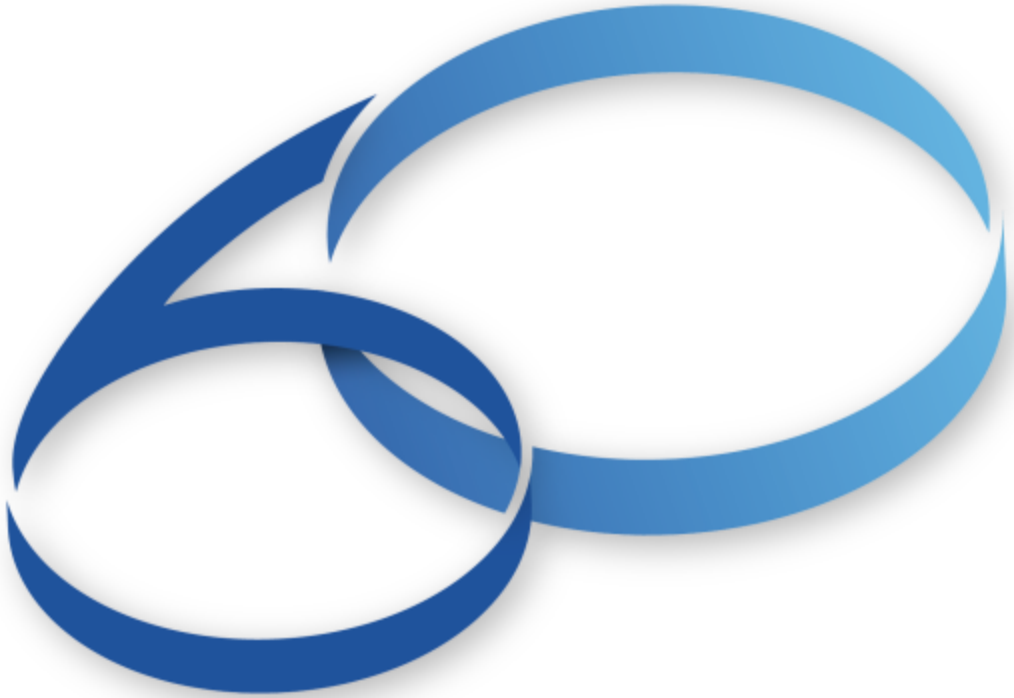

YEARS / ANS **CERN**

CERN | YEARS / ANS **CERN**

Radiation protection study for the HIE-ISOLDE project

S. Giron*, A.-P. Bernardes, A. Dorsival, D. Voulot and J. Vollaire**

* Marie-Curie Fellow now at EDF (France)
** Presenting

CATHI Final Review Meeting 22-26 September - Barcelona

Outline

- Radiation Protection challenges of HIE-ISOLDE
- Shielding design for the post-accelerator
  - X-ray measurements
  - FLUKA calculations for the post-accelerator
- Ion interactions after post-acceleration
  - Operational parameters for HIE-ISOLDE
  - Activation calculations
- Radiation Monitoring System upgrade
- Conclusions

RP challenges of HIE-ISOLDE

- Field emission in RF cavities lead to X-rays
  - Accelerating structures within a shielded enclosure
  - BUT many feed-trough for services
  - Keep the current radiological classification of the hall
- Beam accelerated above the Coulomb barrier
  - Possibility to have nuclear reactions
  - Strong wish to keep the current working practices (access to experimental setup during operation)
- RIB implantation (risk increases with intensity)
  - Hot-spot for gamma emitters
  - Contamination risks when opening the vacuum chamber or working on vacuum related equipment

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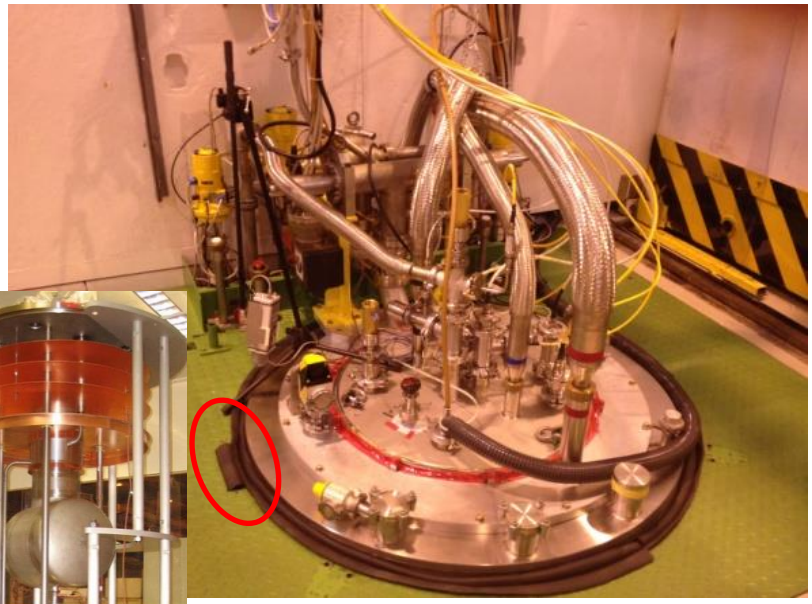
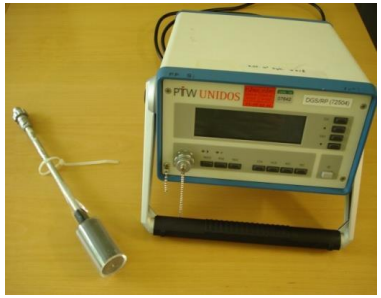
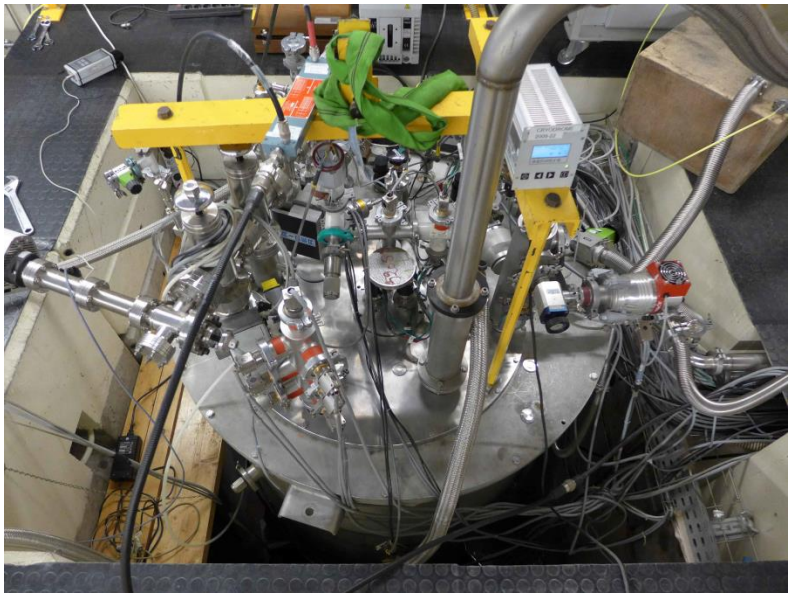
X-ray measurements

Measurements in SM18





Measurements in Orsay

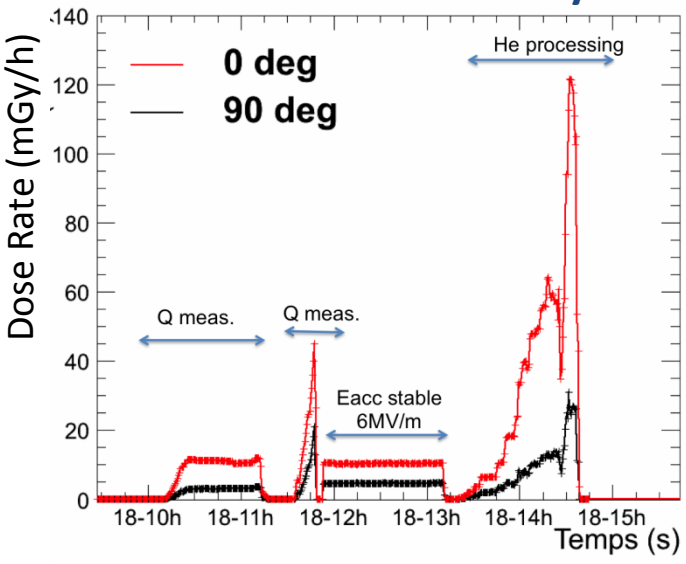


Time dependent measurements
+ passive dosimeters

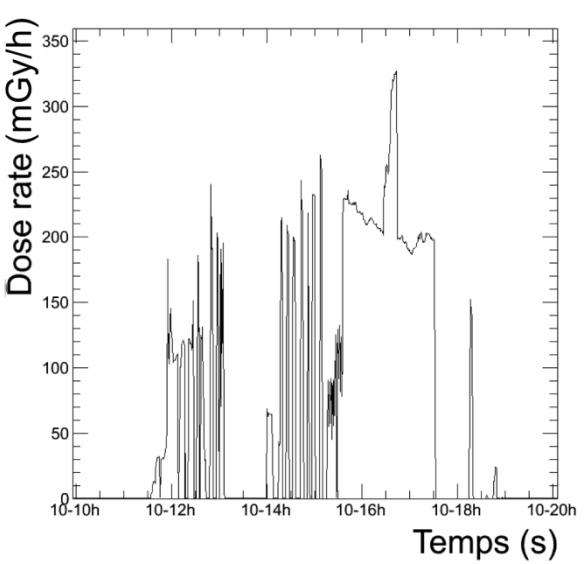
X-ray measurement results

- Measurements in different phases (conditioning, Q…)
- Implementation of the SM18 setup in FLUKA
  - Emission of electrons at the beam axis level
  - Electron emission rate derived from the measured dose rate

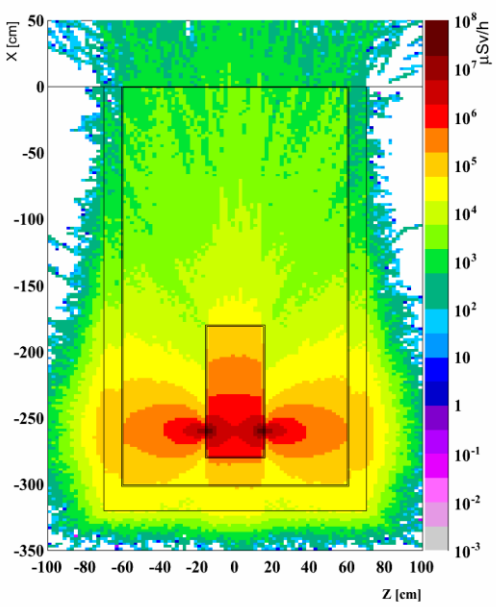
Measurements in Orsay



Measurements in SM18



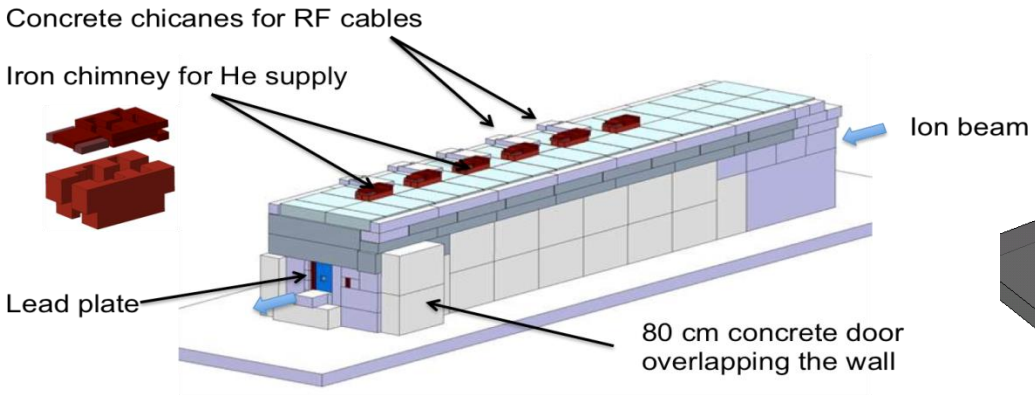
FLUKA simulation



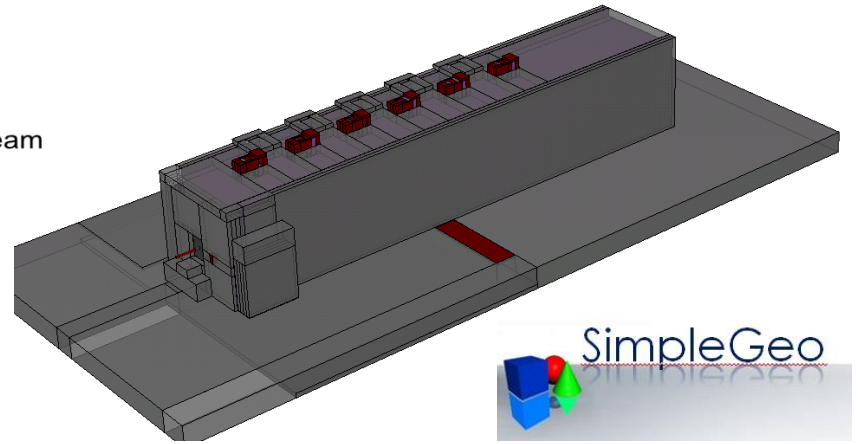
FLUKA calculations

- Detailed model of the accelerator implemented in FLUKA
- Source term based on X-ray measurements (900 keV e^-)
- Considering the most penalizing case (conditioning of all cavities at the same time)

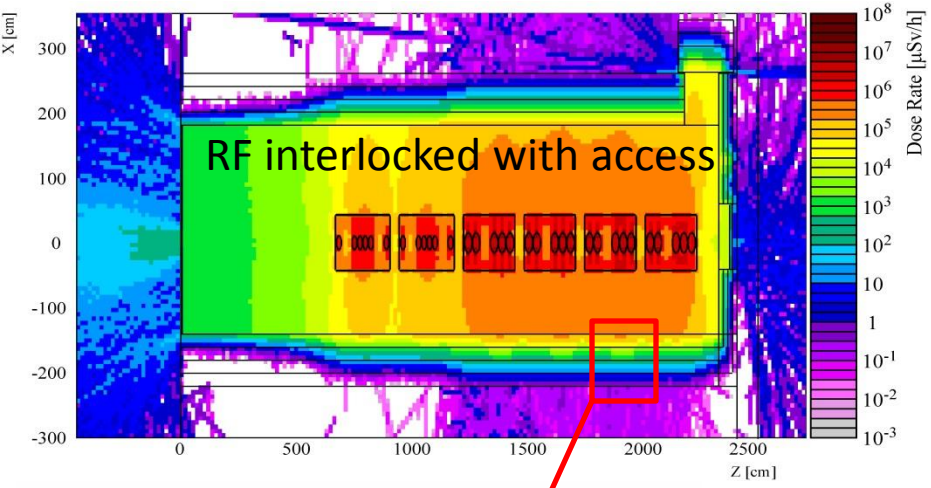
3D model

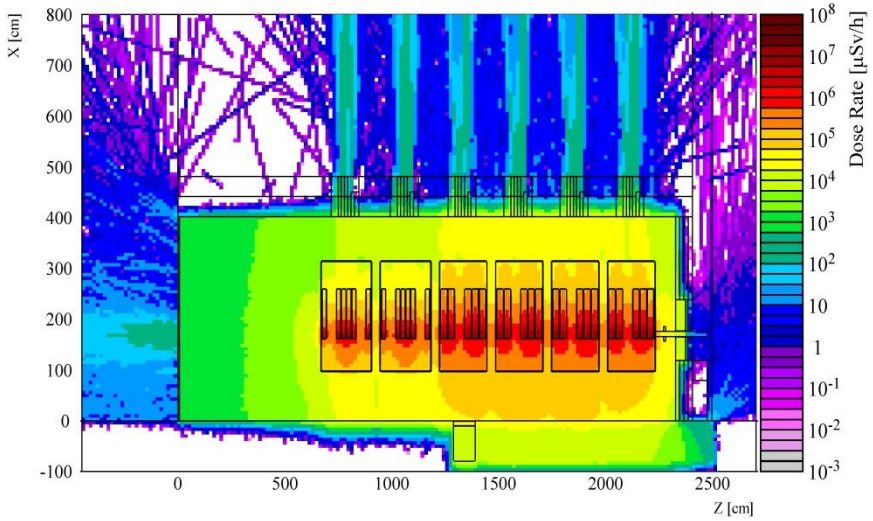


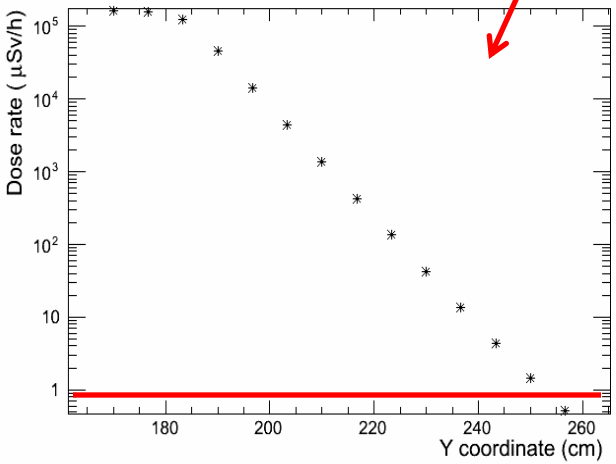
FLUKA geometry



Some results







- 10^5 dose reduction factor
- Exclusion area on the roof (RF on)
- Simulations for Phase 1 and 2
- Conservative scenario…

Outline

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Operational parameters

- RIBs delivered at very low intensity (~ppA)
- Stable beam (C, N, O, Ne or Ar) for setup from REXEBIS rest gas or gas injection
  - 20 e-pA (beam tuning on a weekly basis)
  - Exceptionally (typically once a year) up to 500 e-pA for commissioning and for machine development
- Gas injection is done by experts only and can be destructive (in case of gas leaked in EBIS)

1 p-e pA = 6.25×10^6 particle-charge /s

Prompt dose rate

- Analytical approach for different combinations of beam/target
- Neutron dose rate @ 1 m and 90 degree
- Verified with FLUKA

(approach described in ISAC-II safety file)

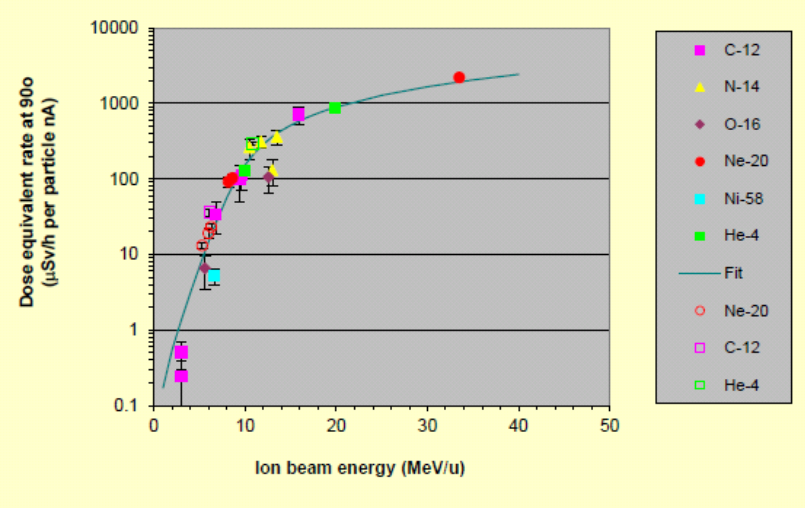
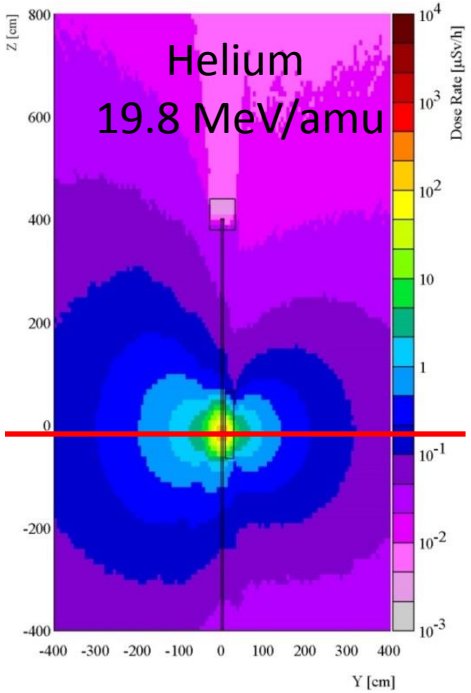
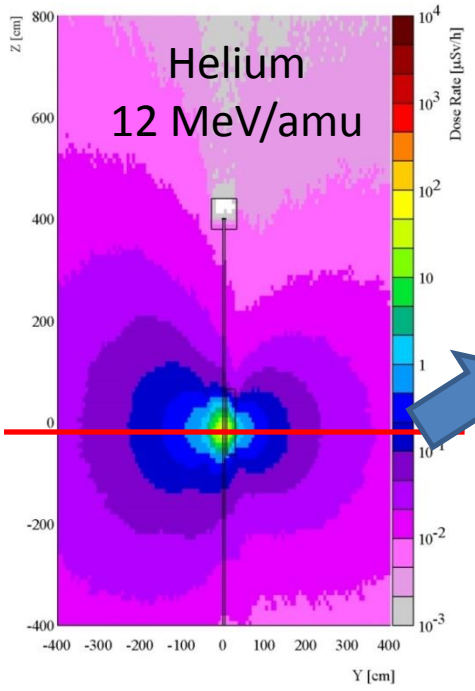


Figure 7-3: The neutron dose rate at 1 m and at 90° from the interaction point of ions bombarding a medium mass target (Fe, Ni or Cu). The discrete points are measured values and the solid line is a fit using the semi-empirical recipe of Walden[16].

Area Classification	Ambient Dose Rate (permanent workplaces)	Ambient Dose Rate (Low occupancy)
Supervised Radiation Area	**<3 µSv/h**	**<15 µSv/h**
Simple Controlled Radiation Area	**<10 µSv/h**	**<50 µSv/h**

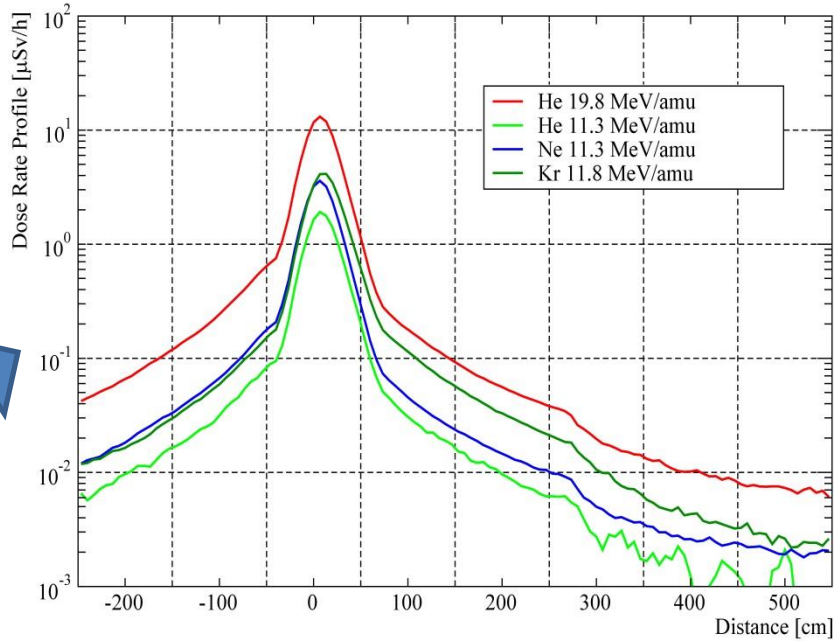
Ion interactions (FLUKA)



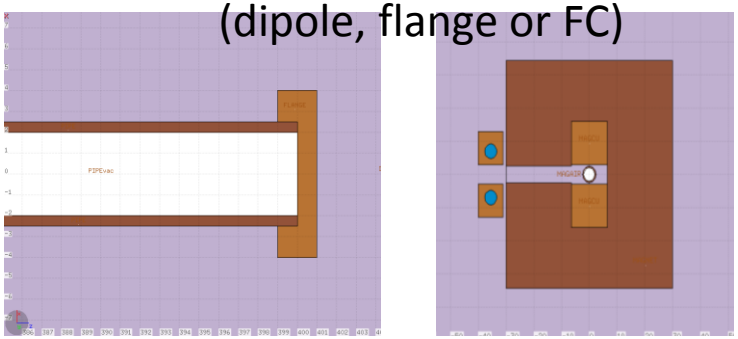


Example full beam loss of 1 ppA

Example full beam loss of 1 ppA



Generic geometries
(dipole, flange or FC)



Very good agreement with the analytical approach used in the ISAC-II safety file

Classification / mitigations

- Optimization (posting)

for beam tuning with 20 epA

- Special measure for emittance measurements (beam permit, exclusion areas ….)
- Experimental setups remain accessible during operation and standard tuning periods

	A	Z	q	A/q	MeV/u Stage1	MeV/u Stage2	MeV/u Stage3	20.0 epA Sv/h at 1 m Stage1	20.0 epA Sv/h at 1 m Stage2	20.0 epA Sv/h at 1 m Stage3	500.0 epA Sv/h at 1 m Stage1	500.0 epA Sv/h at 1 m Stage2	500.0 epA Sv/h at 1 m Stage3
He	4	2	1	4	6.47	10.20	11.45	3.8E-07	3.3E-06	5.0E-06	9.6E-06	8.2E-05	1.2E-04
	4	2	2	2	10.19	16.90	20.05	1.6E-06	6.6E-06	9.0E-06	4.1E-05	1.6E-04	2.2E-04
C	12	6	3	4	6.47	10.20	11.45	1.3E-07	1.1E-06	1.7E-06	3.2E-06	2.7E-05	4.1E-05
	12	6	4	3	7.73	12.54	14.54	2.3E-07	1.6E-06	2.4E-06	5.8E-06	4.1E-05	6.0E-05
	12	6	5	2.4	8.97	14.77	17.38	3.8E-07	2.0E-06	2.8E-06	9.5E-06	5.0E-05	6.9E-05
	12	6	6	2	10.19	16.90	20.05	5.4E-07	2.2E-06	3.0E-06	1.4E-05	5.5E-05	7.5E-05
N	14	7	4	3.5	7.01	11.22	12.81	1.4E-07	1.2E-06	1.7E-06	3.5E-06	2.9E-05	4.3E-05
	14	7	5	2.8	8.09	13.19	15.37	2.3E-07	1.5E-06	2.2E-06	5.8E-06	3.8E-05	5.4E-05
	14	7	6	2.333333333	9.15	15.08	17.77	3.5E-07	1.7E-06	2.4E-06	8.6E-06	4.3E-05	6.0E-05
	14	7	7	2	10.19	16.90	20.05	4.7E-07	1.9E-06	2.6E-06	1.2E-05	4.7E-05	6.4E-05
O	16	8	4	4	6.47	10.20	11.45	9.6E-08	8.2E-07	1.2E-06	2.4E-06	2.1E-05	3.1E-05
	16	8	5	3.2	7.42	11.97	13.79	1.5E-07	1.1E-06	1.7E-06	3.8E-06	2.9E-05	4.2E-05
	16	8	6	2.666666667	8.36	13.67	15.98	2.3E-07	1.4E-06	2.0E-06	5.7E-06	3.4E-05	4.9E-05
	16	8	7	2.285714286	9.28	15.31	18.07	3.2E-07	1.5E-06	2.1E-06	7.9E-06	3.8E-05	5.3E-05
	16	8	8	2	10.19	16.90	20.05	4.1E-07	1.6E-06	2.2E-06	1.0E-05	4.1E-05	5.6E-05
Ne	20	10	5	4	6.47	10.20	11.45	7.7E-08	6.6E-07	9.9E-07	1.9E-06	1.6E-05	2.5E-05
	20	10	6	3.333333333	7.23	11.62	13.33	1.1E-07	8.7E-07	1.3E-06	2.8E-06	2.2E-05	3.2E-05
	20	10	7	2.857142857	7.98	13.00	15.12	1.5E-07	1.0E-06	1.5E-06	3.9E-06	2.6E-05	3.7E-05
	20	10	8	2.5	8.73	14.33	16.83	2.1E-07	1.2E-06	1.6E-06	5.2E-06	2.9E-05	4.1E-05
	20	10	9	2.222222222	9.46	15.64	18.47	2.7E-07	1.2E-06	1.7E-06	6.7E-06	3.1E-05	4.3E-05
	20	10	10	2	10.19	16.90	20.05	3.3E-07	1.3E-06	1.8E-06	8.2E-06	3.3E-05	4.5E-05
	22	10	5	4.4	6.12	9.54	10.55	5.9E-08	5.0E-07	7.5E-07	1.5E-06	1.2E-05	1.9E-05
	22	10	6	3.666666667	6.81	10.85	12.32	8.2E-08	6.9E-07	1.0E-06	2.1E-06	1.7E-05	2.6E-05
	22	10	7	3.142857143	5.07	7.50	13.99	1.9E-08	1.1E-07	1.2E-06	4.7E-07	2.8E-06	3.1E-05
	22	10	8	2.75	8.19	13.37	15.59	1.5E-07	9.7E-07	1.4E-06	3.8E-06	2.4E-05	3.5E-05
	22	10	9	2.444444444	8.86	14.57	17.13	2.0E-07	1.1E-06	1.5E-06	5.0E-06	2.7E-05	3.8E-05
	22	10	10	2.2	9.53	15.75	18.62	2.5E-07	1.1E-06	1.6E-06	6.2E-06	2.9E-05	3.9E-05
Ar	40	18	9	4.444444444	6.08	9.47	10.46	3.2E-08	2.7E-07	4.0E-07	8.0E-07	6.7E-06	1.0E-05
	40	18	10	4	6.47	10.20	11.45	3.8E-08	3.3E-07	5.0E-07	9.6E-07	8.2E-06	1.2E-05
	40	18	11	3.636363636	6.85	10.92	12.40	4.6E-08	3.8E-07	5.8E-07	1.2E-06	9.6E-06	1.4E-05
					7.23	11.62	13.33	5.5E-08	4.3E-07	6.4E-07	1.4E-06	1.1E-05	1.6E-05
					7.60	12.31	14.24	6.5E-08	4.8E-07	7.0E-07	1.6E-06	1.2E-05	1.8E-05
					7.23	11.62	13.33	4.7E-08	3.7E-07	5.5E-07	1.2E-06	9.3E-06	1.4E-05
					8.36	13.67	15.98	9.1E-08	5.5E-07	7.8E-07	2.3E-06	1.4E-05	2.0E-05
					8.73	14.33	16.83	1.0E-07	5.8E-07	8.2E-07	2.6E-06	1.4E-05	2.0E-05
					9.10	14.99	17.66	1.2E-07	6.0E-07	8.4E-07	3.0E-06	1.5E-05	2.1E-05
					9.46	15.64	18.47	1.3E-07	6.2E-07	8.6E-07	3.3E-06	1.6E-05	2.2E-05

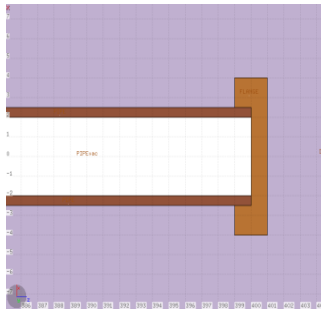
< 3 uSv/h
< 10 uSv/h
< 15 uSv/h
< 50 uSv/h
>= 50 uSv/h

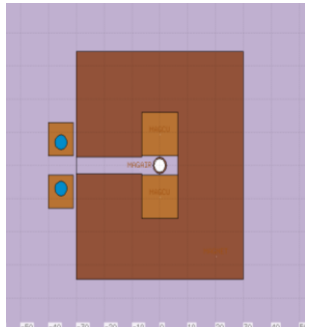
Dose rate @ 1 m / 90 degree in Sv/h

Beam induced activation

- Demonstrate that bulk activation of intercepting devices is not an issue (still contamination from RIBs !)
  - Criteria : $\sum_{i=1}^{n} A_i/LE_i < 1$ (LE = exemption limit)

	Nuclide	$T_{1/2}$	LE_i (Bq)	A_i (Bq)	A_i/LE_i
Copper target	^{73}As	80.3 d	4E+04	4.5E+00 ± 0.96 %	1.1E-04
	^{68}Ga	67.7 m	1E+05	3.1E+01 ± 1.53 %	3.1E-04
	^{68}Ge	270.8 d	8E+03	3.1E+01 ± 1.53 %	3.9E-03
	^{65}Zn	244.2 d	1E+02	2.5E+01 ± 1.02 %	2.5E-01
	^{63}Ni	100.1 y	7E+04	8.6E+00 ± 1.43 %	1.2E-04
	^{60}Co	5.3 y	1E+02	1.2E+01 ± 3.25 %	1.2E-01
	^{57}Co	272.0 d	1E+03	3.5E+01 ± 1.37%	3.5E-02
	^{56}Co	77.3 d	1E+02	1.2E+00 ± 2.37%	1.2E-02
	^{55}Fe	2.7 y	3E+04	5.5E+01 ± 1.36%	1.8E-03
	^{54}Mn	312.5 d	1E+02	1.6E+01 ± 2.20%	1.6E-01
	^{3}H	12.3 y	1E+05	1.3E+02 ± 0.99%	1.3E-03
					Sum = 0.00141





- No activation of the water in the dipole cooling circuit

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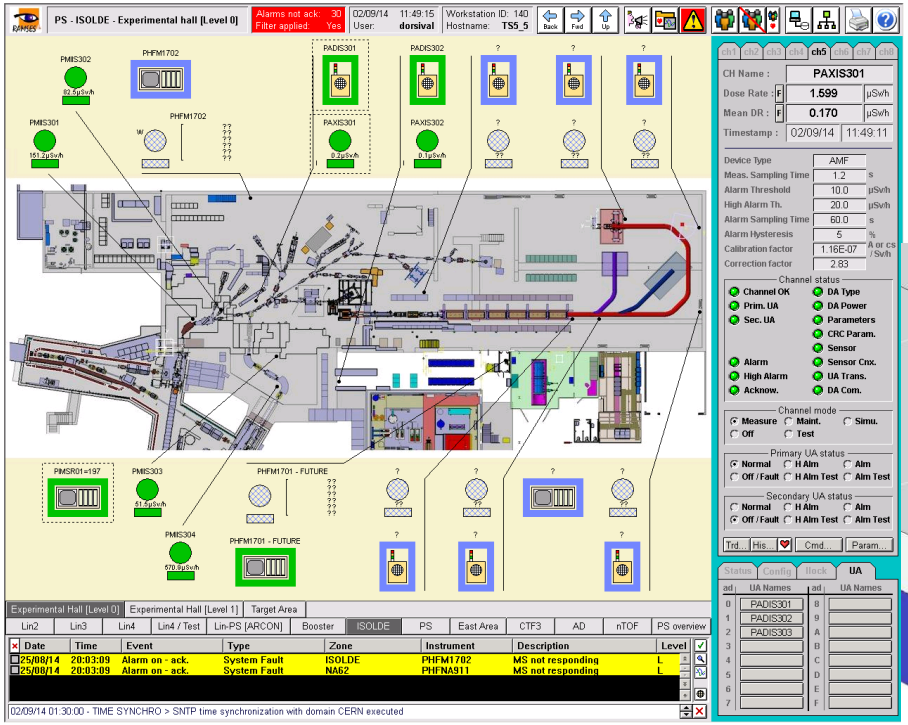
- Radiation Monitoring System upgrade
- Conclusions

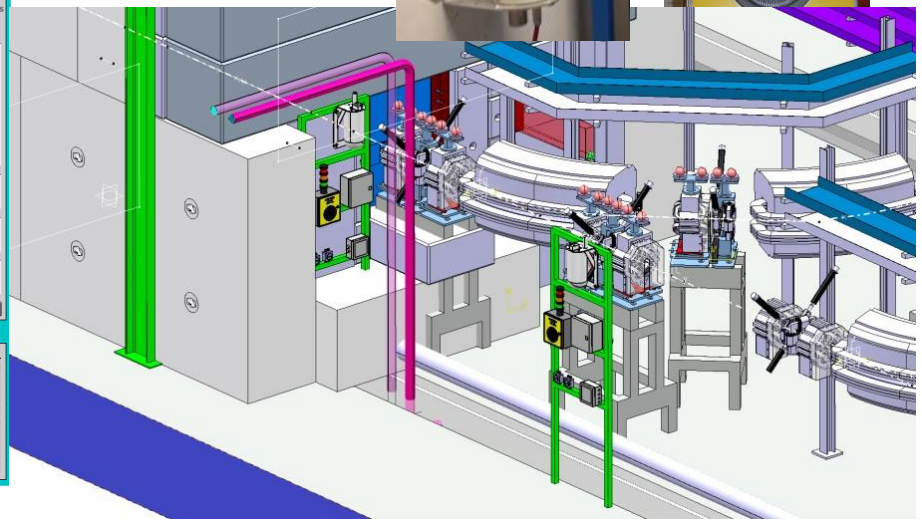
Monitoring upgrade

- Additional radiation monitors needed to ensure the proper area classification
  - Unsufficient number of monitor in some areas
  - New projects
- Old monitoring system not scalable (ARCON)
- New architectural options
  - gamma monitoring (GRAMS)
  - RAMSES (LHC standard)
- Scheduling: LS1 was a good time window

New RAMSES system

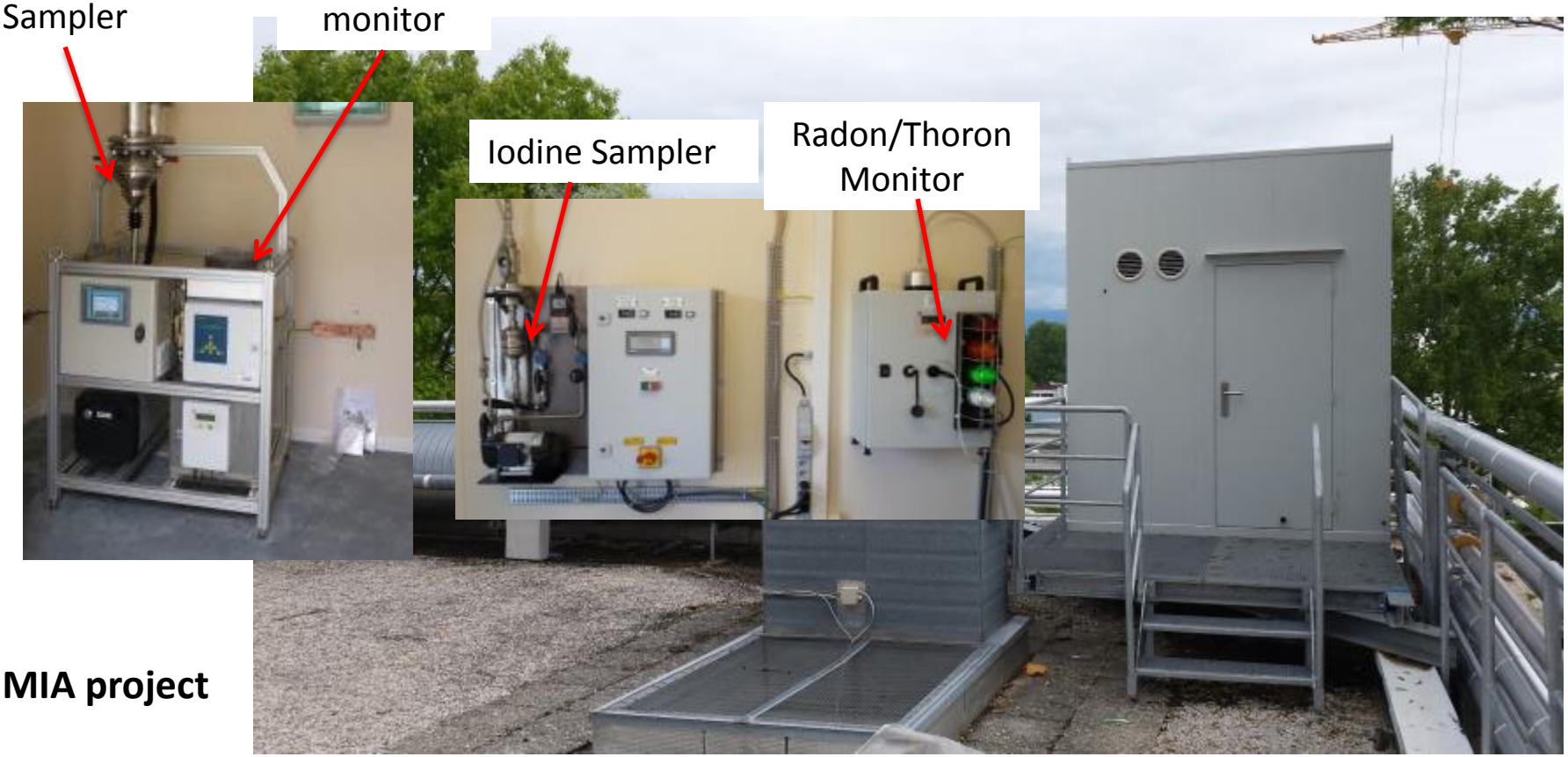
- Ionisation chambers, induced activity / X-ray monitors, Hand foot monitors…..





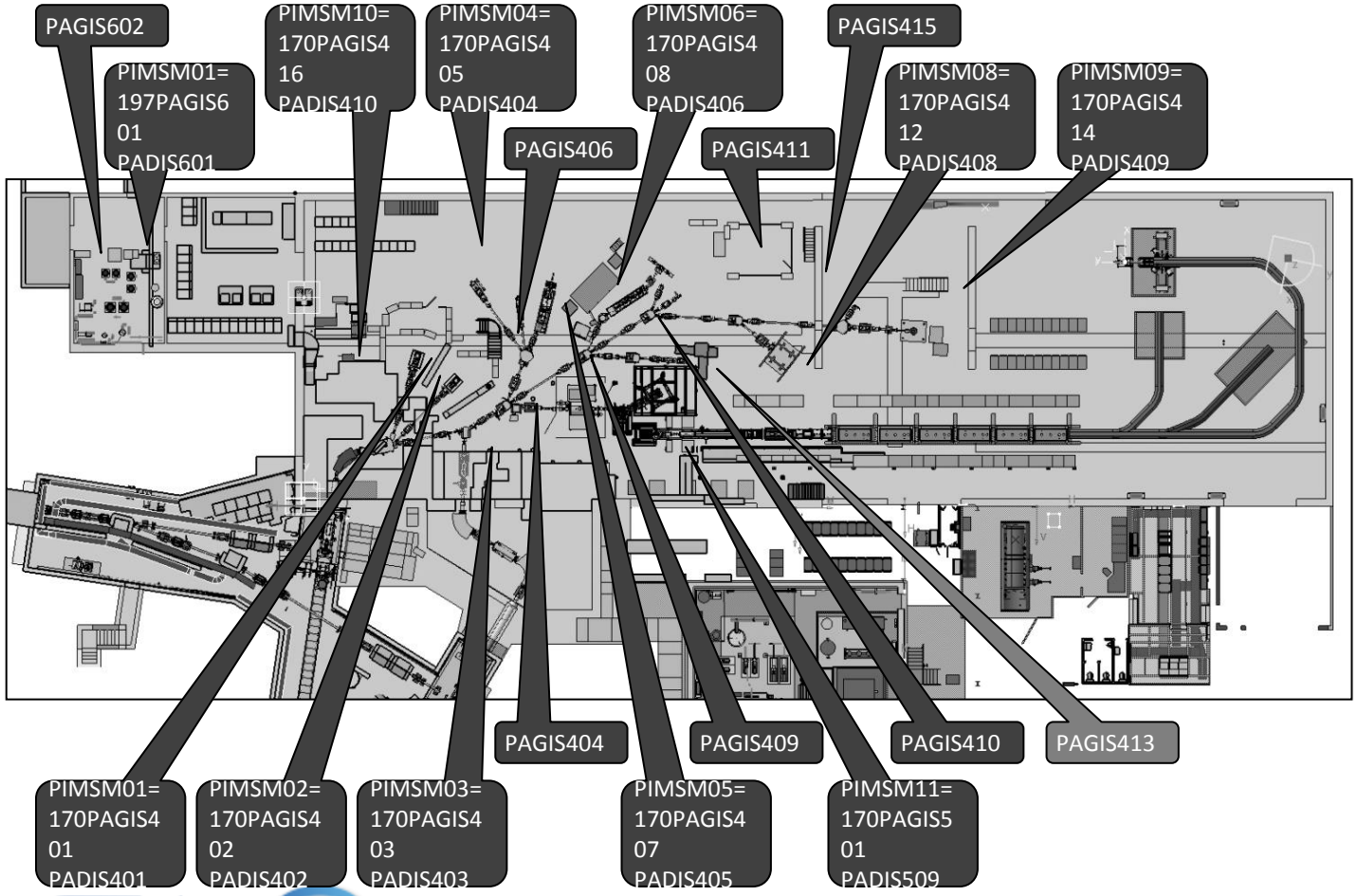
Environmental monitoring

Monitoring of facility releases



INEMIA project

GRAMS in the hall

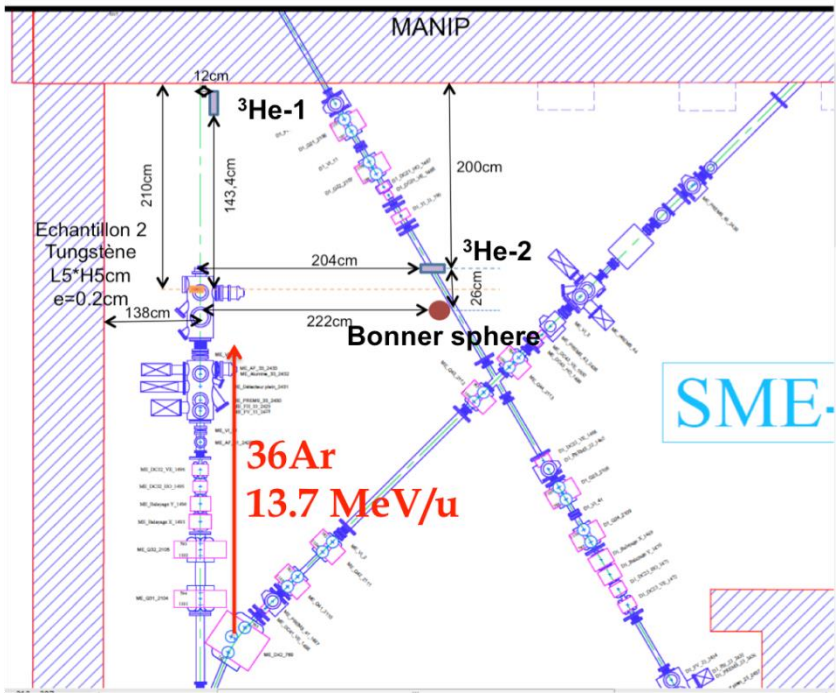


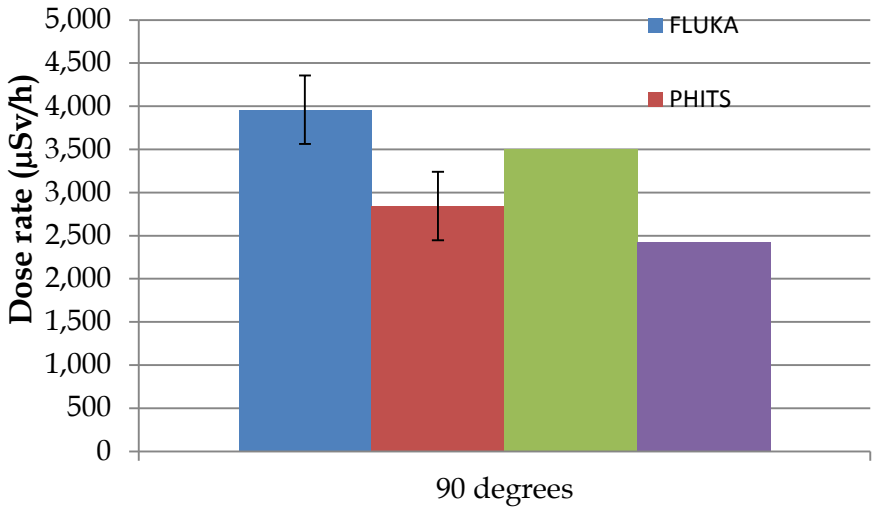
Conclusions

- Complete radiological analysis for the new post-accelerator
  - Post-accelerator shielding (X-ray measurements and FLUKA calculations)
  - Prompt dose due to ion beams interactions
- New monitoring system will facilitate future upgrades of ISOLDE (MEDICIS, TSR….)
- Thanks to partners visited in the frame of the CATHI program (INFN Legnaro, Triumf, GANIL, IPNO, CEA where Sandra made her secondment…)

Questions ?

Experimental benchmark

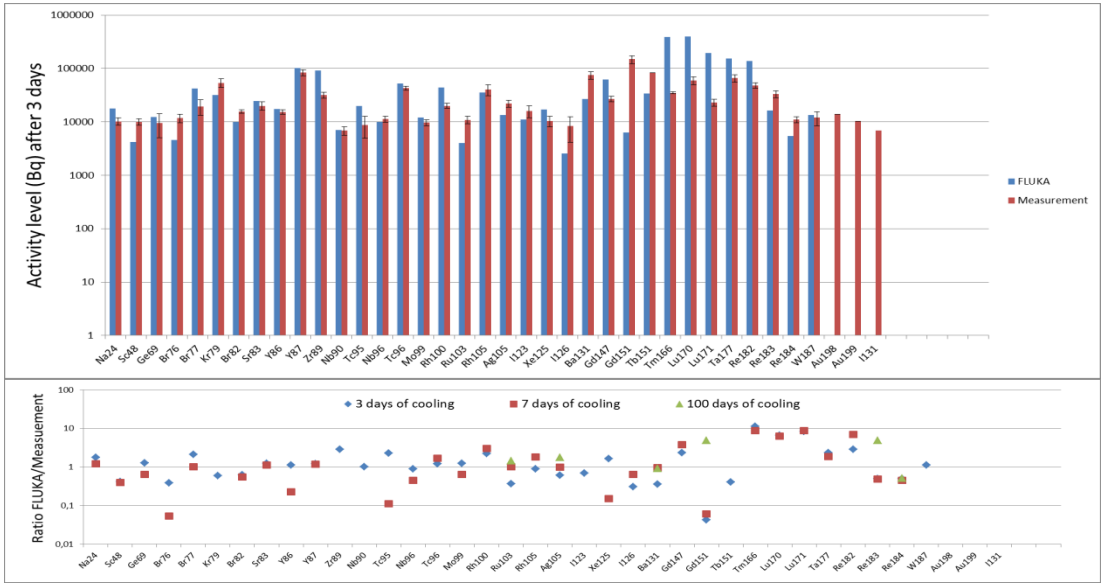




Uncertainty on beam intensity prevent to be conclusive

	Interaction model	Evaporation model	Evolution model
PHITS 2011.2b-5	BME	SDM	DCHAIN SPD2001
		GEM	
FLUKA 2.64	QMD	New evap model (heavy fragments)	RADDECAY

Experimental benchmark



Uncertainty on beam intensity prevent to be conclusive