Development of an In-Situ Radiological Classification Technique for Material from CERN's Accelerators and Experimental Facilities

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Introduction

Since 1954 **CERN, The European Organization for Nuclear Research,** operates high energy accelerators for particle physics research. Material flow out of the accelerator facilities and experimental zones originates from maintenance, repair and upgrade actions as well as from decommissioning. After several years of operation, due to beam losses and particle interactions, radioactivity can be induced in certain accelerator components. For safe handling, transport and elimination of these components it is essential to perform a reliable radiological characterization already at the exit of the accelerator.

1 Induced Radioactivity in High-Energy Accelerators

- In High-energy accelerators proton losses create hadronic showers. The showers consist of secondary **n, p,** π^+, π^- & **photons**.
- These secondary particles can react in
  - Spallation reaction of high-energy secondary hadrons e.g. **(p, xp), (p, xn), (n, xp), (n, xn)**
  - Radiative neutron capture **(n,** γ**)**
  - Compound nucleus reactions e.g. **(p, n), (p, 2n), (p, pn), (p,** α**)**

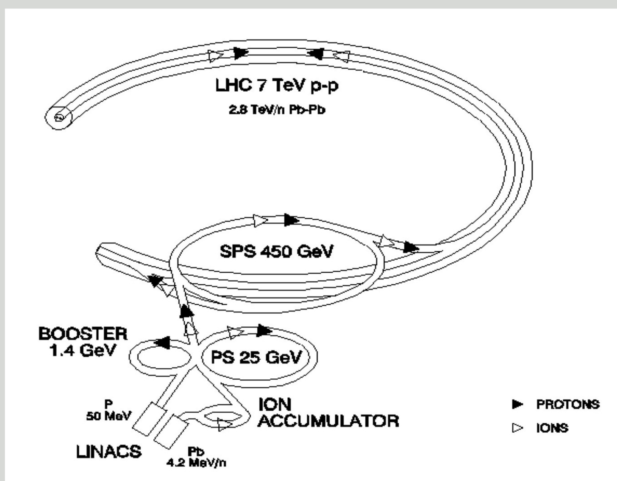
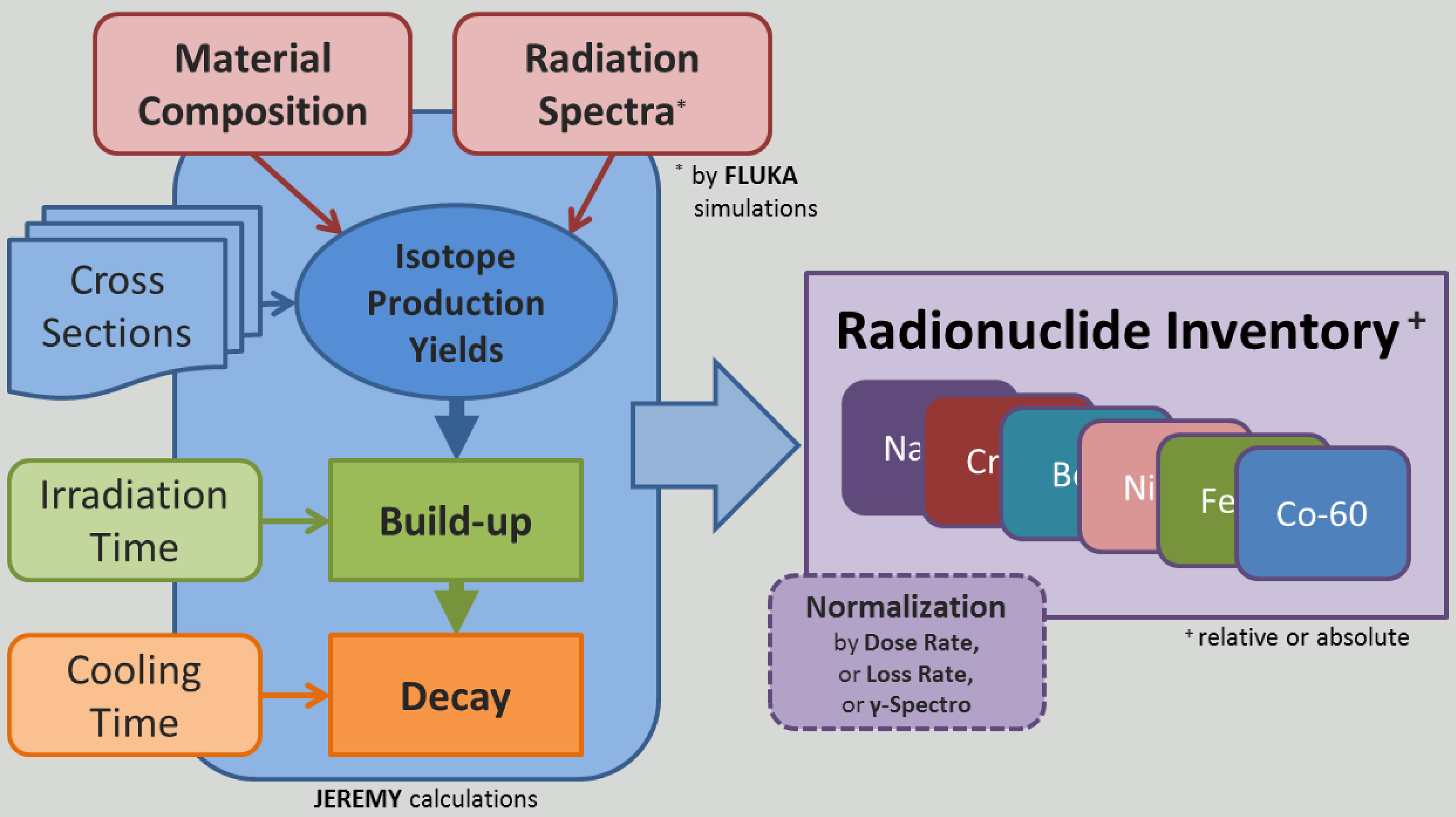


Figure: CERN accelerator complex, corresponding beam energies included

2 Situation at CERN / Current Characterization Process

- The situation in CERN accelerator facilities is characterized by
  - wide ranges of particles and particle energies
  - many different materials and material compounds
  - various irradiation & cooling time scenarios
- This leads to a large variety of time-dependent radionuclide inventories!



3 Radionuclide Inventories / Activity Limits [Switzerland & France]

The mass specific activity is, apart from dose rate and surface contamination, one of the main criteria for the radiological characterization. Since CERN's installations straddle across the French-Swiss boarder, for elimination of material as TFA(Très faible activité) to France the IRAS classification and for Free-Release of material to Switzerland the LE limits have to be respected.

$$\mathbf{LE} = \sum_i \frac{a_i}{LE_i} \quad \text{and} \quad \mathbf{IRAS} = \sum_i \frac{a_i}{IRAS_i}$$

	Steel	Copper	Alu	Steel	Copper	Alu	Steel	Copper	Alu
	No cooling time			after 10 years cooling			after 20 years cooling		
activity fraction > 10%	Fe-55 Cr-51 Mn-54	Cu-64	Na-22 H-3 Cr-51 Cu-64	Fe-55 Co-60 Ni-63 H-3	Co-60 Ni-63 H-3	H-3 Na-22	Ni-63 H-3 Co-60 Fe-55	Ni-63 H-3 Co-60	H-3
activity fraction < 10%	Co-60 V-49 Co-58 Co-57 H-3 V-48 Mn-52	Co-60 Co-58 Co-57 Fe-55 H-3 Ni-63 Mn-54	Na-24 Mn-54 Fe-55 Be-7 V-49 Zn-65		Fe-55	Fe-55 Ni-63			Ni-63 Na-22
activity fraction < 1%	Ni-63 Co-56 Mo-99 Tc-99M Sc-46 Ni-57 Fe-59 Co-58m Sc-47 Sc-44	Co-56 Cr-51 Co-58m Ni-57	Co-58 Co-57 V-48 Mn-56 Sc-46 Mn-52 Sc-47 Ni-63 Co-60 Nb-95				Sc-44 Ti-44	Fe-55	
	Σ > 99%	Σ > 99%	Σ > 99%	Σ > 99%	Σ > 99%	Σ > 99%	Σ > 99%	Σ > 99%	Σ > 99%

Figure: Calculated radionuclide inventories of common materials; 20 years of irradiation; cooling times of 0, 10 and 20 years; beam energy of 7 TeV; material position adjacent to a magnet

Isotope	LE*	IRAS*
H-3	200	1000
Be-7	400	(10)
Na-22	3	10
Na-24	20	(10)
Cl-36	10	1000
Ti-44	2	10
V-49	600	1000
Cr-51	300	(10)
Mn-54	10	10
Fe-55	30	1000
Co-57	50	100
Co-58	10	(10)
Co-60	1	10
Ni-63	70	1000
Cu-64	80	(10)
Zn-65	3	10
Ag-110	4	10
Cs-137	0.8	10
Eu-152	7	10

*[Bq/g]

Figure: LE limits and IRAS classification for common radionuclides. Taken from ORAP(Swiss) & ANDRA regulations(French)

4 FLUKA MonteCarlo Simmulations

Within the characterization process MonteCarlo simulations (FLUKA code) are used to obtain e.g. particle spectra, radionuclide production rates, dose rate/activity conversion factors or geometrical effects

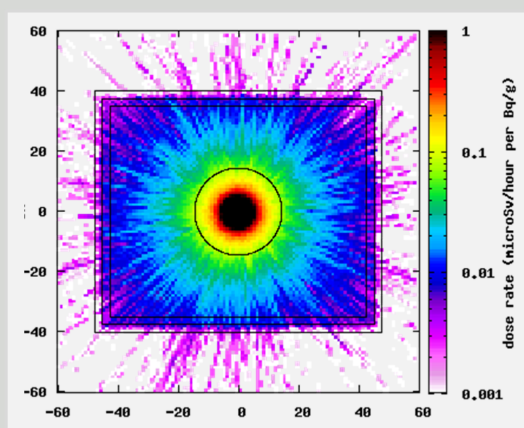


Figure: Dose rate distribution

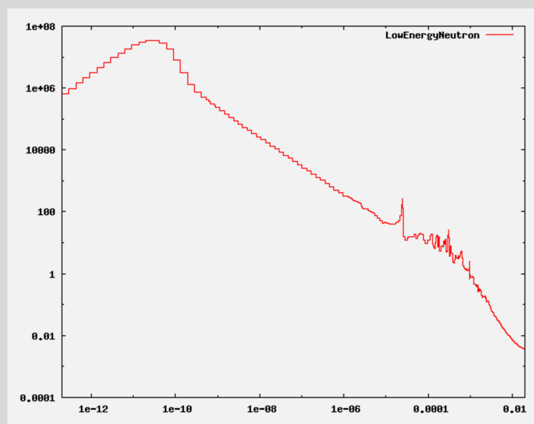


Figure: Neutron particle spectra

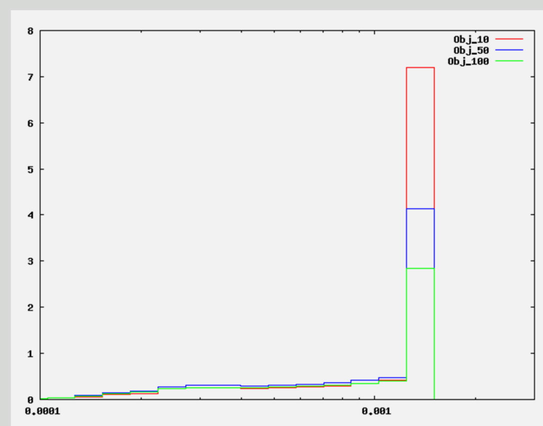


Figure: Auto-attenuation effects

5 Conclusion and Future Prospects

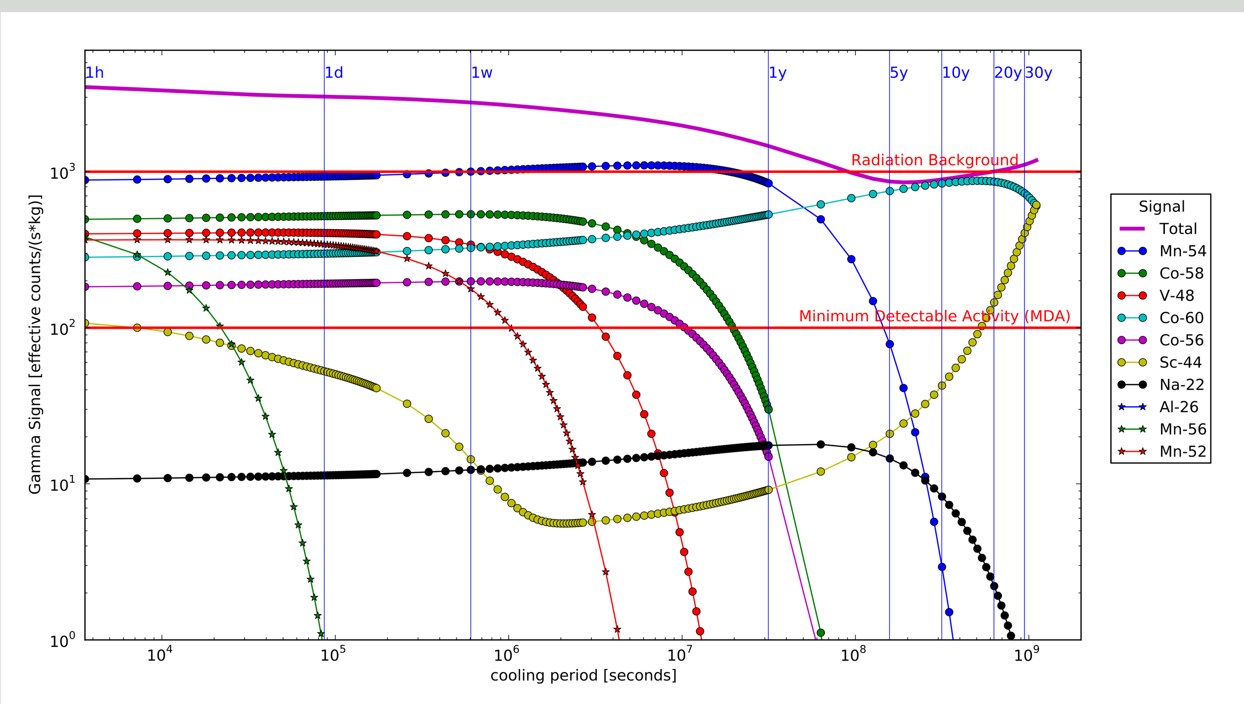


Figure: Resulting gamma signal of irradiated steel (20years, 7 TeV) over the cooling time. Values folded with device efficiency and normalized to mass specific activity a_{sum} = LE

- The current process has been established & validated
  - Use of total gamma chamber is applicable, even for very low activities
  - Gamma/beta ratios are known for common materials
  - 7 typical radiation fields, that represent the most common CERN radiation scenarios, are identified (ActiWiz project*)
- The next steps to identify enveloping radionuclide inventories
  - Finalization of gamma/beta studies for more materials
  - Validation of enveloping radiation spectra
  - Combination of total gamma chamber & In-situ gamma spectroscopy measurements

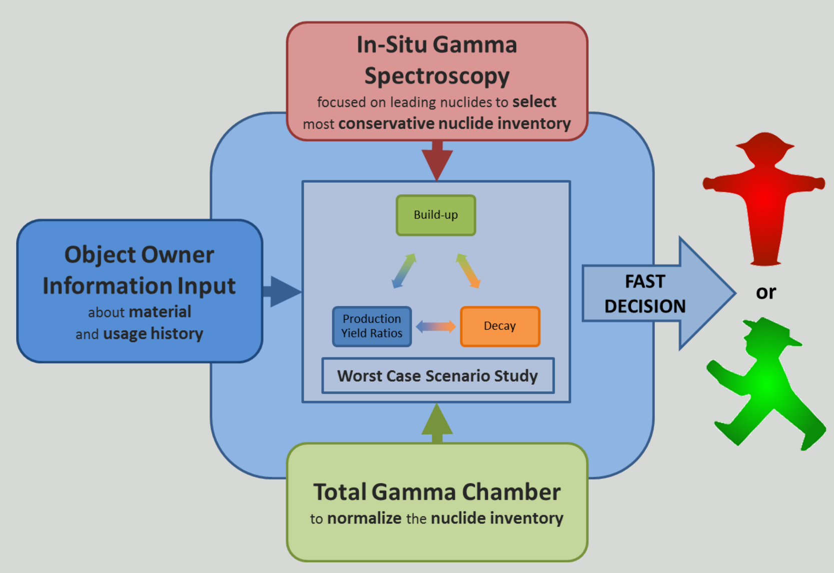


Figure: Possible future characterization process

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