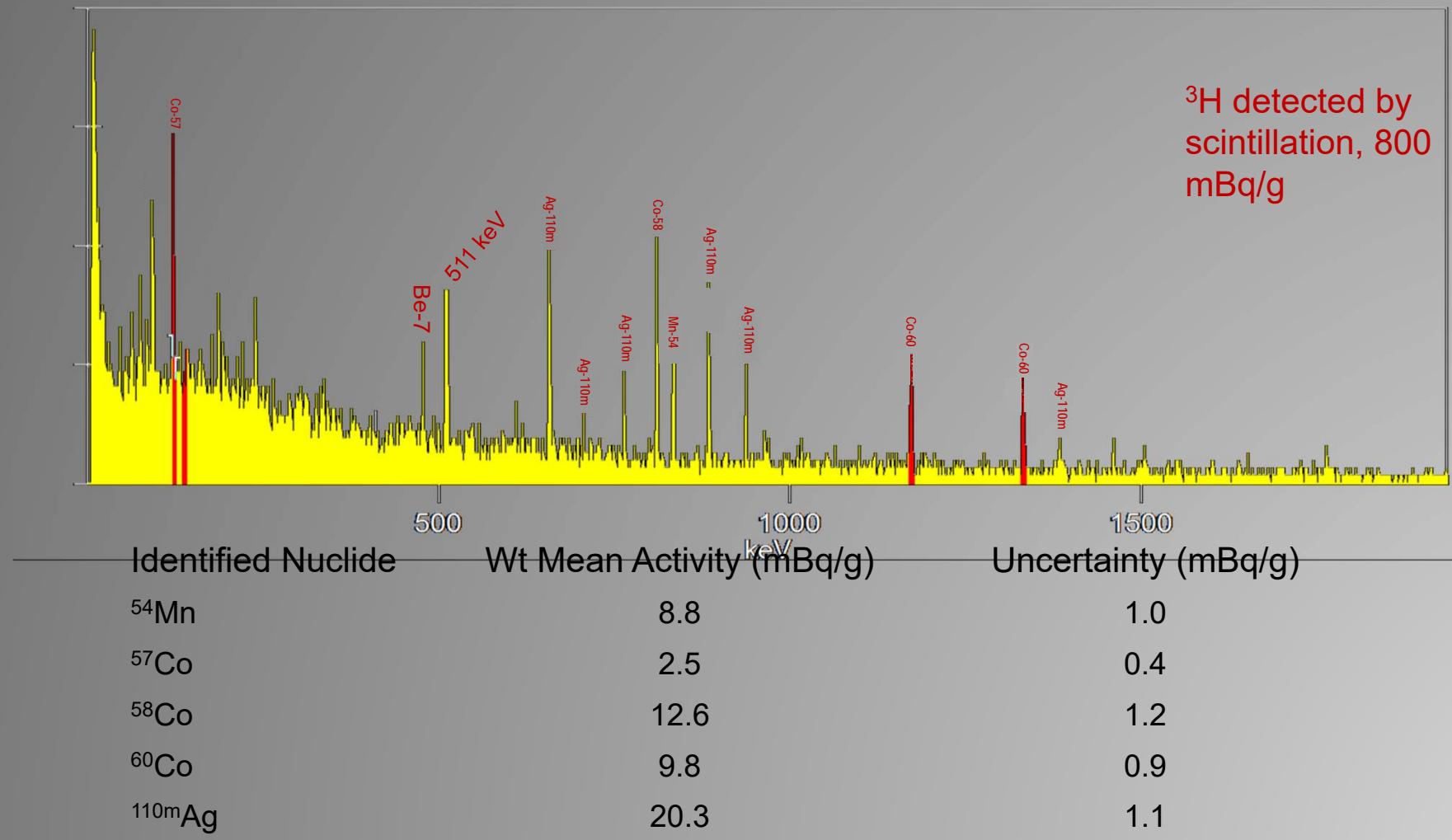
# *Cooling water activation of the cyclotron probe*

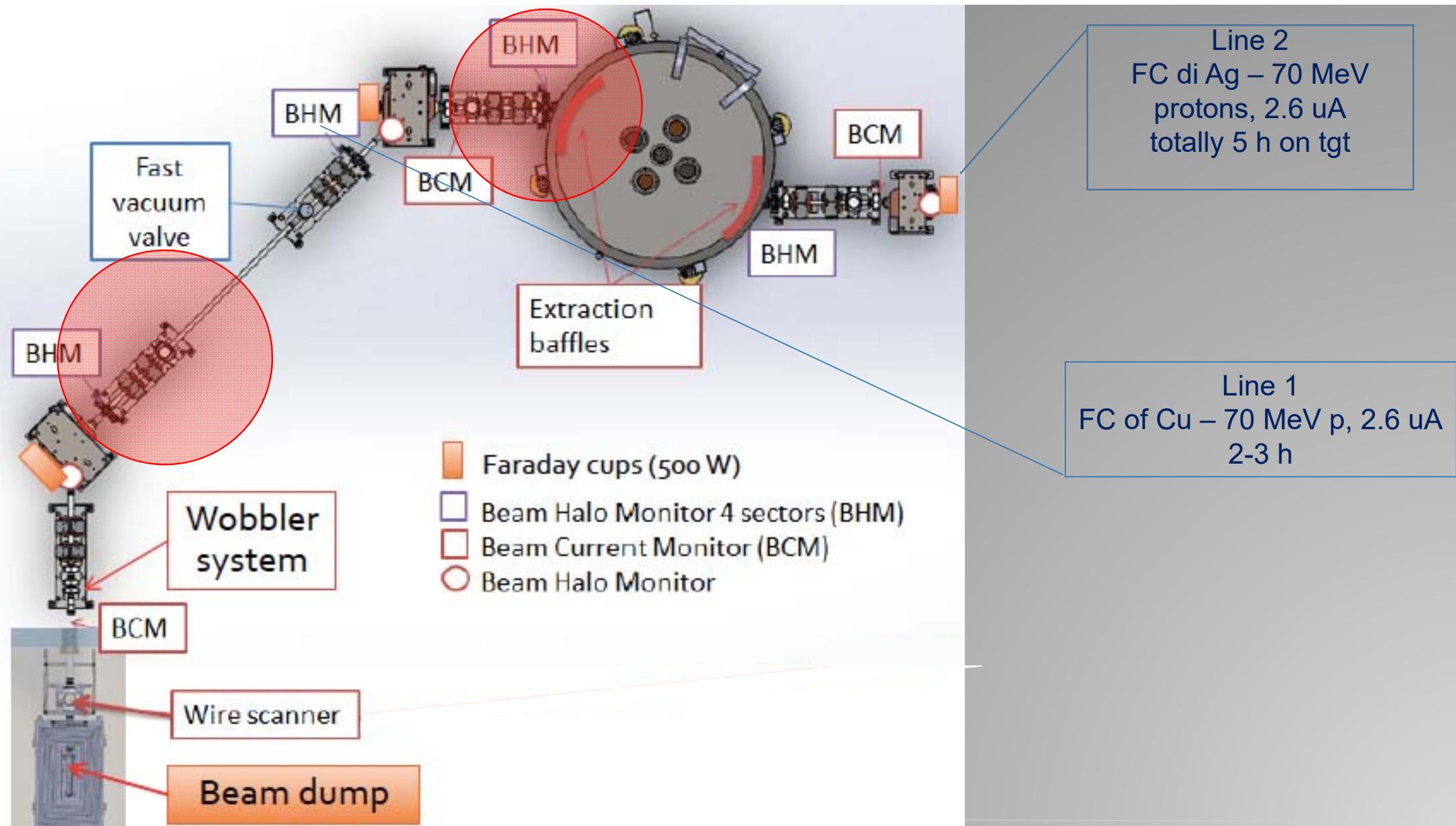
Real parameters of liquid circulation were taken under account



After a few days of high-power operation: Be-7 measured 830 Bq/liter, calculated 50 Bq/liter. Some effects not foreseen such as the removal, by the refrigerant fluid, of radionuclides generated in the cooling system

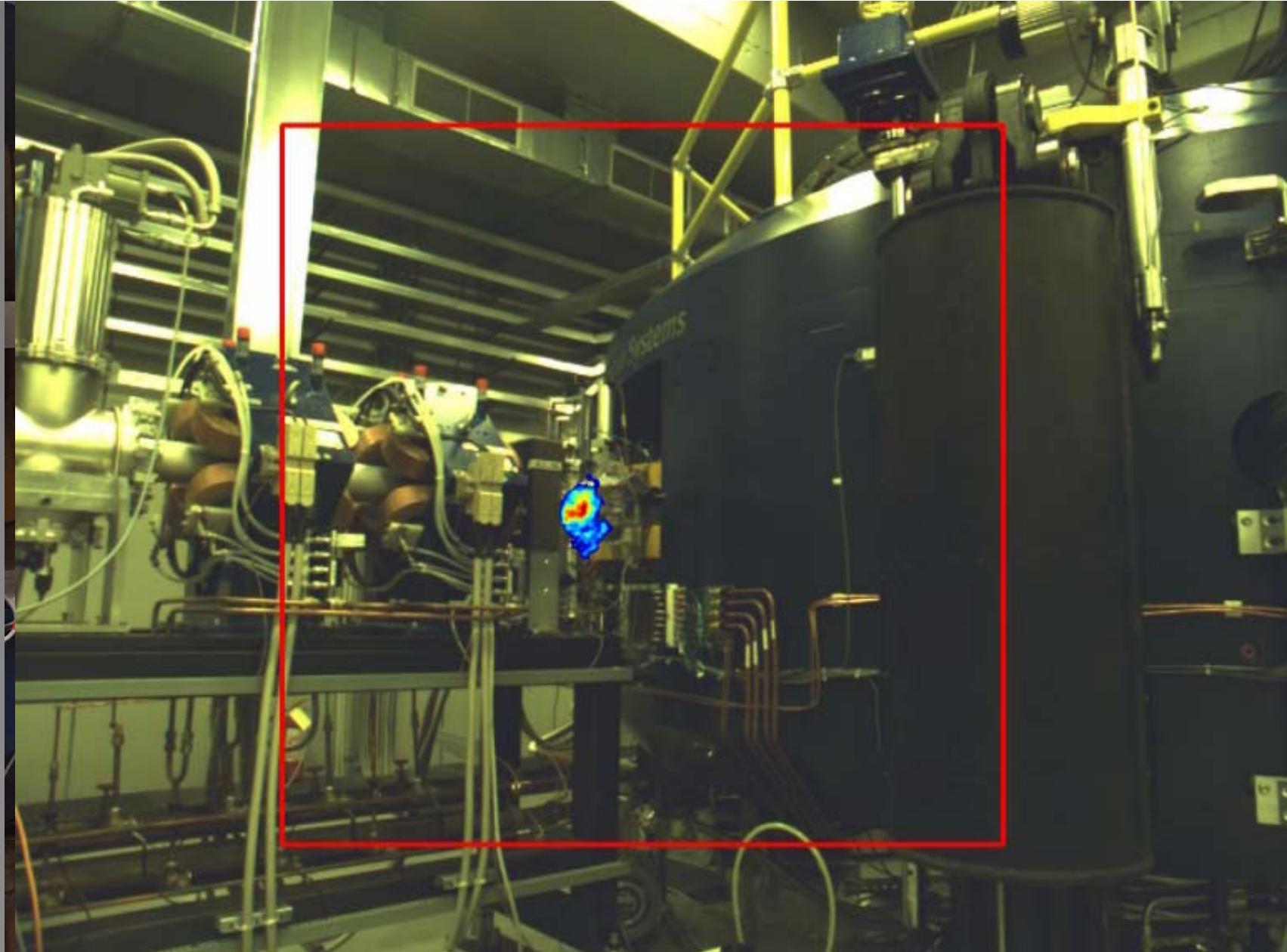
# *Cooling water activation of the cyclotron probe*







An image taken with iPix accurately localize the hotspot on the proton transfer line.  
Dose rate at contact around 2 mSv/h.



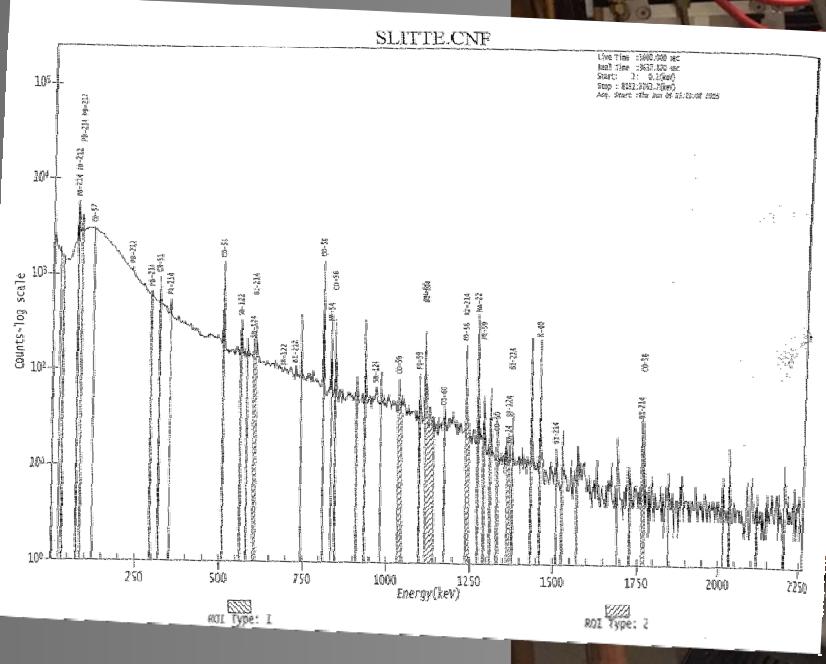
Dose rate at contact  
around 2 mSv/h.  
Dose at 1 meter distance  
1,5  $\mu$ Sv/h.



# Cyclotron commissioning tests from May 27<sup>th</sup> to June 1<sup>st</sup> (2016)



SLITTE.CNF



\*\*\*\*\* I N T E R F E R E N C E C O R R E C T E D R E P O R T \*\*\*\*\*

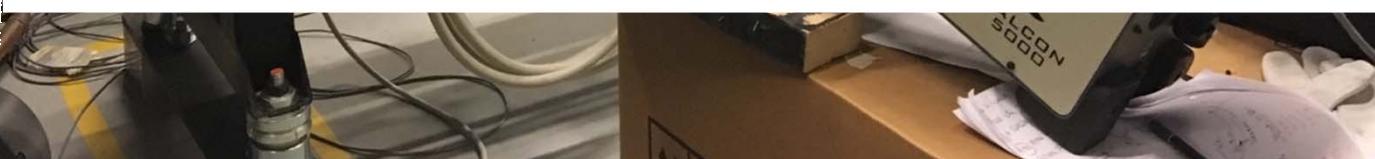
	Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /Unit)	Wt mean Activity Uncertainty
X	NA-22	0.950	6.580418E+003	3.018097E+002
X	NA-24	0.985	1.934522E+002	5.746823E+001
X	K-40	0.925	3.534547E+004	1.847160E+003
X	CR-51	1.000	1.395540E+004	1.603640E+003
X	MN-54	0.983	2.669283E+003	1.779944E+002
X	CO-56	0.875	3.220638E+003	1.225419E+002
X	MN-56	0.615		
X	CO-57	0.824	4.095547E+002	1.331209E+002
X	CO-58	0.983	1.307472E+004	7.152301E+002
X	FE-59	0.802	1.430109E+003	1.409251E+002
X	CO-60	0.994	4.438725E+002	6.368097E+001
X	ZN-65	0.969	6.127894E+003	3.038467E+002
X	SB-122	0.995	1.764763E+003	1.953311E+002
X	I-124	0.624		
X	SB-124	0.417	3.502322E+002	4.988672E+001
	BI-212	0.492	1.501580E+003	5.350967E+002
	PB-212	0.529	1.059770E+003	2.079446E+002
	BI-214	0.664	2.927439E+003	1.462062E+002
	PB-214	0.567	1.998471E+003	2.549193E+002

? = Nuclide is part of an undetermined solution

X = Nuclide rejected by the interference analysis

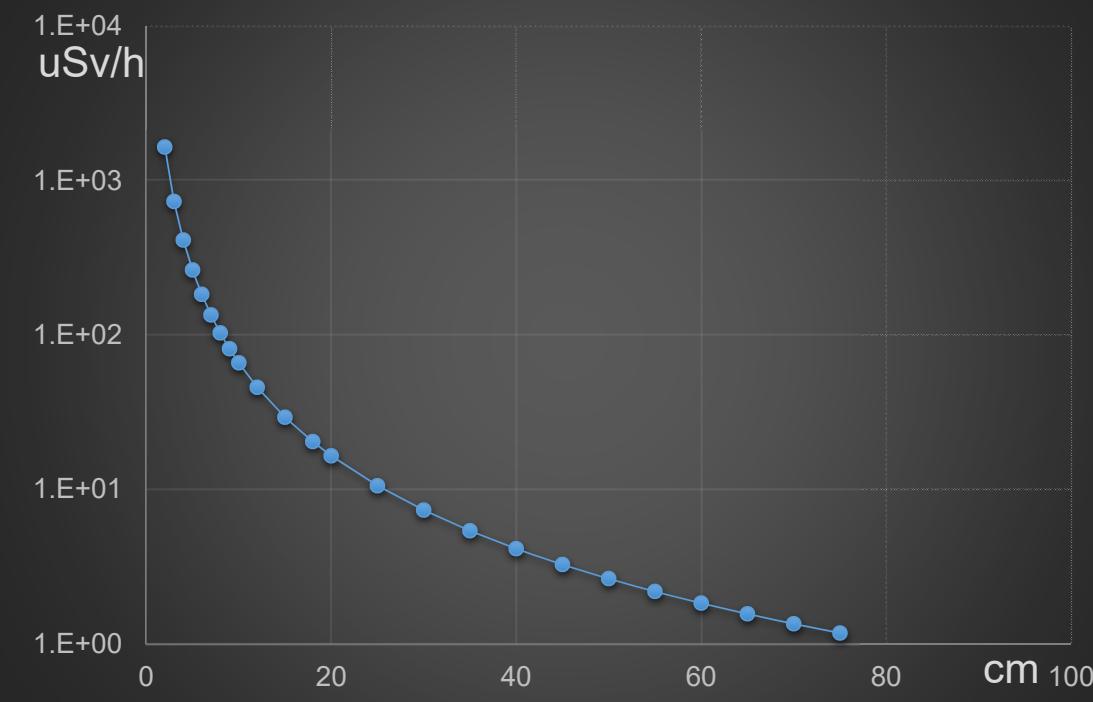
@ = Nuclide contains energy lines not used in Weighted Mean Activity

Errors quoted at 1.000 sigma



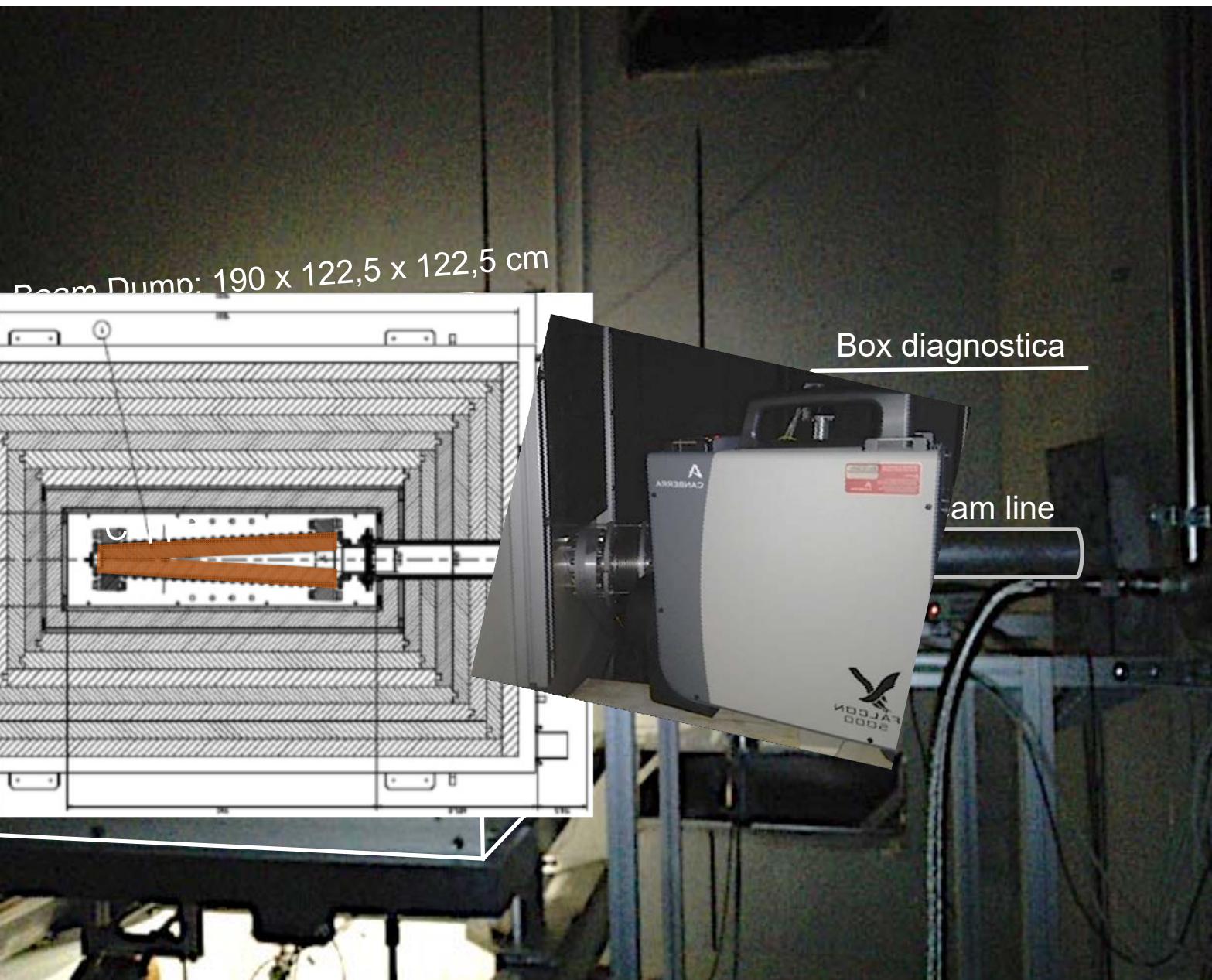
# Cyclotron commissioning tests from May 27<sup>th</sup> (2016) to March 31<sup>st</sup>, 2018

Measures taken on March 5° 2019



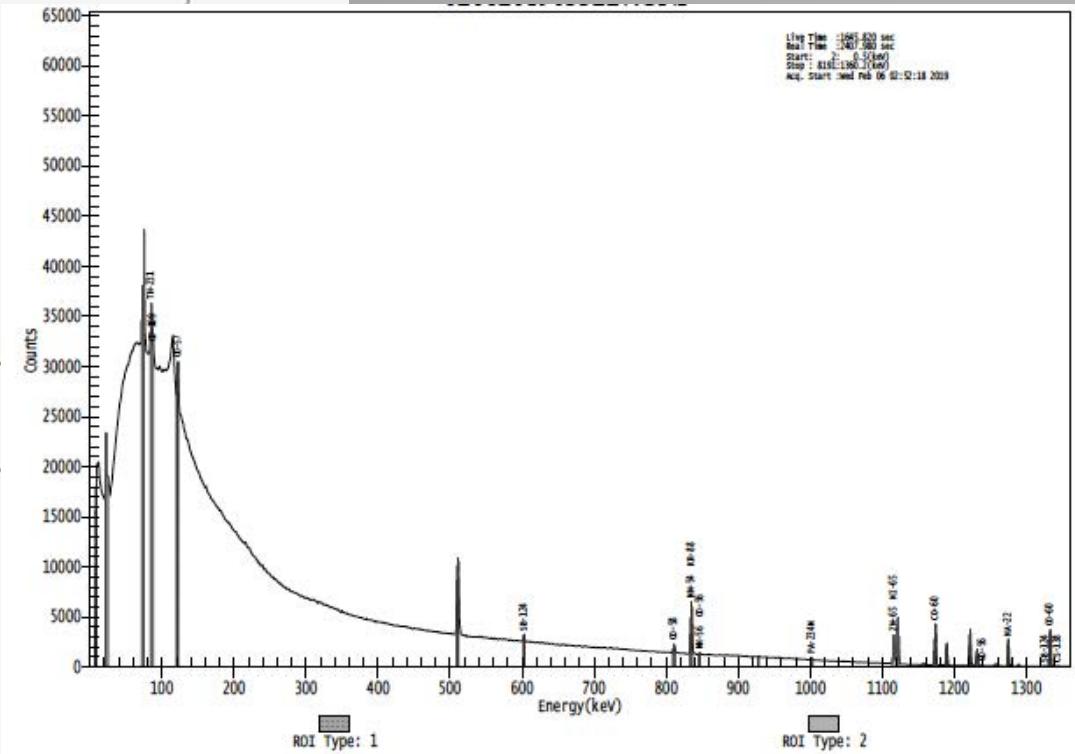
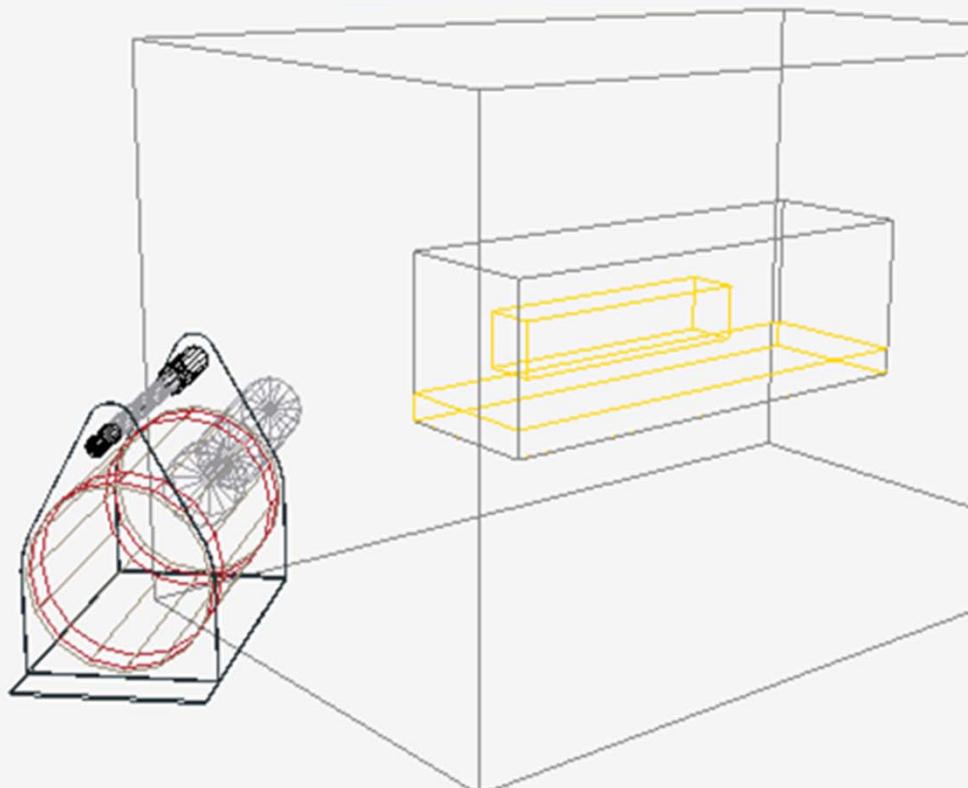
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****						
		Sample Title: Slitte Linea 1 ciclotrone Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB				
..... IDENTIFIED NUCLIDES .....						
Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (Bq /Unit)	Activity Uncertainty	
NA-22	0.984	1274.54*	99.94	1.737E+006	6.975E+004	
MN-54	1.000	834.83*	99.97	1.560E+005	8.141E+003	
CO-57	0.808	122.06*	85.51	7.448E+004	9.093E+003	
		136.48	10.60			
CO-60	0.990	1173.22*	100.00	1.479E+004	9.321E+002	
		1332.49*	100.00	1.539E+004	8.503E+002	





Date	Proton energy (MeV)	Current (microA)
29-SET-17	40	110
	40	200
02-OTT-17	70	100
	55	125
03-OTT-17	35	210
06-OTT-17	70	110
22-NOV-17	70	240
23-NOV-17	70	220
27-NOV-17	70	275
	70	330
28-NOV-17	70	425
	70	466
	70	375
29-NOV-17	70	480

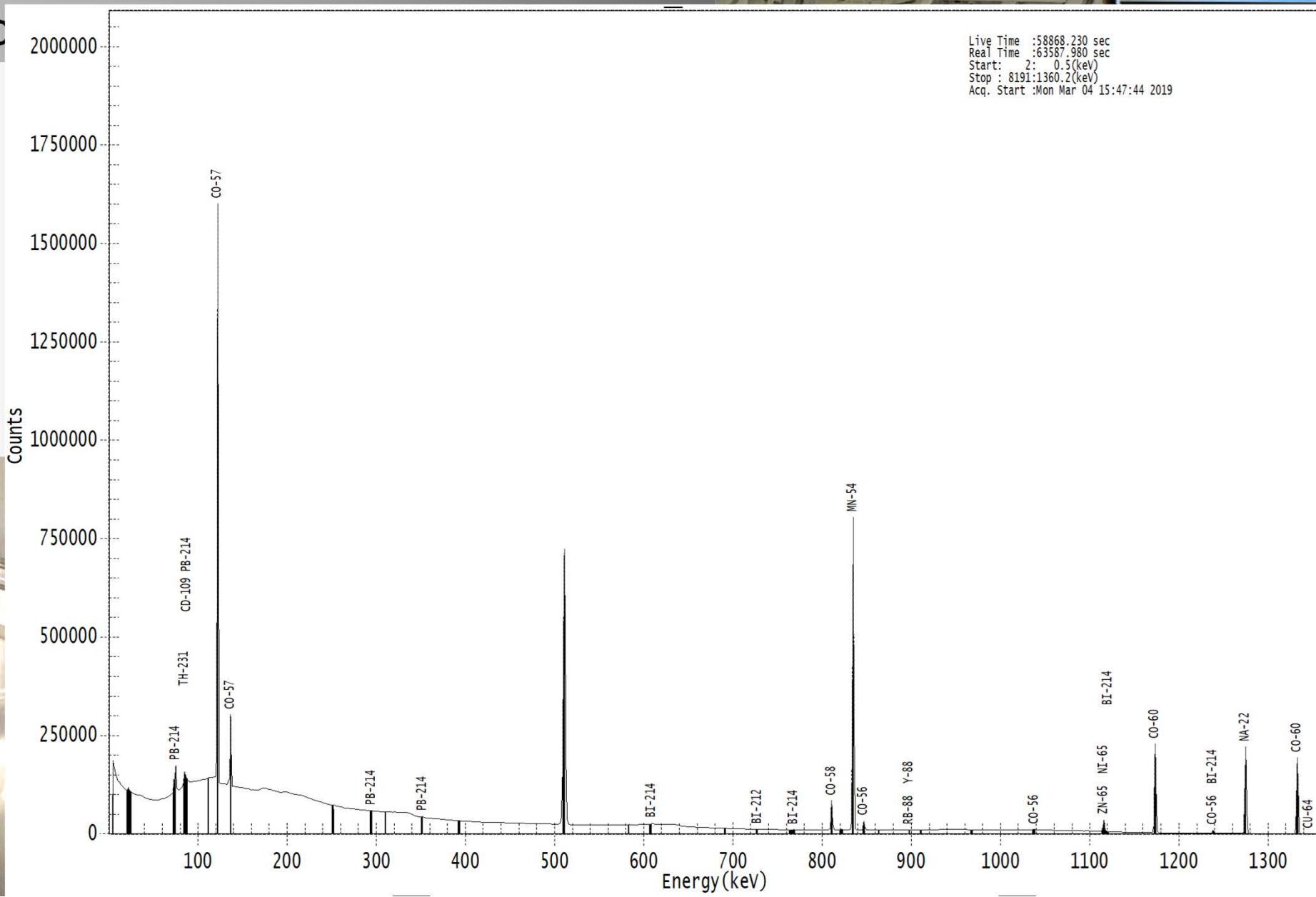
# High power beam dump ISOCS geometry

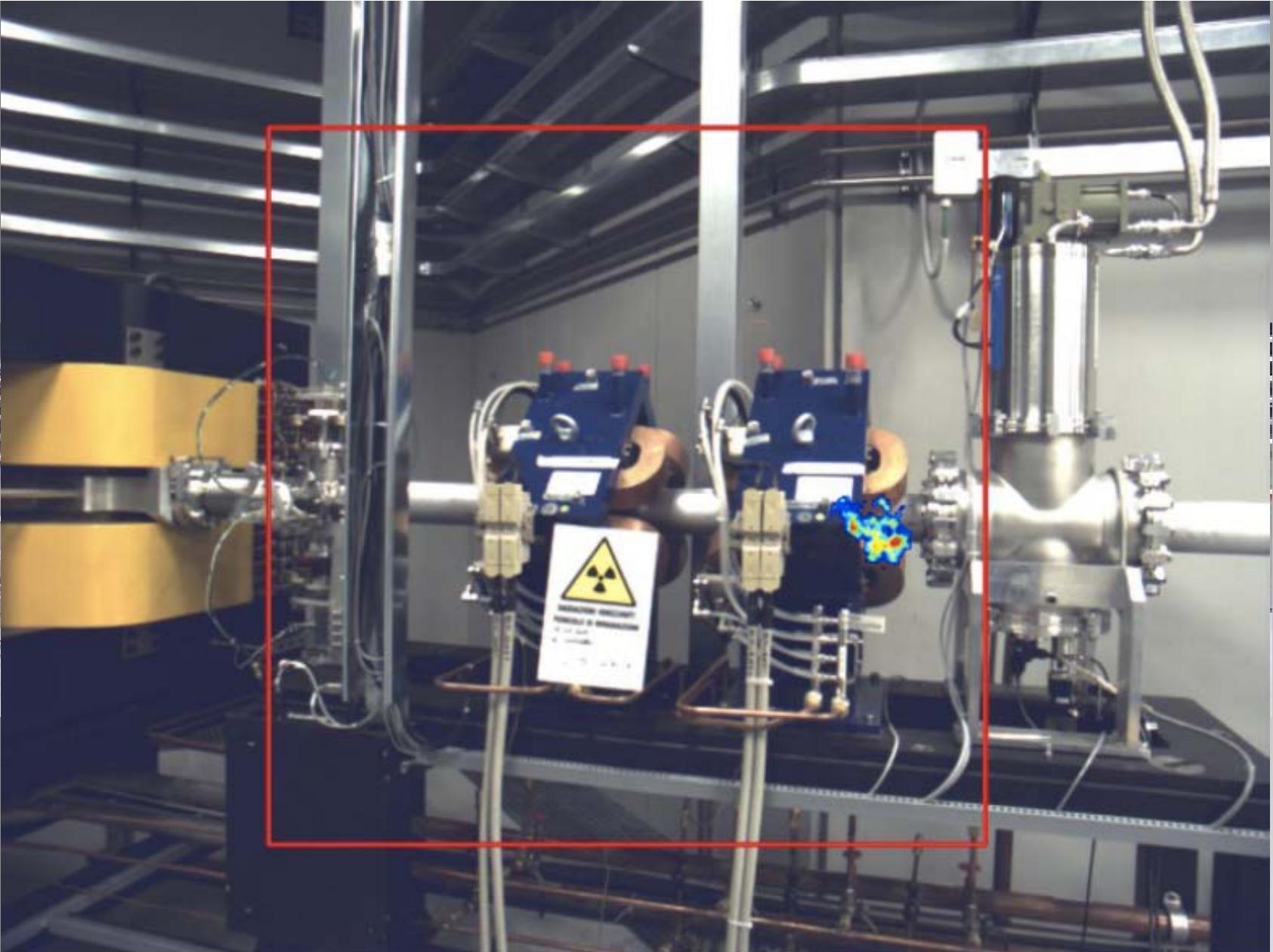


Nuclide Name	Activity (Bq/unit)	Activity Uncertainty	Monte Carlo FLUKA simulation*
Na-22	$6,3 \cdot 10^7$	$2,5 \cdot 10^6$	-
Mn-54	$1,6 \cdot 10^8$	$8,2 \cdot 10^6$	$2,6 \cdot 10^8$
Co-56	$3,4 \cdot 10^6$	$4,6 \cdot 10^5$	$2,6 \cdot 10^8$
Mn-56	$3,7 \cdot 10^6$	$5,1 \cdot 10^5$	-
Co-57	$3,1 \cdot 10^9$	$3,2 \cdot 10^8$	$3,5 \cdot 10^9$
Co-58	$2,3 \cdot 10^7$	$1,3 \cdot 10^6$	$8,3 \cdot 10^8$
Co-60	$9,7 \cdot 10^7$	$3,9 \cdot 10^6$	$8,8 \cdot 10^7$
Zn-65	$1,4 \cdot 10^8$	$5,7 \cdot 10^6$	$1,0 \cdot 10^9$

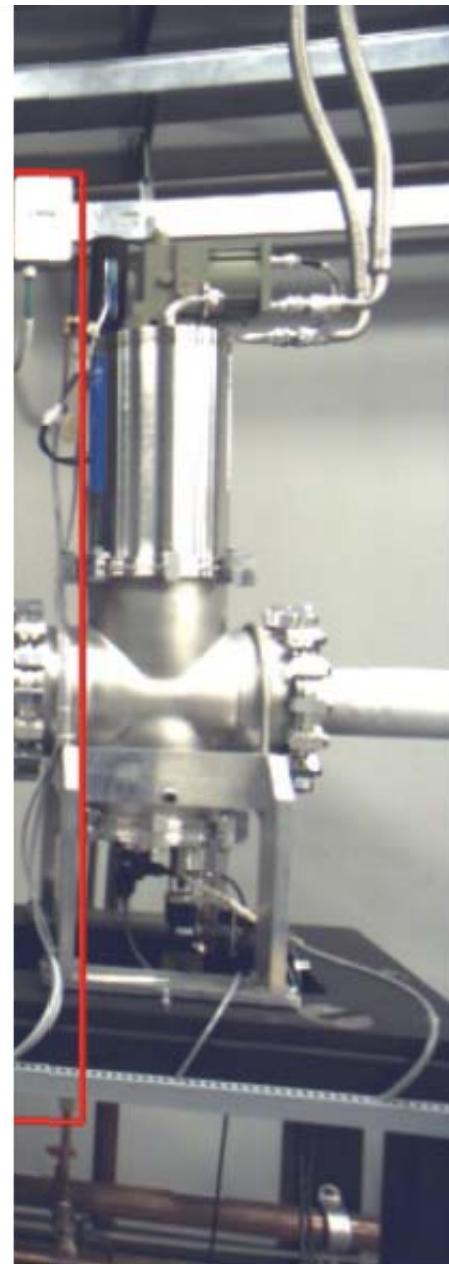
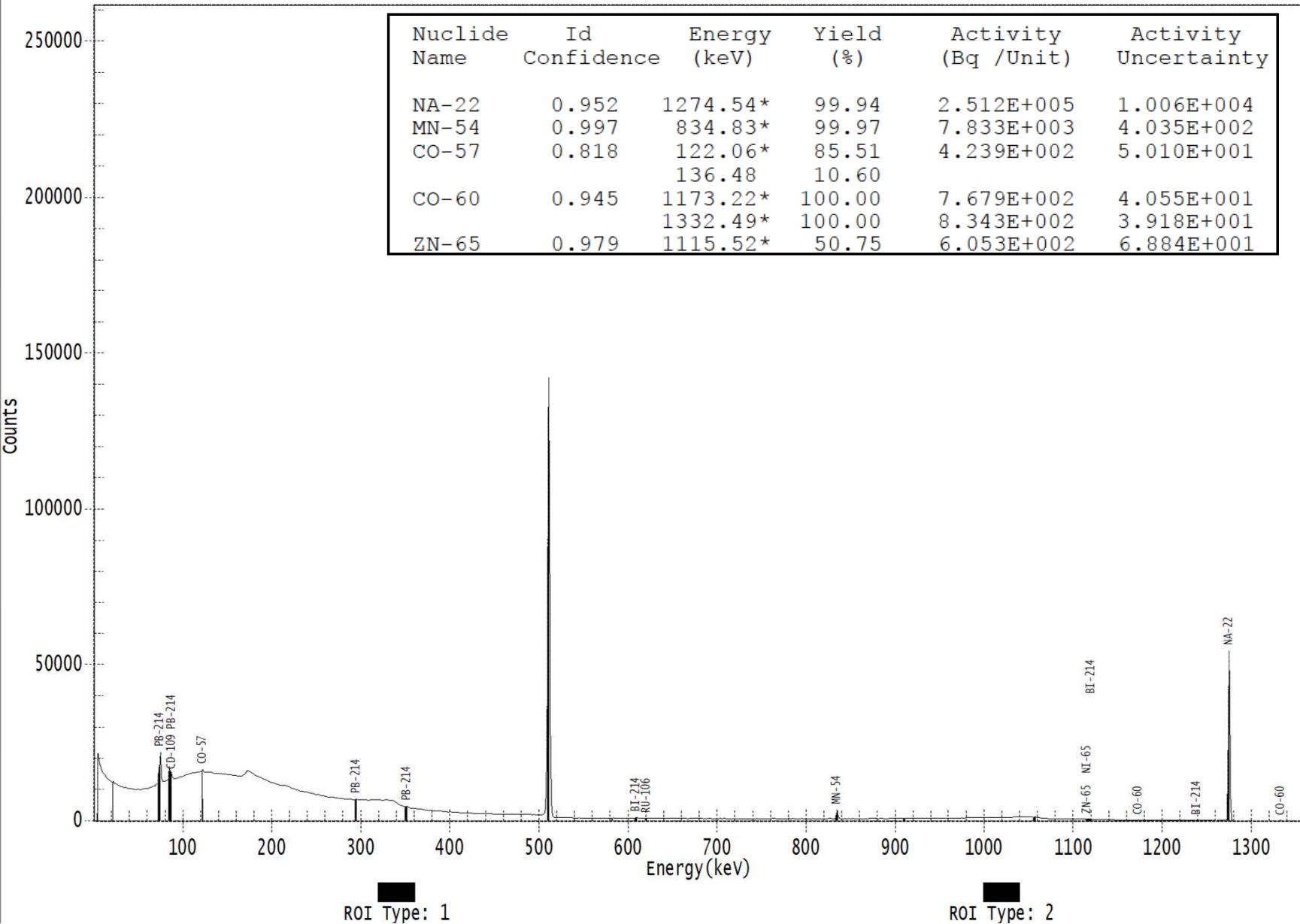
\* BD made of copper irradiated with 70 MeV protons with 100 microA current for 60 hours. The reported radioactivity is the residual after 10 months of cooling time.

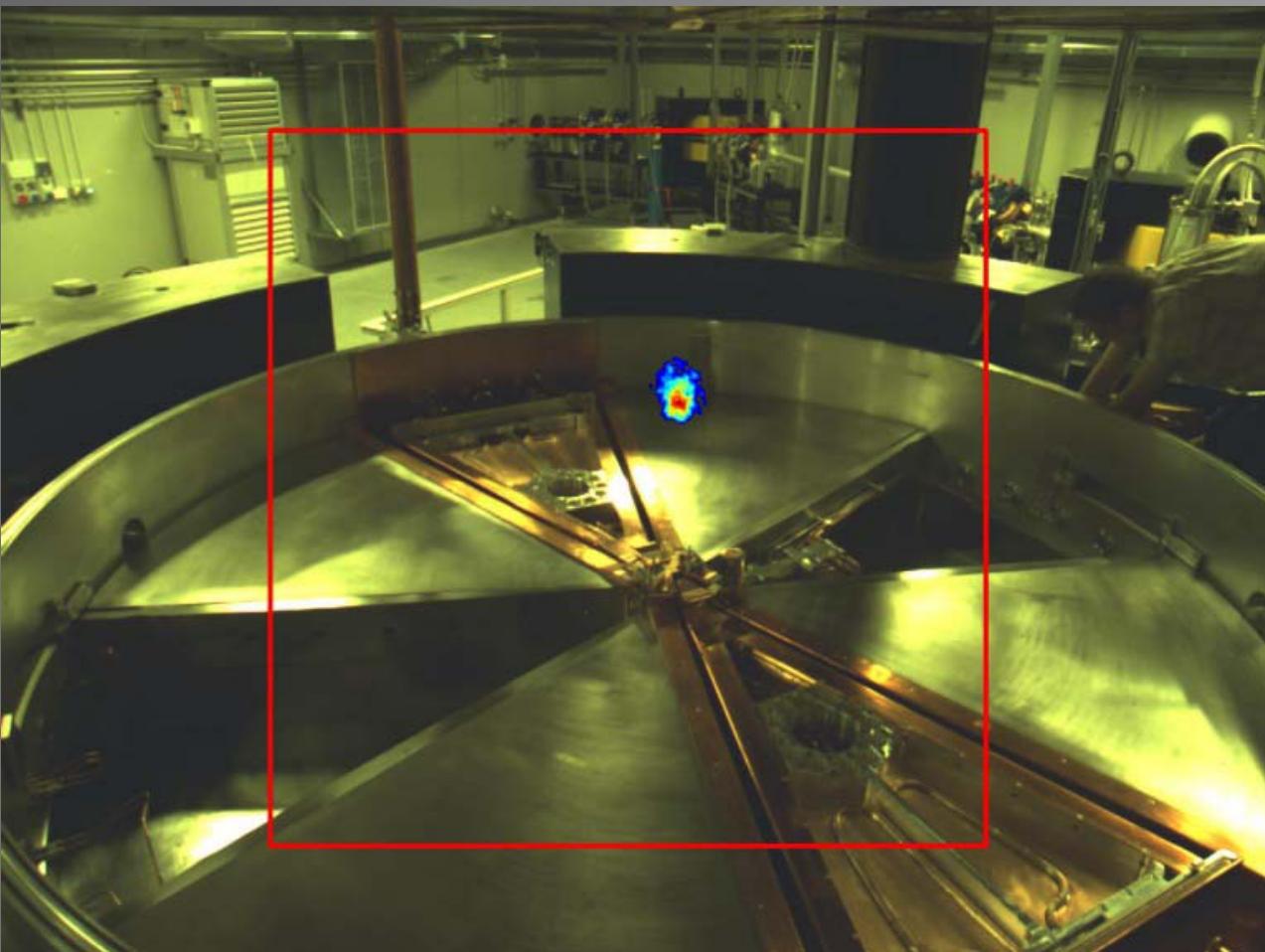
Pro



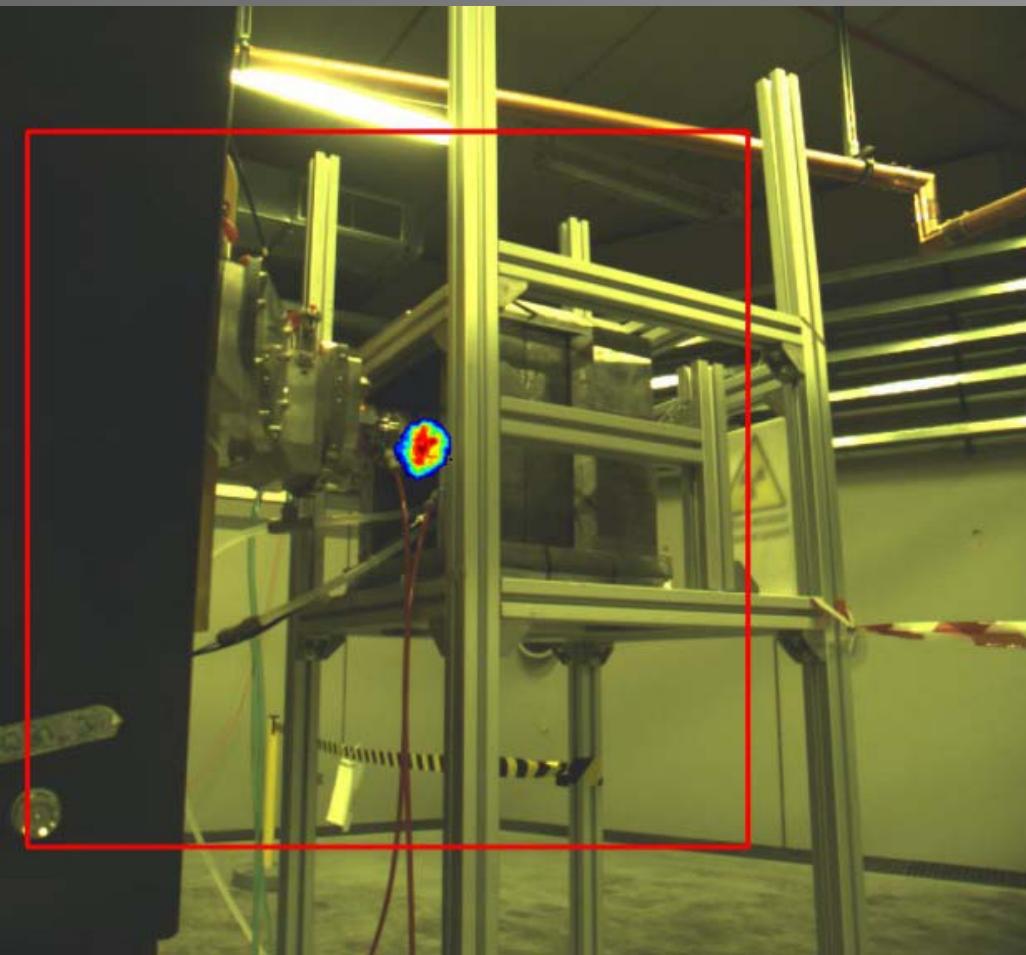


# 02132019051112.CNF

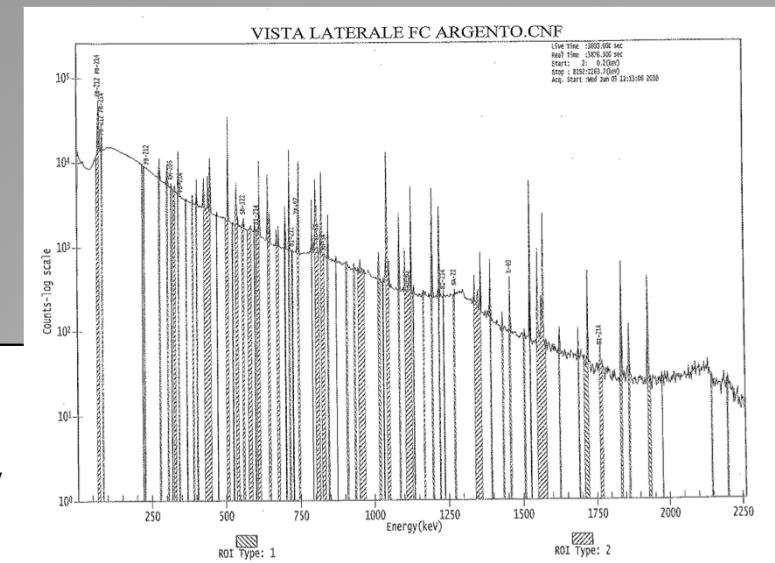


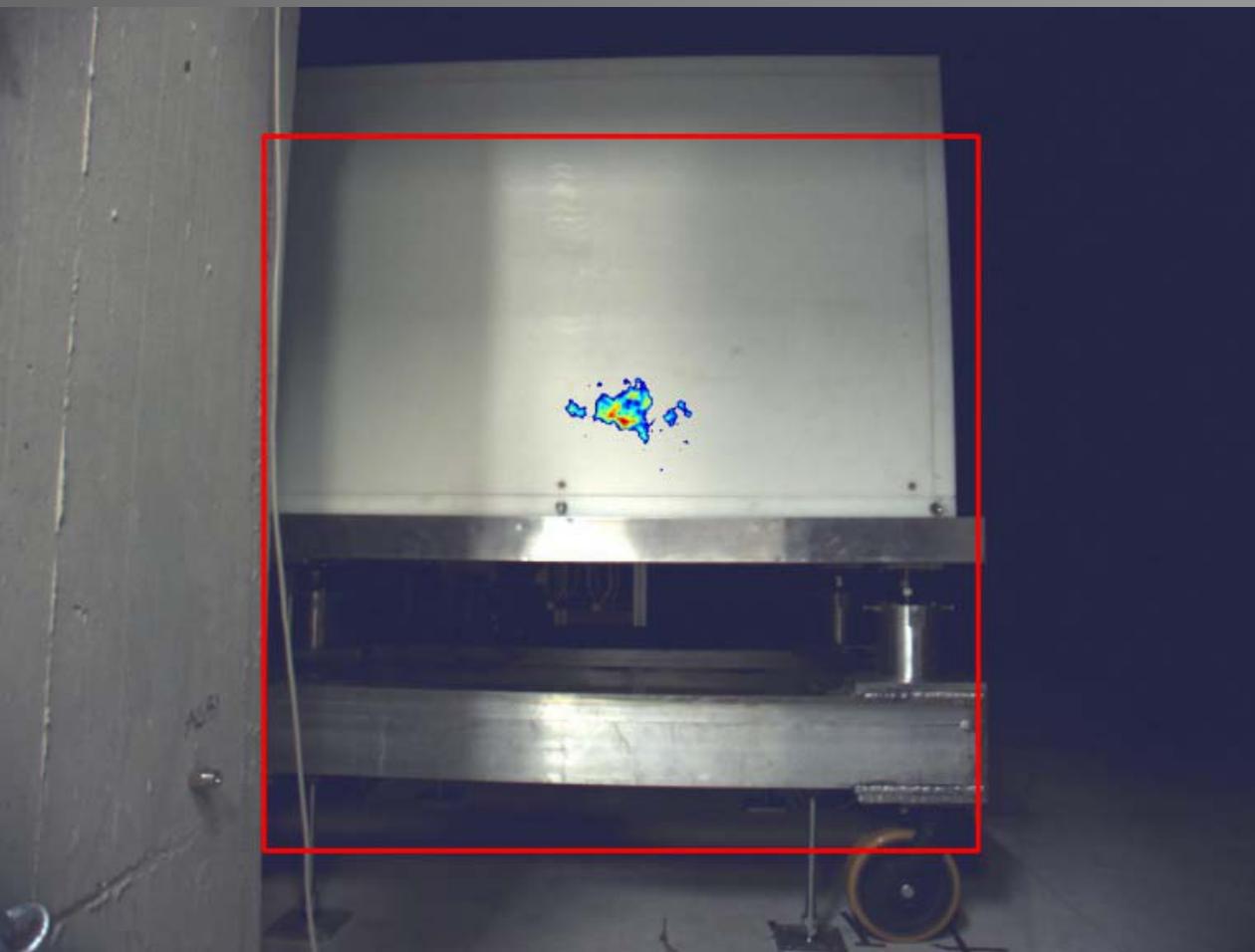


Localization of the activated beam stopper inside the cyclotron.  
Image captured in order to plan a maintenance on the vacuum chamber



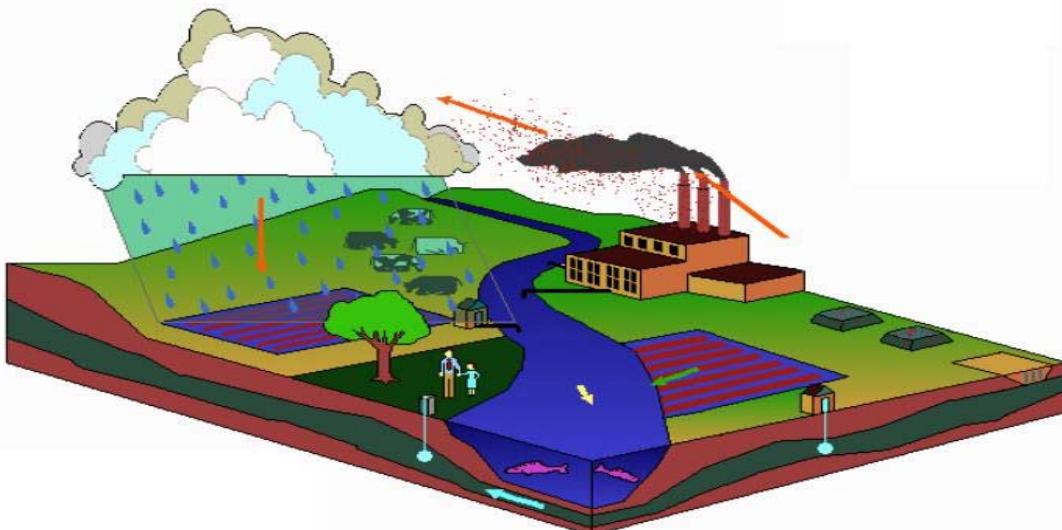
Nuclide	Wt mean activity (Bq / unit)		
Na-22	$2.03 \cdot 10^5$	Zr-97	$1.05 \cdot 10^6$
K-40	$1.37 \cdot 10^7$	Rh-105	$1.07 \cdot 10^7$
Mn-54	$2.02 \cdot 10^5$	Cd-109	$1.09 \cdot 10^{10}$
Co-58	$6.96 \cdot 10^5$	Sn-113	$2.88 \cdot 10^6$
Zn-65	$1.94 \cdot 10^5$	Sb-122	$1.66 \cdot 10^6$
Y-92	$1.94 \cdot 10^6$	Te-132	$6.05 \cdot 10^5$





Beam dump polyethylene shielding:  
the gamma imaging spot identifies  
the point with higher dose rate at  
contact, compared to the background  
level out of the red square.

# Code GENII-FRAMES ver. 2.0



GENII ver.2.0 is an environmental radiation dosimetry package which runs within the FRAMES Framework for Risk Analysis in Multimedia Environmental Systems.

Has been developed by the Pacific Northwest National Laboratory, for the Environmental Protection Agency (EPA), Office of Radiation and Indoor Air, with subsequent revisions for the US DOE and US NRC.

**PURPOSE:** to provide the capability to perform dose and risk assessments of environmental releases of radionuclides.

## Code GENII-FRAMES ver. 2.0 (1)

The code was used to calculate effective doses due to release of chronic and acute releases of radioactive gases due to SPES operation.

In particular:

- 1) Chronic releases of radioactive air from SPES bunkers
- 2) Acute release of all radioactive material in a volatile state and radioactive gases from the UC<sub>x</sub> source at the End Of Bombardment (EOB)

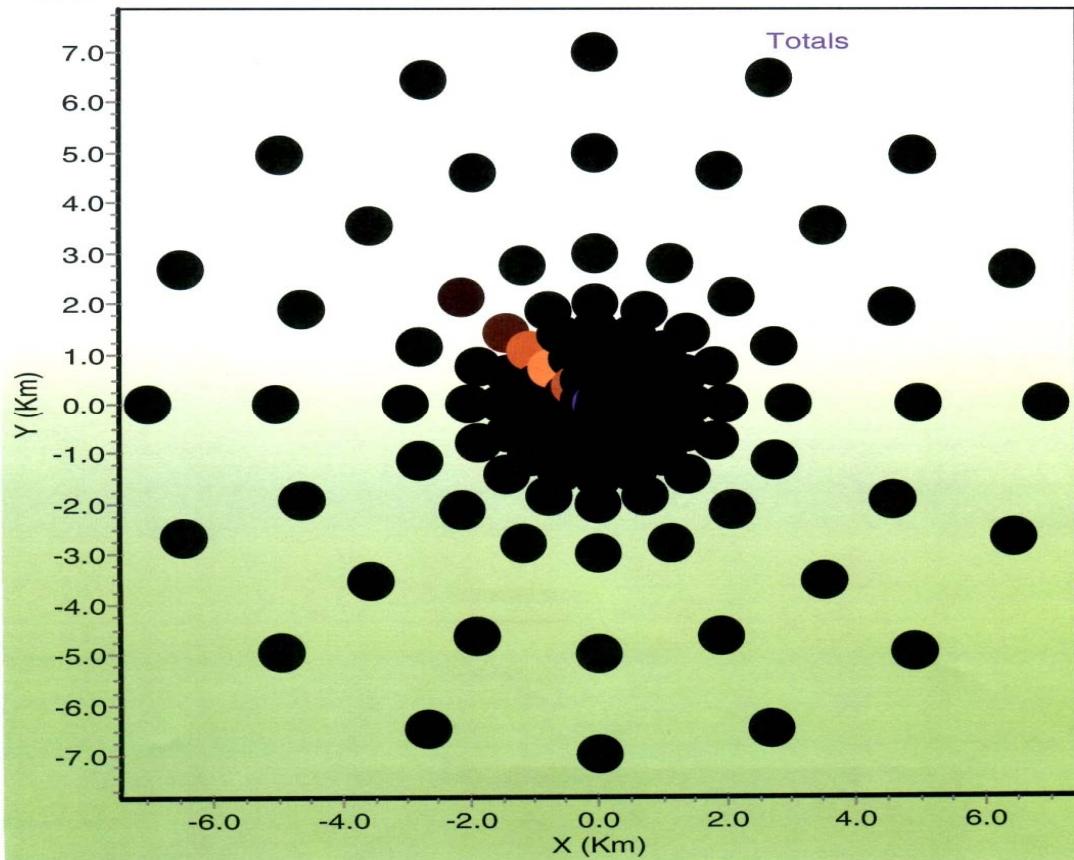
Code GENII/FAMES ver. 2.0 (2)  
Chronic release of radioactive air products

- 1) 7 radionuclides considered:  $^{41}\text{Ar}$ ,  $^7\text{Be}$ ,  $^{11}\text{C}$ ,  $^{14}\text{C}$ ,  $^3\text{H}$ ,  $^{13}\text{N}$ ,  $^{15}\text{O}$ ,  $^{35}\text{S}$
- 2) Activity released up to  $1.1 \times 10^{13}$  Bq
- 3) Evaluation in a year of the effective dose received by all the ways of irradiation included the introduction of radioactive material in the body considering all possible ways
- 4) Two age groups of population considered: 7-12 and 17-70 years
- 5) Without and with plume rise (gas exit velocity 10 m/s)

# Code GENII/FRAMES ver. 2.0 (3)

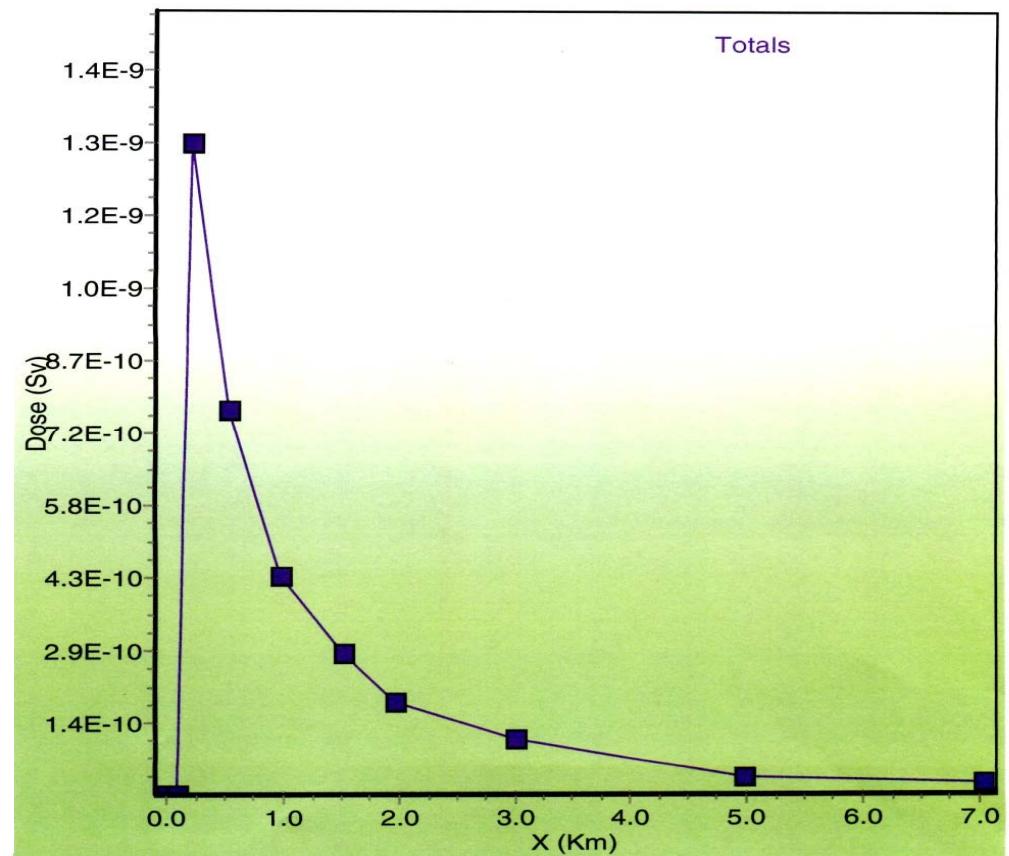
## Chronic release of radioactive air products

Data from the file: C:\FRAMES\SPESB.HIF



Ring 5, Sector 14, Location (-0.7 km, 0.7 km)

Data from the file: C:\FRAMES\SPESB.HIF

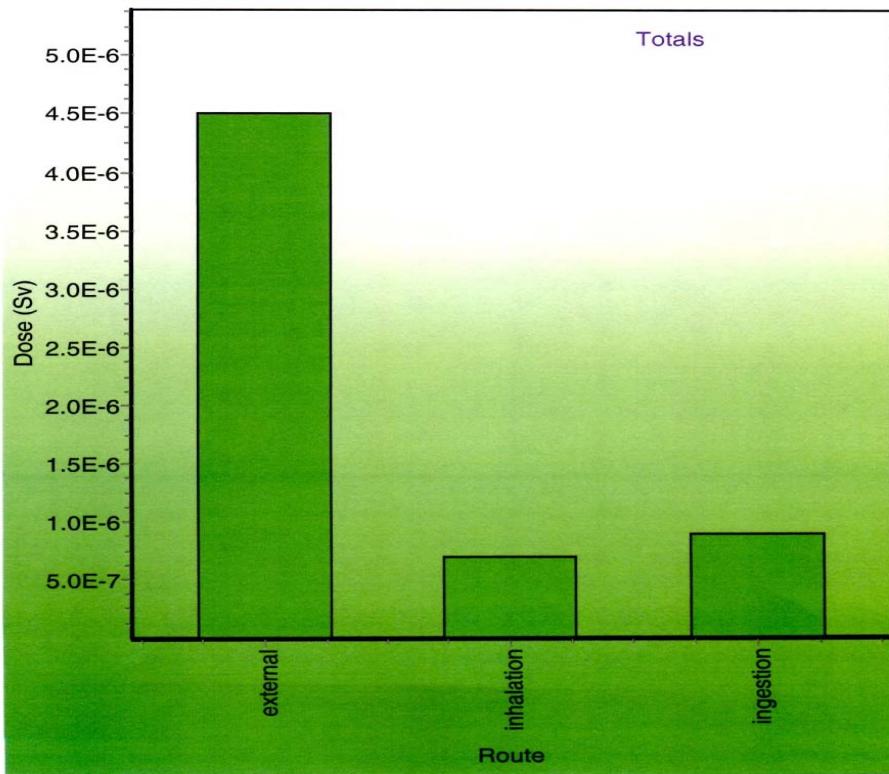


Current max.  $1.3 \times 10^{-9}$  Sv

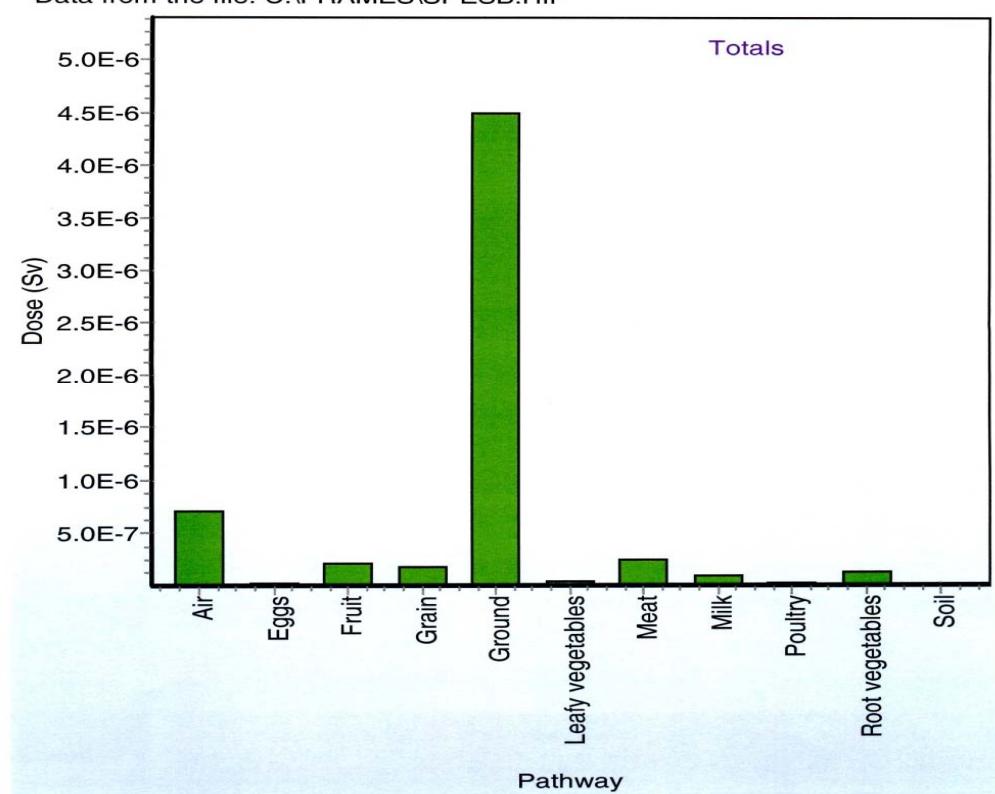
# Code GENII/FRAMES ver. 2.0 (4)

## Chronic release of radioactive air products

Data from the file: C:\FRAMES\SPESB.HIF



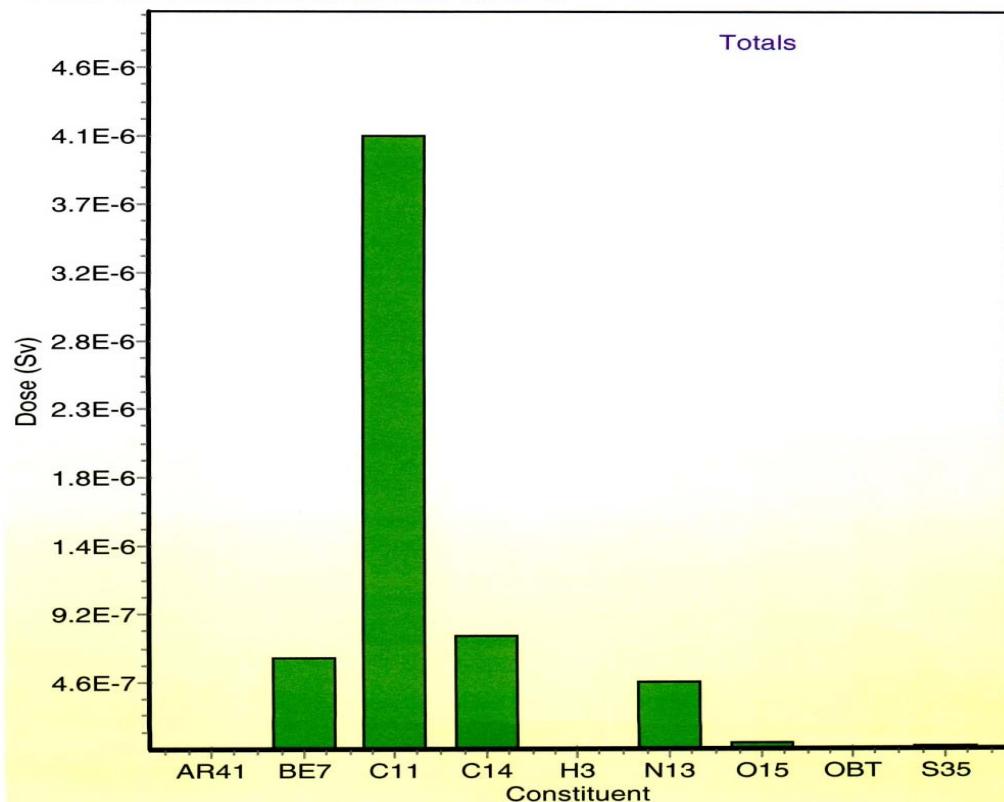
Data from the file: C:\FRAMES\SPESB.HIF



# Code GENII/FRAMES ver. 2.0 (5)

## Chronic release of radioactive air products

Data from the file: C:\FRAMES\SPESB.HIF



Max. effective dose at 700 m from the release point: **1.1  $\mu$ Sv**, for the group 7-12 years old, mainly due to external exposure to the plume (0.79  $\mu$ Sv (0.14  $\mu$ Sv for inhalation and 0.16  $\mu$ Sv for ingestion)).

Max. effective dose at 700 m from the release point: **1  $\mu$ Sv**, for the group 12-70 years old.

**WITH PLUME RISE:** Max. effective dose at 1100 m from the release point: **0.13  $\mu$ Sv** for the group 7-12 years old and **0.10  $\mu$ Sv** for the group 12-70 years old.

# Code GENII/FRAMES ver. 2.0 (6)

## Chronic release of radioactive air products

### LARAMED-TEMP

Protons of 70 MeV, 200  $\mu$ A on  $^{85}\text{Rb}$  for  $^{82}\text{Sr}$  production  
(p,4n) reaction.

Irradiation profile given by BEST Company.

No plume rise

Max. effective dose at 700 m from the release point: **1.4  $\mu\text{Sv}$** ,  
for the group 7-12 years old, mainly due to external exposure  
to the plume.

Max. effective dose at 700 m from the release point: **1.3  $\mu\text{Sv}$** ,  
for the group 12-70 years old.

**WITH PLUME RISE:** Max. effective dose at 1100 m from the  
release point: **0.19  $\mu\text{Sv}$**  for the group 12-70 years old.

MAX. TOTAL EFFECTIVE DOSE IN A YEAR, DUE TO THE RELEASE OF THE  
RADIOACTIVE AIR GASES PRODUCED FROM BUNKER AIR ACTIVATION, GROUP 7-  
12 YEARS OLD **2.5  $\mu\text{Sv}$**

# HotSpot ver. 3.02 (Livermore U.S.A.)

Radionuclides production in air in ISOL bunker 1 due to the interaction of 40 MeV protons, 200  $\mu\text{A}$  on UCx SPES tgt;

Radionuclides production taken into account:  $^{41}\text{Ar}$ ,  $^{7}\text{Be}$ ,  $^{11}\text{C}$ ,  $^{14}\text{C}$ ,  $^{3}\text{H}$ ,  $^{13}\text{N}$ ,  $^{15}\text{O}$ ,  $^{35}\text{S}$

Chronic continuous annual release, total:

$$1.1 \times 10^{13} \text{ Bq}$$



# Radionuclides mixture

```
CEDEOnlyFile.mix - Blocco note
File Modifica Formato Visualizza ?
40 MeV protons-200 microA on UCx tgt
Mixture Scale Factor : 1.0000E+00

Nuclide [01] : H-3   1.2320E+01 y
Halflife (Years) : 1.2320E+01
Inhalation 50-yr CEDE (Sv/Bq) : 0.0000E+00
Submersion (Sv-m3)/(Bq-sec) : 0.0000E+00
Ground Shine (Sv-m2)/(Bq-sec) : 0.0000E+00
Total Activity Released (Bq) : 7.8000E+07
Airborne Fraction : 1.0000E+00
Respirable Fraction : 1.0000E+00
Respirable Deposition Velocity (cm/sec) : 3.0000E-01
Non-resp. Deposition Velocity (cm/sec) : 8.0000E+00

Nuclide [02] : Be-7   F   53.3d
Halflife (Years) : 1.4603E-01
Inhalation 50-yr CEDE (Sv/Bq) : 3.7600E-11
Submersion (Sv-m3)/(Bq-sec) : 2.2100E-15
Ground Shine (Sv-m2)/(Bq-sec) : 4.7600E-17
Total Activity Released (Bq) : 3.6000E+09
Airborne Fraction : 1.0000E+00
Respirable Fraction : 1.0000E+00
Respirable Deposition Velocity (cm/sec) : 3.0000E-01
Non-resp. Deposition Velocity (cm/sec) : 8.0000E+00

Nuclide [03] : C-11   F   20.38m
Halflife (Years) : 3.8775E-05
Inhalation 50-yr CEDE (Sv/Bq) : 1.0800E-11
Submersion (Sv-m3)/(Bq-sec) : 4.5600E-14
Ground Shine (Sv-m2)/(Bq-sec) : 1.0000E-15
Total Activity Released (Bq) : 3.9000E+12
Airborne Fraction : 1.0000E+00
Respirable Fraction : 1.0000E+00
Respirable Deposition Velocity (cm/sec) : 3.0000E-01
Non-resp. Deposition Velocity (cm/sec) : 8.0000E+00

Nuclide [04] : C-14   F   5730y
Halflife (Years) : 5.7300E+03
Inhalation 50-yr CEDE (Sv/Bq) : 2.0300E-10
Submersion (Sv-m3)/(Bq-sec) : 2.6000E-18
Ground Shine (Sv-m2)/(Bq-sec) : 1.2800E-20
Total Activity Released (Bq) : 1.6000E+08
Airborne Fraction : 1.0000E+00
Respirable Fraction : 1.0000E+00
Respirable Deposition Velocity (cm/sec) : 3.0000E-01
Non-resp. Deposition Velocity (cm/sec) : 8.0000E+00

Nuclide [05] : N-13   9.9650E+00 m
Halflife (Years) : 1.8959E-05
Inhalation 50-yr CEDE (Sv/Bq) : 0.0000E+00
Submersion (Sv-m3)/(Bq-sec) : 4.5700E-14
Ground Shine (Sv-m2)/(Bq-sec) : 1.0300E-15
Total Activity Released (Bq) : 3.2000E+12
```

## HotSpot Table Output - Blocco note

Microsoft Word Microsoft SharePoint

File Modifica Formato Visualizza ?  
 HotSpot Version 3.0.2 General Plume  
 lug 22, 2015 04:34

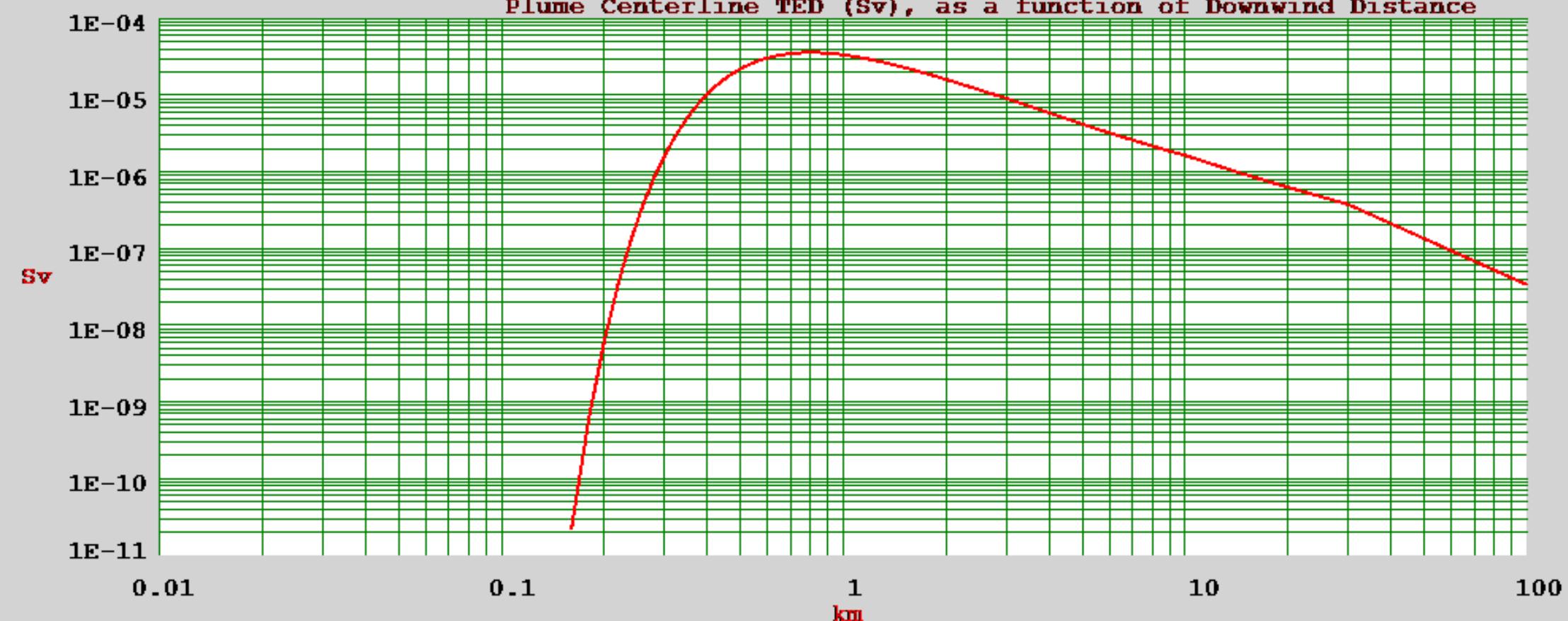
Source Term : EOBSPES5.mix (Mixture Scale Factor = 1.0000E+00)  
 Physical Stack Height : 16.0 m  
 Stack Exit Velocity : 10.00 m/s  
 Stack Diameter : 15.0 m  
 Stack Effluent Temp. : 20.0 deg C  
 Air Temperature : 20.0 deg C  
 Effective Release Height : 16 m  
 Wind Speed (h=10 m) : 1.50 m/s  
 Wind Speed (h=H-eff) : 1.94 m/s  
 Stability Class : F  
 Receptor Height : 1.5 m  
 Inversion Layer Height : None  
 Sample Time : 10.000 min  
 Breathing Rate : 2.61E-04 m<sup>3</sup>/sec  
 Distance Coordinates : All distances are on the Plume Centerline  
 Maximum Dose Distance : 0.80 km  
 Maximum TED : 3.62E-05 Sv  
 Inner Contour Dose : 0.010 Sv  
 Middle Contour Dose : 5.00E-05 Sv  
 Outer Contour Dose : 1.00E-05 Sv  
 Exceeds Inner Dose Out To : Not Exceeded  
 Exceeds Middle Dose Out To : Not Exceeded  
 Exceeds Outer Dose Out To : 2.8 km

Include Plume Passage Inhalation and Submersion  
 Exposure Window:(Start: 0.00 days; Duration: 365.00 days) [100% stay time].

DISTANCE km	T E D (Sv)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Bq-sec)/m <sup>3</sup>	ARRIVAL TIME (hour:min)
0.030	0.0E+00	0.0E+00	<00:01
0.100	0.0E+00	3.0E-09	<00:01
0.200	6.5E-09	6.0E+04	00:01
0.300	1.6E-06	1.3E+07	00:02
0.400	1.0E-05	7.3E+07	00:03
0.500	2.2E-05	1.5E+08	00:04
0.600	3.1E-05	2.0E+08	00:05
0.700	3.5E-05	2.2E+08	00:06
0.800	3.6E-05	2.2E+08	00:06
0.900	3.6E-05	2.1E+08	00:07
1.000	3.4E-05	2.0E+08	00:08
2.000	1.6E-05	8.2E+07	00:17
4.000	5.9E-06	2.3E+07	00:34
6.000	3.2E-06	1.1E+07	00:51
8.000	2.2E-06	6.1E+06	01:08
10.000	1.6E-06	4.1E+06	01:25
20.000	6.3E-07	1.2E+06	02:51
40.000	2.1E-07	3.3E+05	05:43



HotSpot Version 3.0.2 General Plume lug 22, 2015 04:38  
Plume Centerline TED (Sv), as a function of Downwind Distance



Source Material :EOBSPES5.mix

Eff. Release Height :16 m

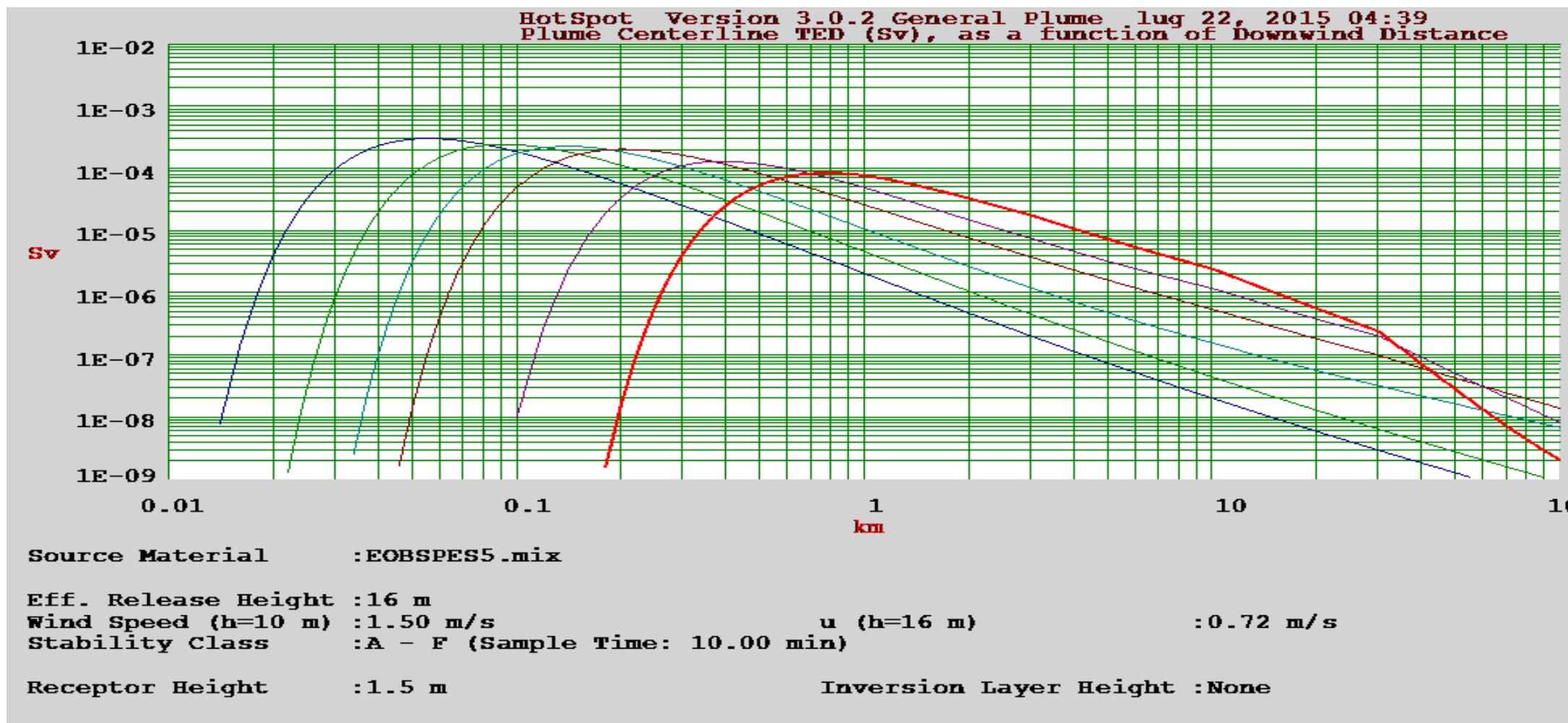
Wind Speed (h=10 m) :1.50 m/s      u (h=16 m) :1.94 m/s

Stability Class :F (Sample Time: 10.00 min)

Receptor Height :1.5 m

Inversion Layer Height :None

# Different results based on class stability



# Confronto HotSpot – GENII/FRAMES

## Air Activation Release

### 1. HotSpot

Max. Effective dose: **36  $\mu\text{Sv}$**  at 800 m, 100% presence outside

Model used (Pasquille/Gifford) Class stability F (Moderately stable)

### 2. GENII/FRAMES

Max. Effective dose: **1  $\mu\text{Sv}$**  at 700 m

100% presence outside

Different Model used (Brigg's Open Country)

Same Class stability F

Fraction of time spent indoors 0.7

Fraction of time spent outdoors 0.3

Days/y exposed to contaminated ground

Code GENII/FRAMES  
Acute Plume at the End Of Bombardment di SPES (1)

- 1) 110 radionuclides, without any filtration are released in air for 1 hour
- 2) Activity released up to  $1 \times 10^{13}$  Bq
- 3) Evaluation of the effective dose received from the plume in 1 hour
- 4) Evaluation in a year of the effective dose received by all the ways of irradiation included the introduction of radioactive material in the body considering all possible ways
- 5) Age of population considered: 17-70 years