HSE
Occupational Health & Safety
and Environmental Protection unit

Characterization Methodologies and Management of Radioactive Waste at CERN

Nabil MENAA/ CERN

Radiation Protection Group (RP) - Occupational Health & Safety and Environmental Protection Unit (HSE)

Authorship Acknowledgment

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Lecture given to participants of the European Summer School organized from 1 to 5 July 2024.
https://indico.in2p3.fr/event/20710/

1. CERN introduction
2. Radioactive Waste management at CERN
3. Radioactive waste produced
4. Radioactive waste classification and Elimination pathways
5. Radioactive waste Reception and Processing
6. Radioactive waste characterization
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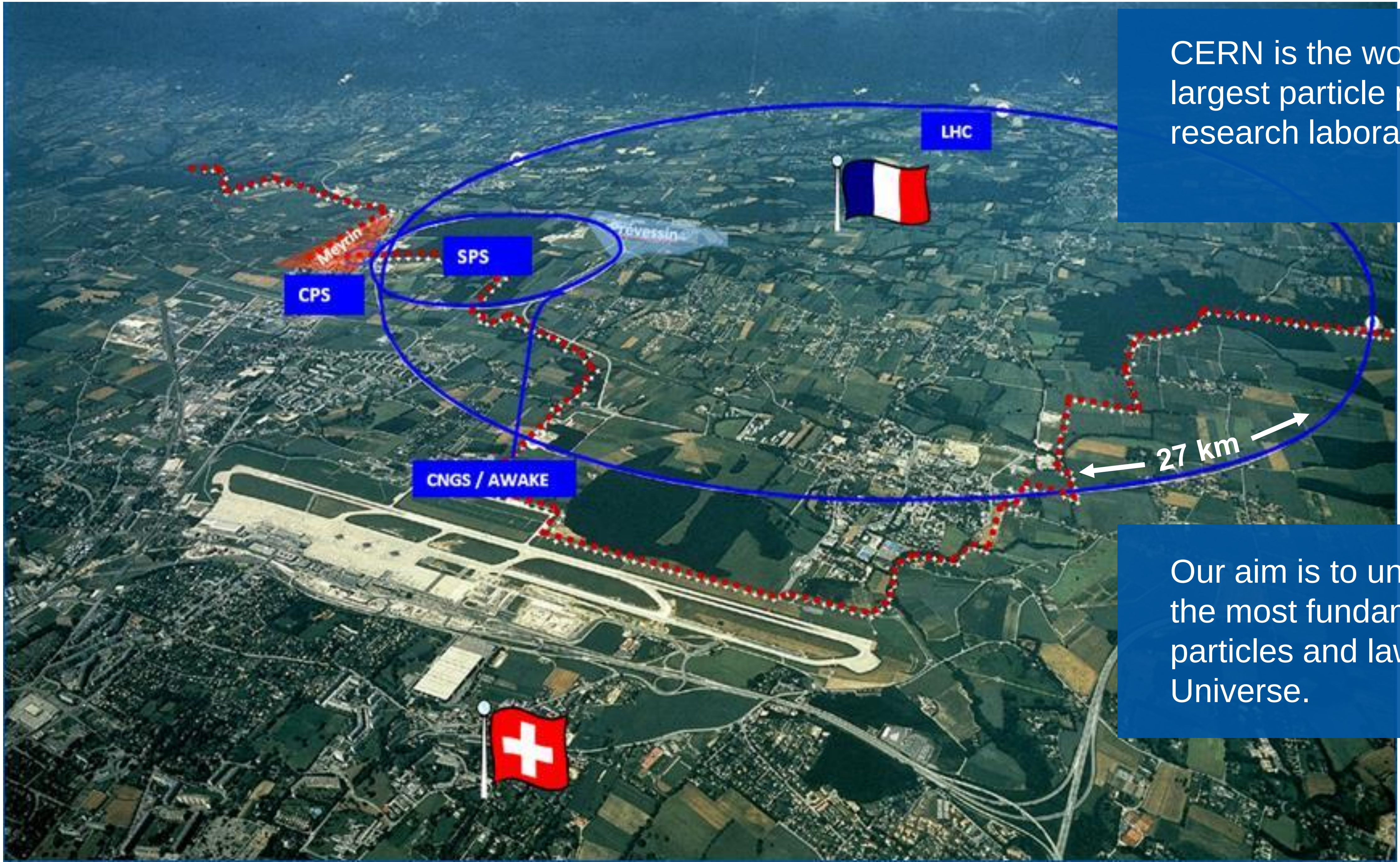
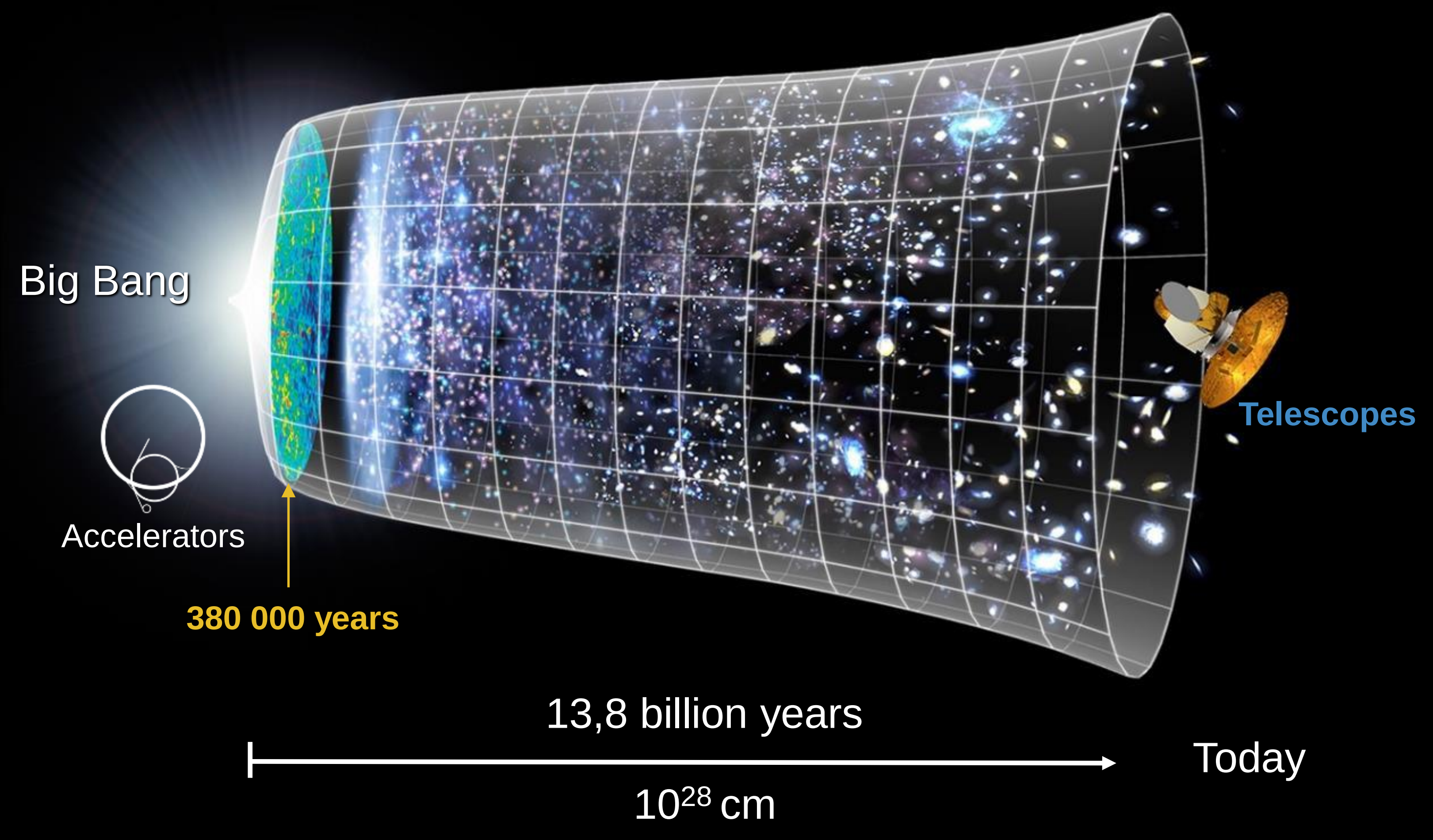
8. Questions/answers
9. Career opportunities at CERN


THE WORLD'S LARGEST
PARTICLE PHYSICS LABORATORY



CERN is the world's largest particle physics research laboratory.

Our aim is to understand the most fundamental particles and laws of the Universe.

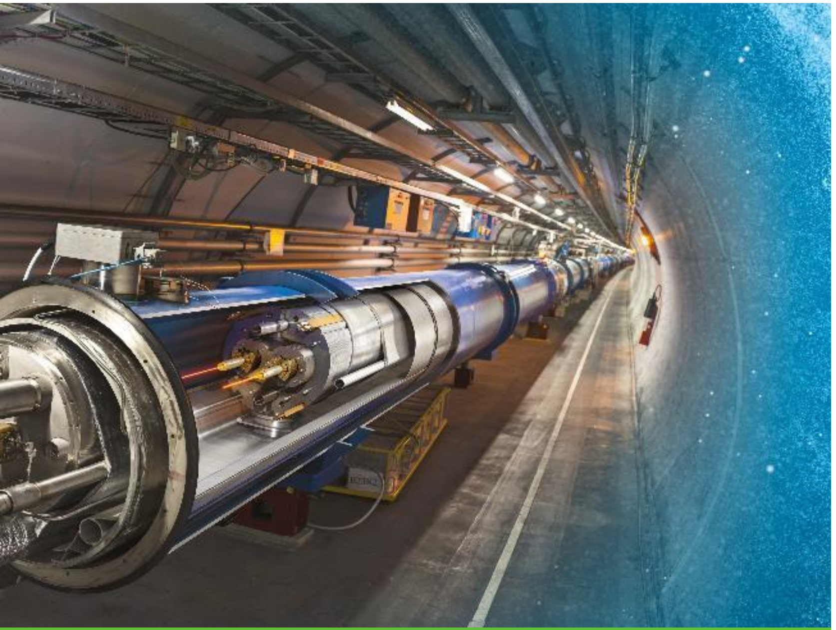


How did the Universe begin?

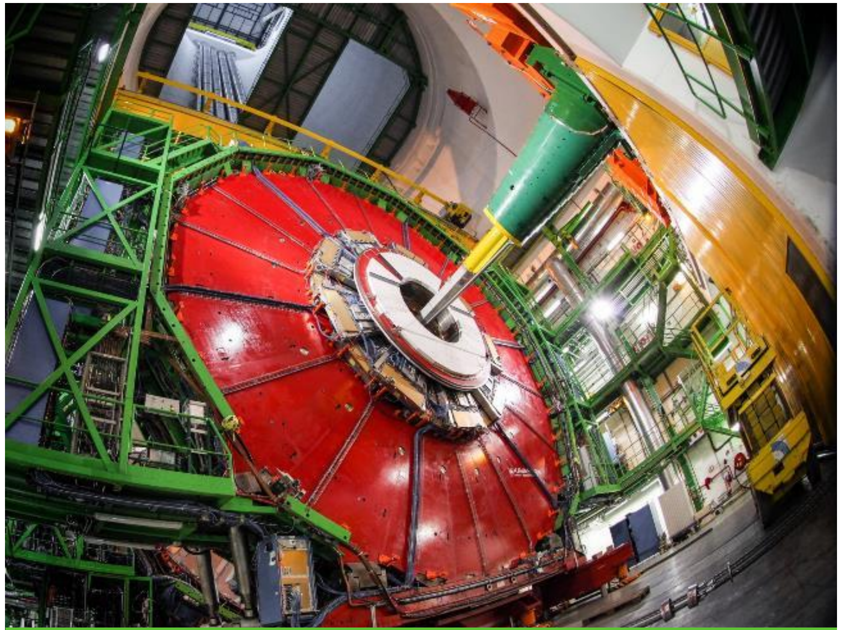
- We are reproducing the conditions that prevailed a fraction of a second after the Big Bang, in order to understand the structure and evolution of the Universe.

Key facts related to CERN

- ~400 buildings hosting radiation areas
- 7000 to 11000 persons accessing in radiation areas every year
- More information: https://home.cern/resources/faqs



~50 km of accelerator tunnels



Over 160 physics experiments

Radioactive waste produced

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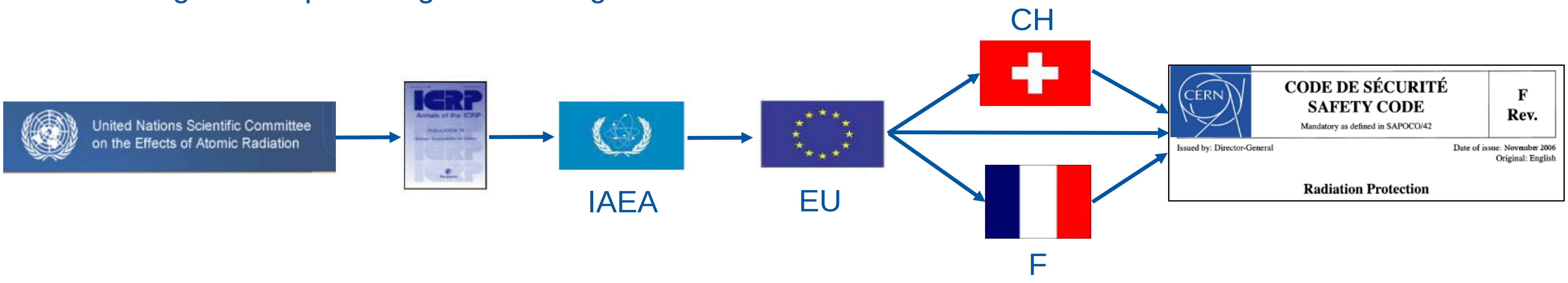
CERN Radiation Protection Legal Framework

CERN is an intergovernmental Organization subject not to national but **international law**. Its status has been recognized by its host states where it must ensure their safety and security.

CERN has the right to establish **its own rules** as necessary for the proper functioning of the Organization, among others, **Safety Rules**.

CERN agrees to follow best practices in matters of radiation protection and radiation safety taking into account the legislation of its host states, as well European and international standards. Their implementation is discussed between the host states authorities, ASN (F) and OFSP (CH), and CERN according to a "Tripartite Agreement” signed in 2010.



Tripartite agreement: Article 7 – Radioactive Waste

Radioactive waste from CERN Facilities is **disposed of by the host States** according to the existing pathways, in conformity with their national legislation.

For the management of radioactive waste, the Organization draws up and communicates to the other Parties a **waste study** covering all Facilities.

This study specifies which elimination pathways are planned for each type of waste produced. It is updated as necessary. The waste study takes into account the need for a **fair distribution** between the host States, according to the quantity, activity and toxicity of the waste, and aims to ensure that it is disposed of through the **most technically and economically advantageous pathways**.

The choice of **elimination pathways is approved by the Parties** after review in Tripartite meeting.

The Organization keeps an up-to-date **inventory of radioactive waste** disposed of in the host States and present on its site.

The Occupational Health& Safety and Environmental Protection Unit (HSE)

Expert advice and services in matters of ***Occupational Health and Safety & Environment***

Establishing ***Safety Rules*** as required for the proper functioning of the Organization

Granting ***authorizations*** for installations, equipment, activities and projects with major Safety implications

Monitoring the environmental impact of the Organization's activities

Responsible for ***Radiation Protection***

Responsible for ***Occupational Medicine***

Responsible for ***Fire and Rescue and Emergency response***

The HSE Unit reports directly to the Director General

CERN Radiation Protection Group

Mandate

"The Radiation Protection Group (HSE-RP) of the HSE Unit ensures that personnel on the CERN sites and the public are protected from potentially harmful effects of ionizing radiation linked to CERN activities. The HSE-RP Group fulfils its mandate in collaboration with the CERN departments owning or operating sources of ionizing radiation and having the responsibility for Radiation Safety of these sources."

Operational Radiation Protection

- Risk assessments for personnel and public
- Definition of protective measures, authorization of operation
- Lead in implementation of ALARA principle
- Studies for projects and upgrades
- R&D for tools and methods, operation of shielding benchmark facility

Environmental Radiation Protection

- Environmental monitoring program Studies of environmental impact for upgrades and new facilities

Radioactive Waste Management

- Operation of pre-conditioning and interim storage facility
- Waste disposal towards host states
- Support to departments in radioactive waste minimization and treatment

Individual Dosimetry

- Monitoring of external and internal doses and reporting (CERN dosimetry service carries official accreditation in Switzerland)
- Operation of calibration facility

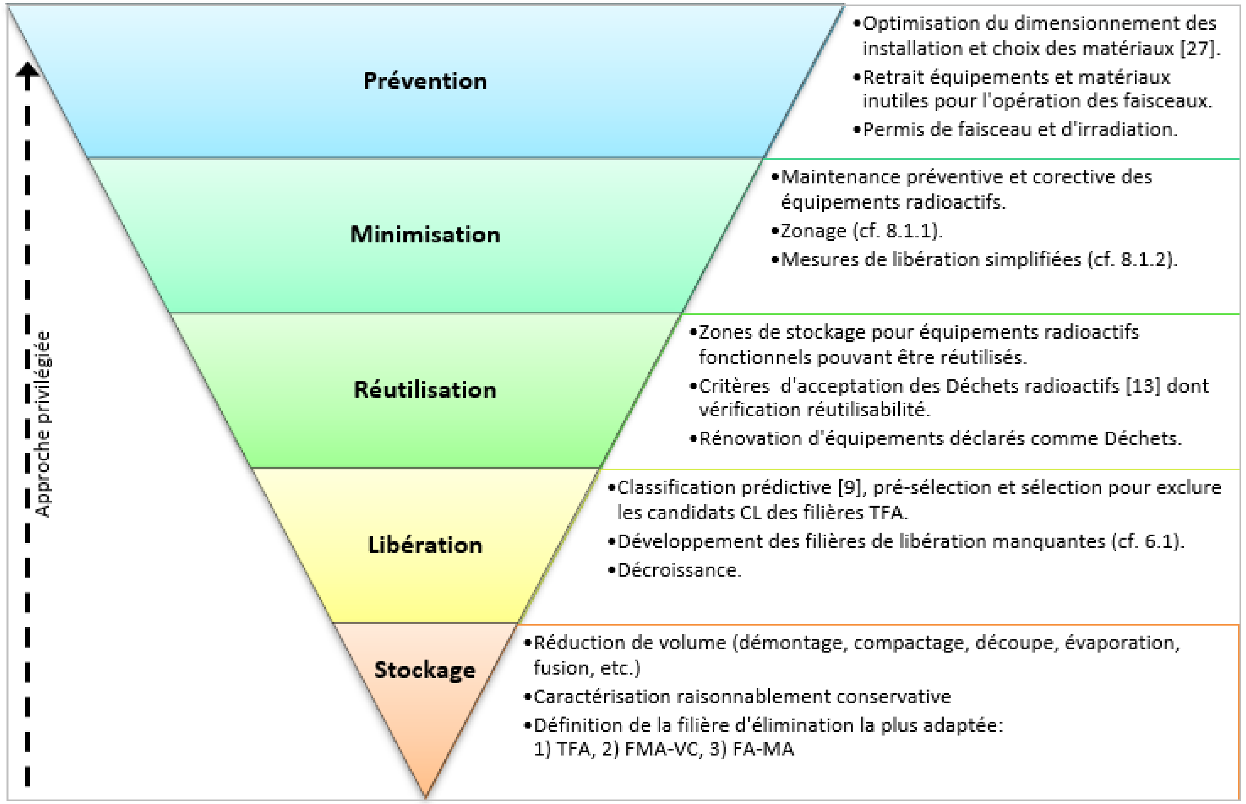
Instrumentation

- Development, Installation and operation of radiation monitoring system

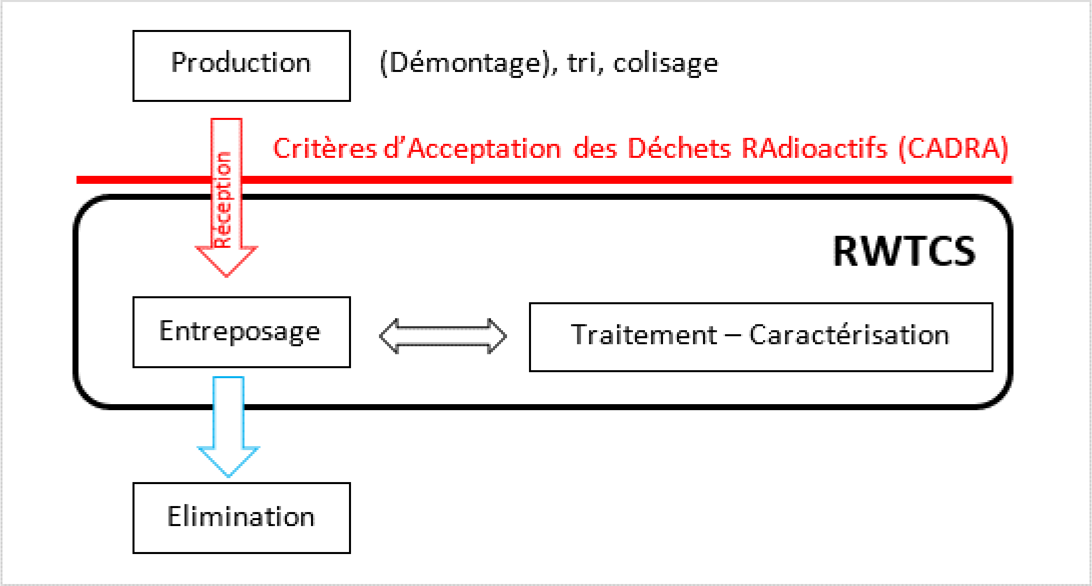
Services

- Inter/intra-site radioactive transport
- Shipping (import/export) of radioactive goods
- Radiological characterization of material and waste, operation of analytical laboratory
- Radioactive sources service

Radioactive Waste management – *policy and organization*

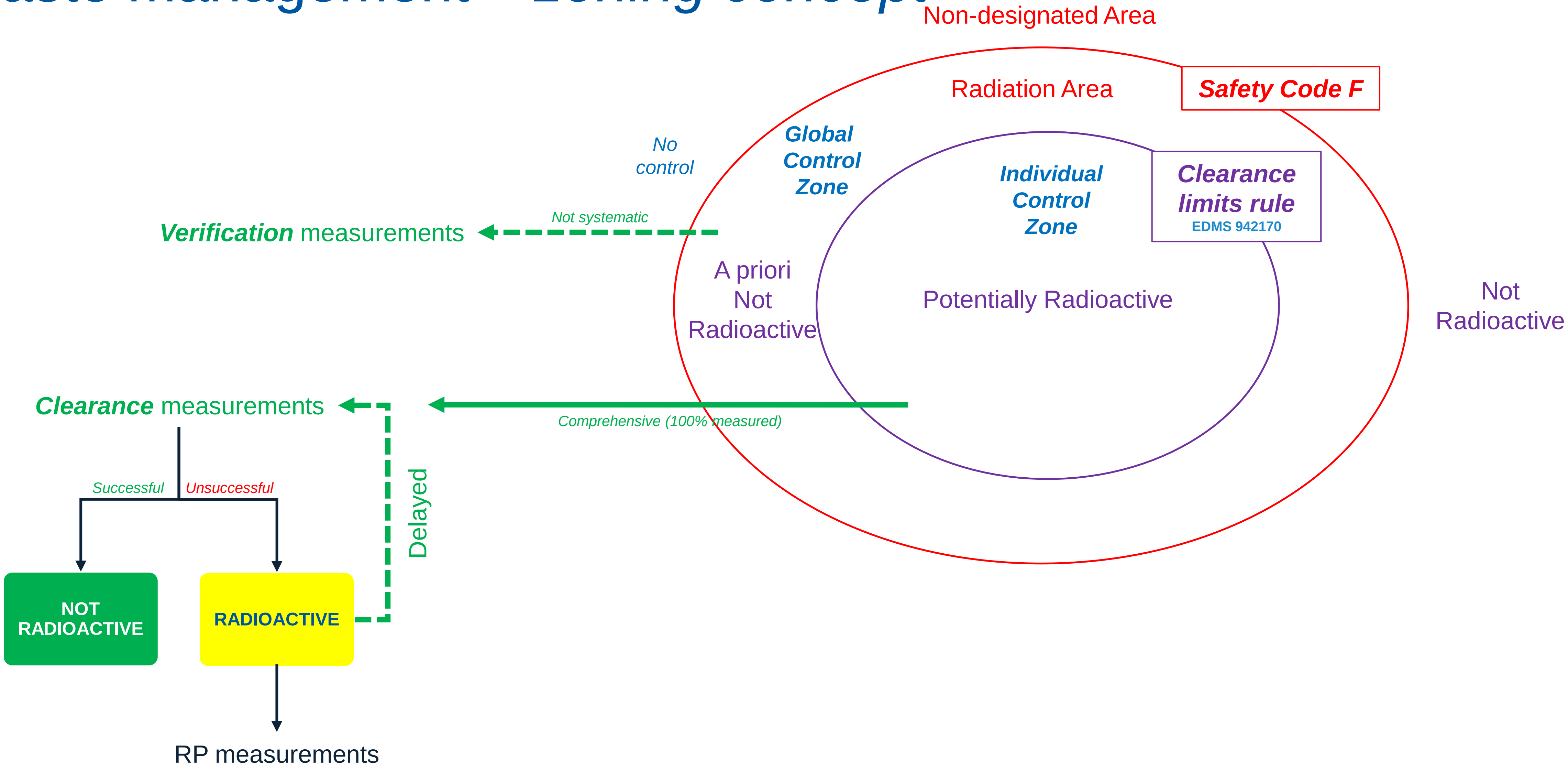


Radioactive Waste reduction policy at CERN



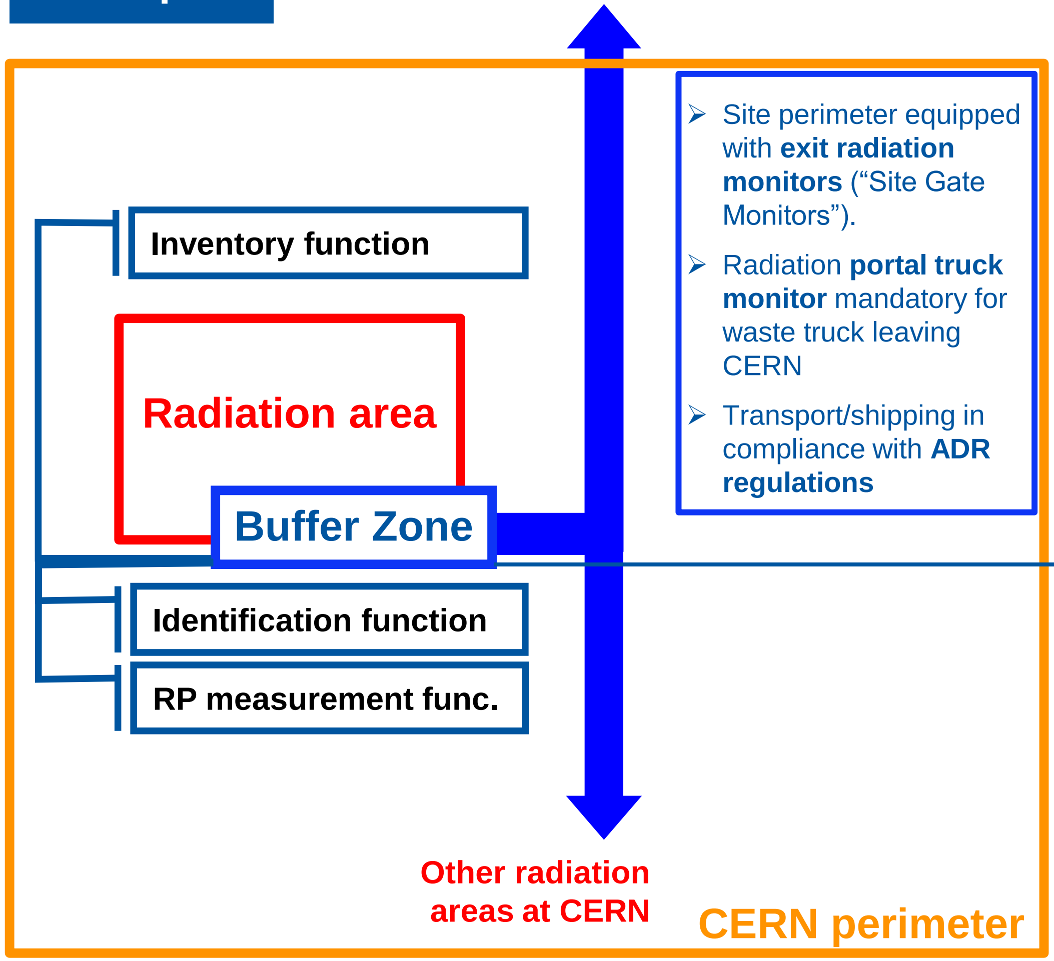
Centralized management of CERN's Radioactive Waste

Waste management – *zoning concept*

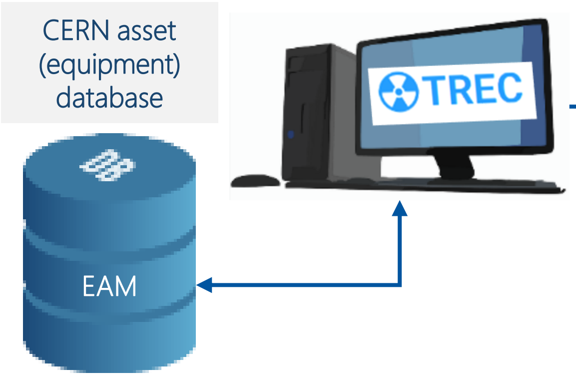


Waste management – *traceability*

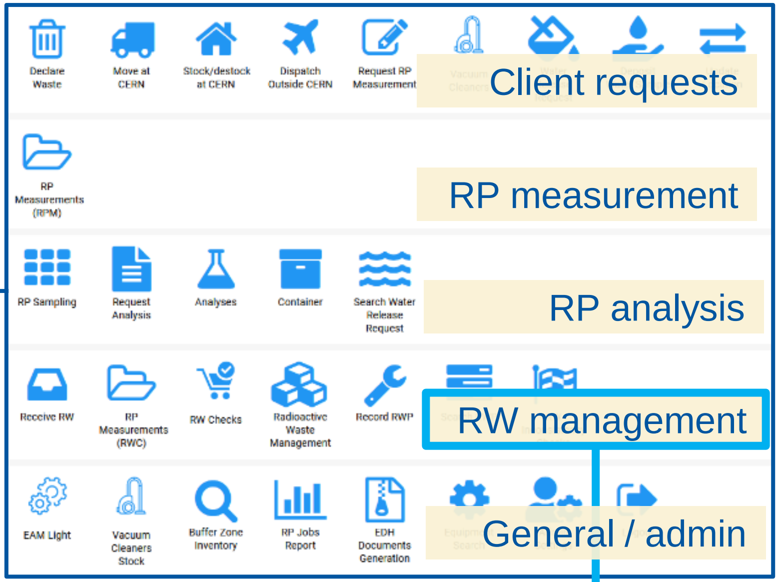
Concept



Hardware



Software



- **Single, centralised database**
- **Capturing waste properties**
- **Tracing life-cycle & processes**
- **Allowing extraction of statistics & KPI**

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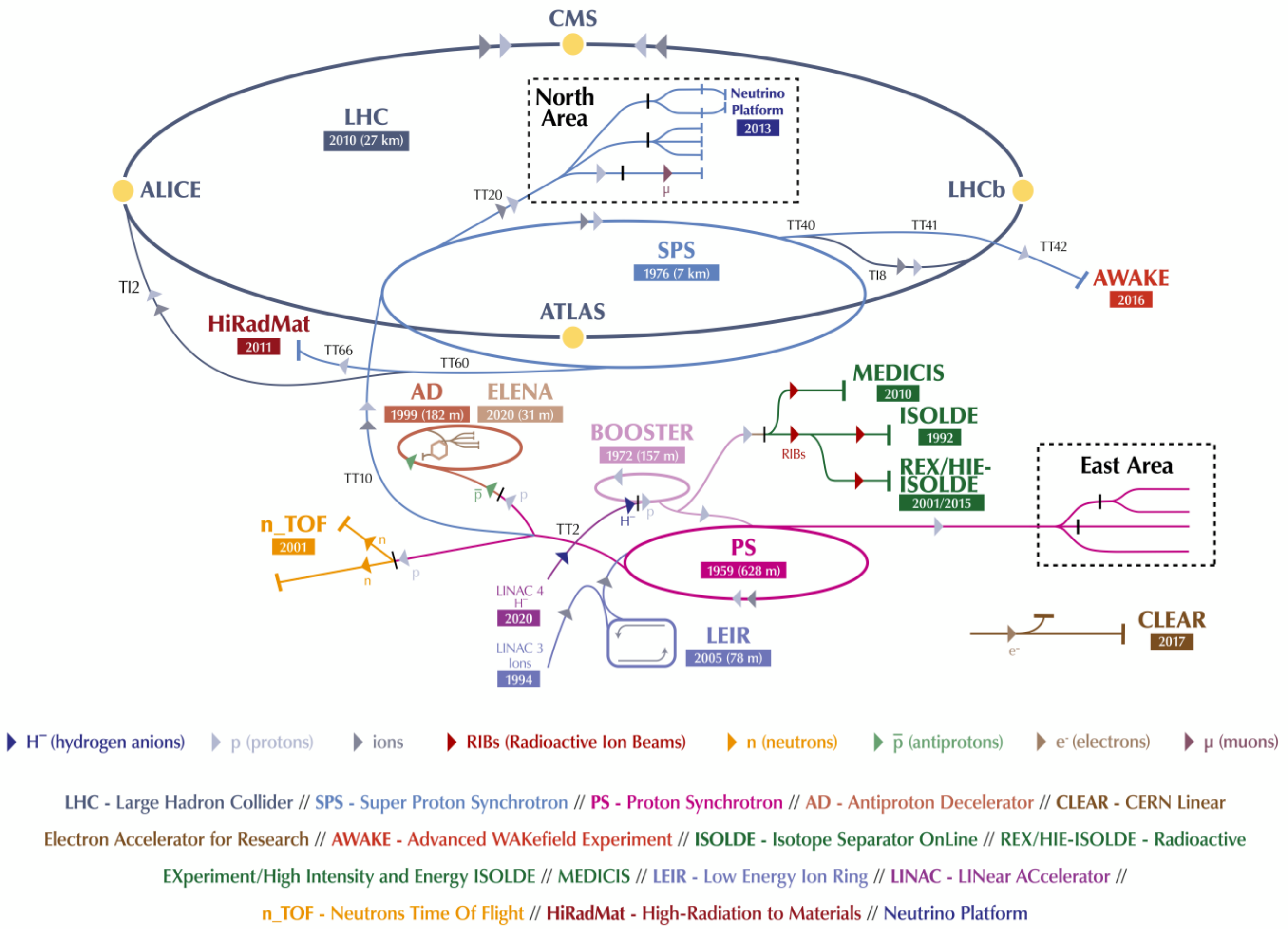
Facilities generating ionising radiation

- Electronics, Sources/Targets, Metals, comestibles, Inert (building material), liquids (ex: processed water), ion exchange resin (from demineralized water circuits), mixed waste, and other
- Mainly activated waste of very low, low and medium activity, mainly from operations (maintenance, replacement of equipment) and modifications/upgrades of installations.
- The waste packages are categorised into 10 families, the main one being metal waste.
- Other characteristics are recorded to categorise the waste: origin, materials, subsidiary hazards, radiological measurements and analyses.

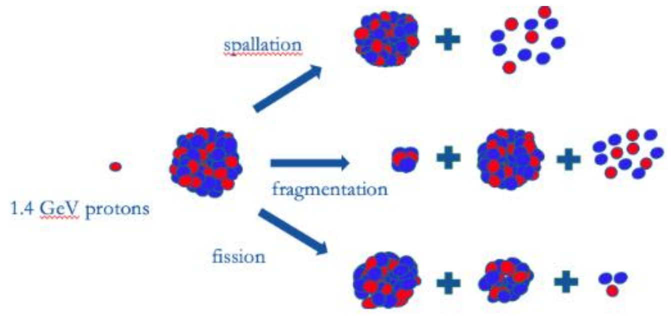


Typical CERN’s Radioactive Waste

- **Activated** waste (spallation, neutron capture, etc.)
- **Very-low** to **intermediate-level** rad. waste.
- **Mainly β-,γ- emitters**.
- Large **variety of radionuclides (RN)**.
- **Very limited contamination**.
- Short to medium lived radionuclides (**no long-lived RN**, apart from very specific experiments).
- **Limited quantities of** activated or contaminated **liquids**.
- Possible mixed waste (waste presenting a chemical hazard linked to the radiological hazard).

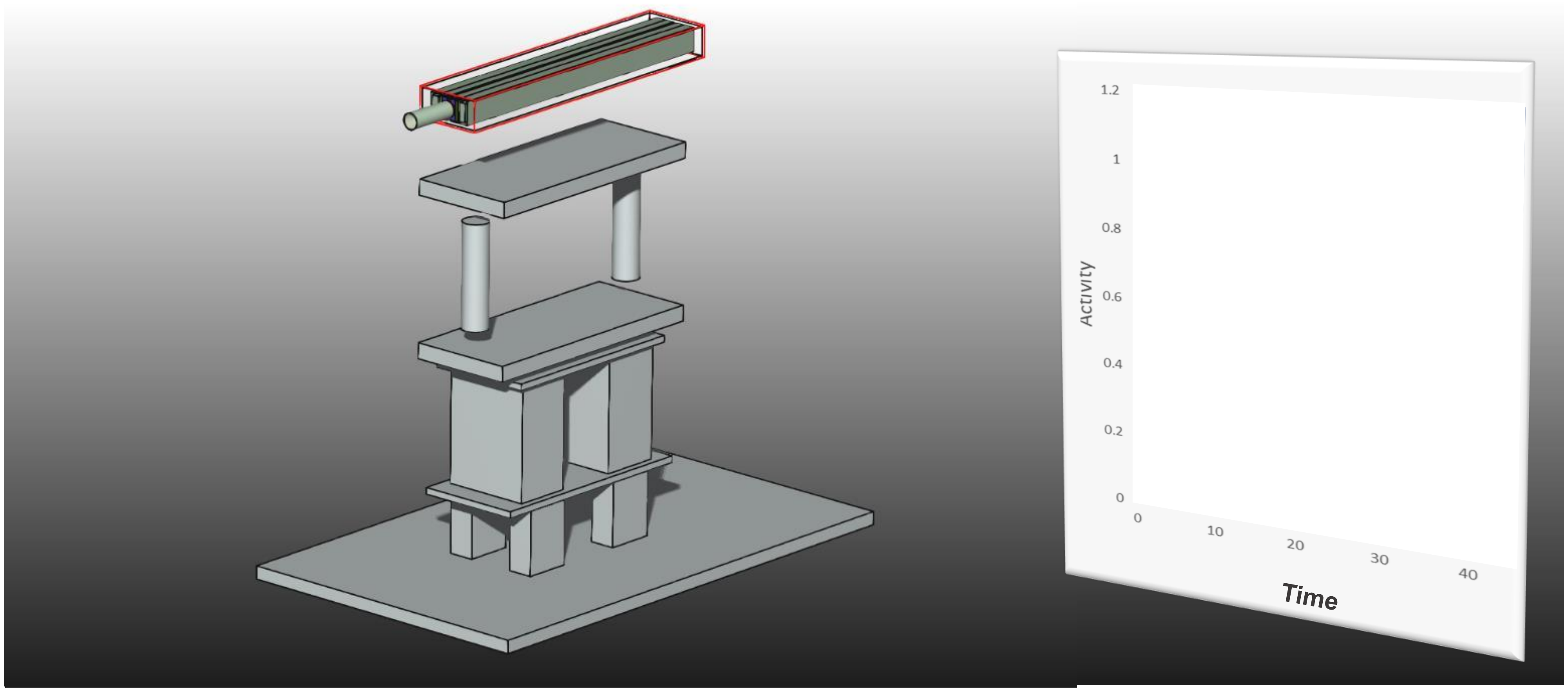
Activation

- The interaction of particles with matter can be :
  - Intentional ⇒ beam sent on **fixed targets** or beam dumps
  - Unwanted ⇒ beam losses



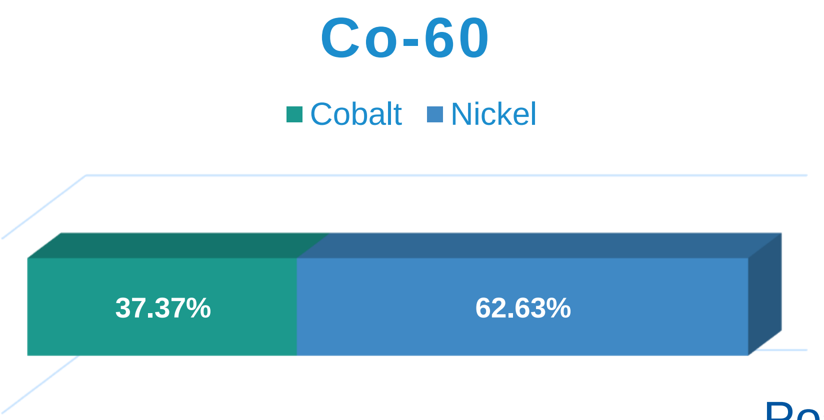
- Activation :
  - is the product of the interaction of particles with matter
  - depends on the type of impacting particles (p+, e−, ions, π+ and π−) and their energy (from MeV up to TeV) and neutrons with energy ranges down to thermal energies

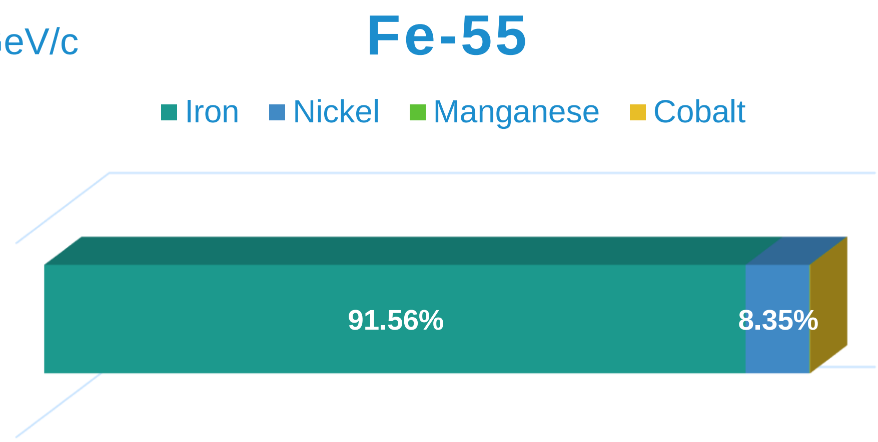
Material activation



Activation mechanisms: examples

EXAMPLE:
Material: Stainless Steel SST304L
Irradiation time: 10 years
Decay time: 15 years
LHC machine: SPS, 400 GeV/c
at the beam impact area





Possible mechanisms:

$$^{59}Co\ (n,\gamma)^{60}Co$$

$$^{60}Ni\ (n,p)^{60}Co$$

$$^{56}Fe\ (p,pn)^{55}Fe$$

$$^{54}Fe\ (\alpha,n2p)^{55}Fe$$

and other

CERN’s radioactive waste classification

Formalized by decision of host state authorities ASN (France) and OFSP (Switzerland), revised on 14/03/2022

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Division de Lyon

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22 MARS 2022
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RÉPUBLIQUE FRANÇAISE

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Madame la Directrice Générale du CERN
Prof. Fabiola Gianotti
CERN
1211 Genève
SUISSE

Lyon, le 14 mars 2022

Objet : Principes de la répartition équitable des déchets radioactifs du CERN entre la France et la Suisse

Pièce-jointe : Décision CERN n° 2022-001 de l’ASN et de l’OFSP

Madame la Directrice Générale,

J’ai l’honneur de vous communiquer la décision CERN n° 2022-001 de l’Autorité de sûreté nucléaire (ASN) et l’Office fédéral de la santé publique (OFSP) relative aux principes directeurs de la répartition équitable entre la France et la Suisse des déchets radioactifs de l’Organisation européenne pour la Recherche nucléaire (CERN) en vue de leur élimination.

Je vous prie d’agréer, Madame la Directrice Générale, l’assurance de ma considération distinguée.

La chef de la division de Lyon de l’ASN

Nour KHATER

“Fair-share” decision

RW Class	Destination
Negligible activation *(Candidats à la Liberation inconditionnelle – CL)*	Clearance from radiological control and elimination as conventional waste towards ***Switzerland***
Very low activation - VLLW *(Très Faibles Activités – TFA)*	Elimination towards ***France*** according to acceptance criteria of the National Agency for radioactive waste management (ANDRA)
Low and intermediate activation with short half-lifes (< 30 years) – SL-LILW *(Faibles et Moyennes Activités à Vies Courtes - FMA-VC)*	Elimination towards ***France*** according to acceptance criteria of the National Agency for radioactive waste management (ANDRA)
Low and intermediate activation - LILW *(Faibles Activités et Moyennes Activités – FA-MA)*	Elimination towards ***Switzerland*** of waste that does not satisfy the conditions of the FMA-VC category (half-life, activity level)

Overview of CL elimination (CLEARANCE) pathways/projects


Large Electron Positron collider cavities


Old cranes

Water evaporation

- ^{3}H release limits: 80 GBq/year & 5 GBq/week
- Concentration of other RN in the solid residues

Plastic tanks (PLATAN) and burnable technological waste (B-FREE)

- Waste contaminated with metallic and concrete dusts
- Incinerated in a conventional incineration facility (Geneva)

Historical metallic waste

- Several clearance projects for several waste batches (cavities, magnets, cranes, etc.)
- Sold to Swiss scrap-dealers for recycling

Overview of “TFA” / VLLW elimination pathways

Cables

- Different types (signal, power, etc.) and materials (aluminium, copper) of cables
- Packaged in metallic boxes (1.35 or 2.77 m3)

Metallic waste

- Accelerator & infrastructure components
- Any metallic waste fitting in a 1.35, 1.38 or 2.77 m3 box

Electromagnets

- Massive
- Unitary pieces or IP20”

Burnable waste

- Technological waste (overall, gloves, plastic bags, etc.)

Ventilation filters

- Packaged in recyclable containers, 200L drums, GRVS or metallic boxes

Overview of ILLW elimination pathways (FMA-VC and FA-MA)

FMA-VC / SL-ILLW

Melting of steel

- Melting at CENTRACO (Cyclife)
- Open in 2023

Other metallic waste

- Massive or bulk waste
- Packaged in injectable boxes
- Cementation at CSA (Andra)
- Opening in 2025

FA-MA / ILLW

n_TOF* target

- Massive lead target
- Cemented in concrete PSI container

ISOLDE** targets

- Smaller spallation targets
- 30-40 targets produced per year
- Several different material
- Open for non-carburized and non-actinide target
- Open in 2023

* n_TOF: Neutron Time-Of-Flight experiment, producing neutrons for cross-section measurements
** ISOLDE: Isotope Separator On-Line Device, producing radionuclides for studies

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Waste management – *production / “reception”*

CERN
CH-1211 Geneva 23
Switzerland

EDMS NO.	REV.	VALIDITY
1364231	2.4	RELEASED

REFERENCE
–

Date : 12-09-2017

CADRA

■

CRITERES INTERNES AU CERN POUR L'ACCEPTATION DES DECHETS RADIOACTIFS

■

CERN'S INTERNAL ACCEPTANCE CRITERIA FOR RADIOACTIVE WASTE

RESUME ■ ABSTRACT:

Ce document précise les critères internes au CERN pour assurer la prise en charge par le Groupe de Radioprotection (HSE-RP) des déchets radioactifs produits par les Départements et les expériences approuvées dans le but de minimiser les risques d'exposition des opérateurs, de protéger l'environnement, d'optimiser les ressources engagées (espaces d'entreposage, main d'œuvre) et de faciliter la constitution des colis produits en vue de leur élimination.
Dans l'éventualité où le producteur des déchets anticipe qu'il ne pourra pas respecter les critères d'acceptation, il peut contacter la section "Radioactive Waste" du Groupe HSE-RP (rp-rw-operational@cern.ch) pour étudier une procédure de traitement et mise en conteneur qui prendra en compte les possibilités techniques et le type de non-conformité à ce document et ses annexes.

This document details CERN's internal acceptance criteria for radioactive waste produced by the Departments and approved experiments at CERN to be managed by the Radiation Protection Group (HSE-RP). The purpose of the internal acceptance criteria is to minimize the risks of exposure to the operators, to protect the environment, to optimize the resources committed (storage space, manpower) and to facilitate the assembly of the packages for disposal.

In the event that the waste producer foresees that she/he will not meet the acceptance criteria, she/he can contact the "Radioactive Waste" Section of the HSE-RP Group (rp-rw-operational@cern.ch) to study a treatment and packaging procedure that will take into account the technical possibilities and the type of non-compliance to this document and its annexes.

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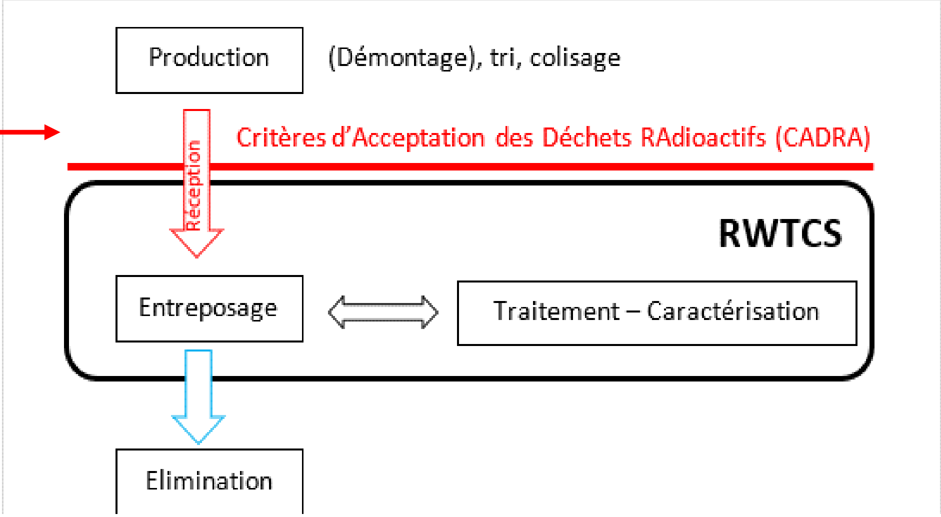
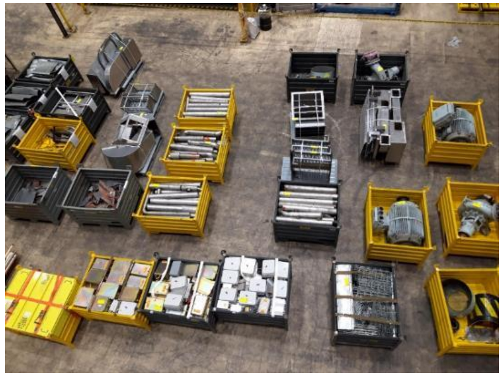
1723932	1.2	RELEASED

ANNEXE I - LISTE DES CONTENEURS

Désignation	Données techniques	Références	Commentaires
Bac 1 m³ 	**Dimensions** Hors-tout / Internes L = 1280 mm / 1150 mm l = 1080 mm / 950 mm h = 880 mm / 610 mm **V utile** = 0.7 m³ **Charge utile** = 1200 kg **Tare** = 97 kg **Empilement** = 1+5	**TREC** HCPWBBK120-B4% **EDMS** 1332064, 1319660 **SCEM** 55.50.75.400.0	Ce conteneur est utilisé pour le transport de pièces métalliques ou d'équipements de petites et moyennes dimensions. La charge utile est limitée à 1200 kg. Ce conteneur est agréé ADR IP-2 pour transport inter-sites s'il est fermé avec son couvercle et muni de 3 sangles de 5 tonnes (fournis par le Groupe Transport EN-HE). Aucun objet de moins de 2 cm de longueur ne peut être placé directement dans ce cas.
Bac IP2 	**Dimensions** Hors-tout / Internes L = 1250 mm / 1135 mm l = 850 mm / 735 mm h = 945 mm / 650 mm **V utile** = 0.5 m³ **Charge utile** = 1200 kg **Tare** = 175 kg **Empilement** = 1+5	**TREC** HCPWBIP200-DC% **EDMS** 1321717 **SCEM** -	Ce conteneur est utilisé pour le transport de pièces métalliques ou d'équipements de petites et moyennes dimensions. La charge utile est limitée à 1200 kg. Ce conteneur est agréé ADR IP-2 pour transport inter-sites s'il est fermé avec son couvercle et muni de ses 2 sangles de 5 tonnes. Aucun objet de moins de 2 cm de longueur ne peut être placé directement dans ce conteneur.
Petit bac modèle 1 	**Dimensions** Hors-tout / Internes L = 880 mm / 750 mm l = 580 mm / 450 mm h = 640 mm / 360 mm **V utile** = 0.1 m³ **Charge utile** = 500 kg **Tare** = 44 kg **Empilement** = -	**TREC** HCPWBPJ001-B4% **EDMS** 1332072 **SCEM** -	Ce conteneur est utilisé uniquement pour le transport de petites pièces métalliques radioactives en provenance de zones tampon. Ce conteneur n'est pas utilisé pour le pré-conditionnement ni l'entreposage. Conteneur non certifié ADR.
Petit bac modèle 2 	**Dimensions** Hors-tout / Internes L = 850 mm / 750 mm l = 550 mm / 450 mm h = 550 mm / 310 mm **V utile** = 0.1 m³ **Charge utile** = 500 kg **Tare** = 44 kg **Empilement** = -	**TREC** HCPWBPJ002-V1% **EDMS** - **SCEM** -	Ce conteneur est utilisé uniquement pour le transport de petites pièces métalliques radioactives en provenance de zones tampon. Ce conteneur n'est pas utilisé pour le pré-conditionnement ni l'entreposage. Conteneur non certifié ADR.
Casier ANDRA 1.35 m³ 	**Dimensions** Hors-tout / Internes L = 1326 mm / 1320 mm l = 1034 mm / 1028 mm h = 967 mm / 956 mm **V utile** = 1.3 m³ **Charge utile** = 4818 kg **Tare** = 182 kg **Empilement** = 1+2	**TREC** HCPWP1E135-DH% **EDMS** 1332091 **SCEM** 55.50.75.400.5	Ce conteneur est utilisé uniquement pour le conditionnement des câbles selon les spécifications de l'Annexe III du CADRA - fiche de conditionnement des câbles (EDMS 1724006). Il doit être utilisé seulement en cas de accord préalable avec HSE-RP-RW. Conteneur non certifié ADR.





Waste management - *processing*

Sélection
- Définition du procédé
- Choix de la période de décroissance
- Vérification conformité

Traitement
- Démantèlement,
- Réduction taille/volume,
- Densification
- Tri
- Decontamination
- Emballage

Colisage
- Choix des conteneurs de Déchets sortants
- Rangement dans le colis
- Respect des prescription de la filière

Mesures
- Dimensions
- Masses
- Débit de dose
- Contamination
- Déchets dangereux
- Présence d'émetteurs alpha

Waste management – *radiation protection & radiation safety*

Area classification

Dosimetry

Monitoring

ALARA rules

	DIMR I	DIMR II	DIMR III
Collective dose		500 person.µSv or	5 person.mSv
Individual dose		100 µSv	1 mSv
Dose rate		50 µSv/h	2 mSv/h
Airborne contamination		5 CA	200 CA
Surface contamination		10 CS	100 CS

Group 2 criteria (applicable on RSO & RP decision)

- Rad. work permit (DIMR)
- Work and Dose Planning
- Dosimetry comparison

IMPACT

Hot cell & telemanipulator

PPE for contaminated filters

PPE for plasma cutting

Cutting cell

HVAC equipped with HEPA filters

CERN’s radioactive waste classification (Reminder)

Formalized by decision of host state authorities ASN (France) and OFSP (Switzerland), revised on 14/03/2022


asn — Division de Lyon

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RÉPUBLIQUE FRANÇAISE

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Madame la Directrice Générale du CERN
Prof. Fabiola Gianotti
CERN
1211 Genève
SUISSE

Lyon, le 14 mars 2022

Objet : Principes de la répartition équitable des déchets radioactifs du CERN entre la France et la Suisse

Pièce-jointe : Décision CERN n° 2022-001 de l'ASN et de l'OFSP

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Je vous prie d'agréer, Madame la Directrice Générale, l'assurance de ma considération distinguée.

La chef de la division de Lyon de l'ASN

Nour KHATER

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“Fair-share” decision

RW Class	Destination
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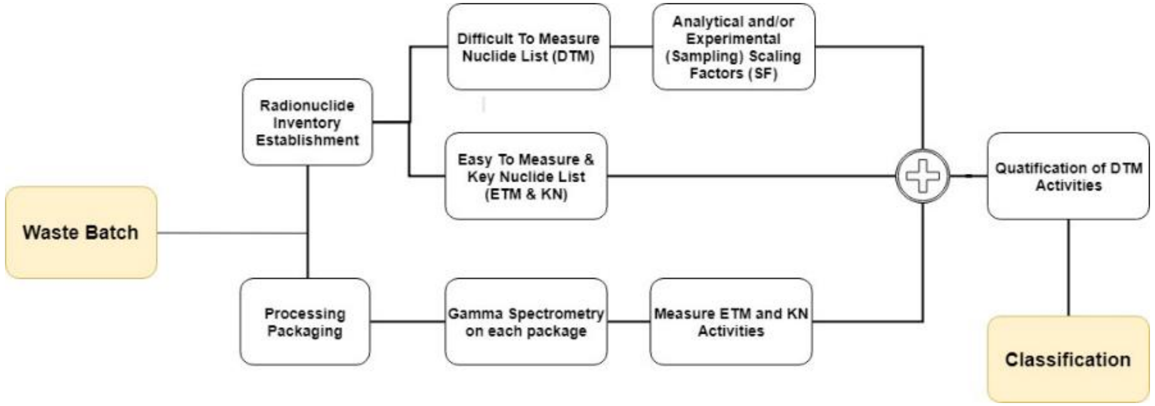
Very low activation - VLLW *(Très Faibles Activités – TFA)*	Elimination towards ***France*** according to acceptance criteria of the National Agency for radioactive waste management (ANDRA)
Low and intermediate activation with short half-lifes (< 30 years) – SL-LILW *(Faibles et Moyennes Activités à Vies Courtes - FMA-VC)*	Elimination towards ***France*** according to acceptance criteria of the National Agency for radioactive waste management (ANDRA)
Low and intermediate activation - LILW *(Faibles Activités et Moyennes Activités – FA-MA)*	Elimination towards ***Switzerland*** of waste that does not satisfy the conditions of the FMA-VC category (half-life, activity level)

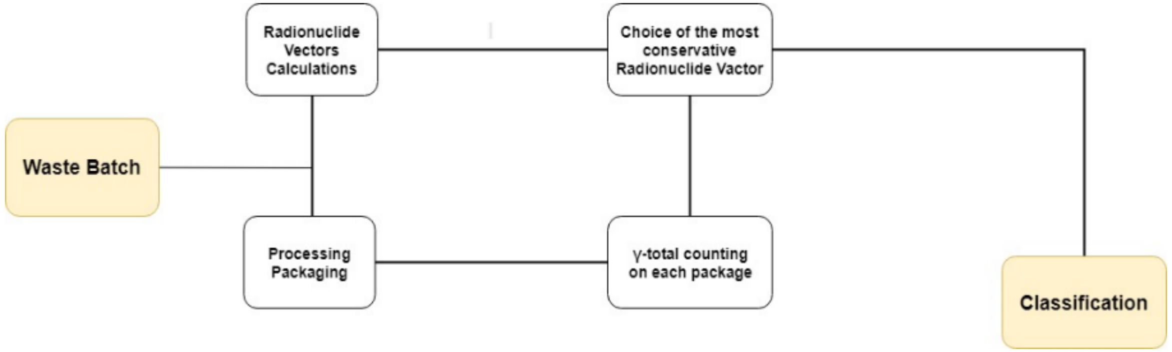

ANDRA CIRES (France)


ANDRA CSA (Aube)

Waste management – *characterization*



Characterization strategy for "TFA" waste



Characterization strategy for "CLEARANCE" waste

Inventory Prediction – ETM, DTM & ITMs, and radionuclide vectors

Monte Carlo

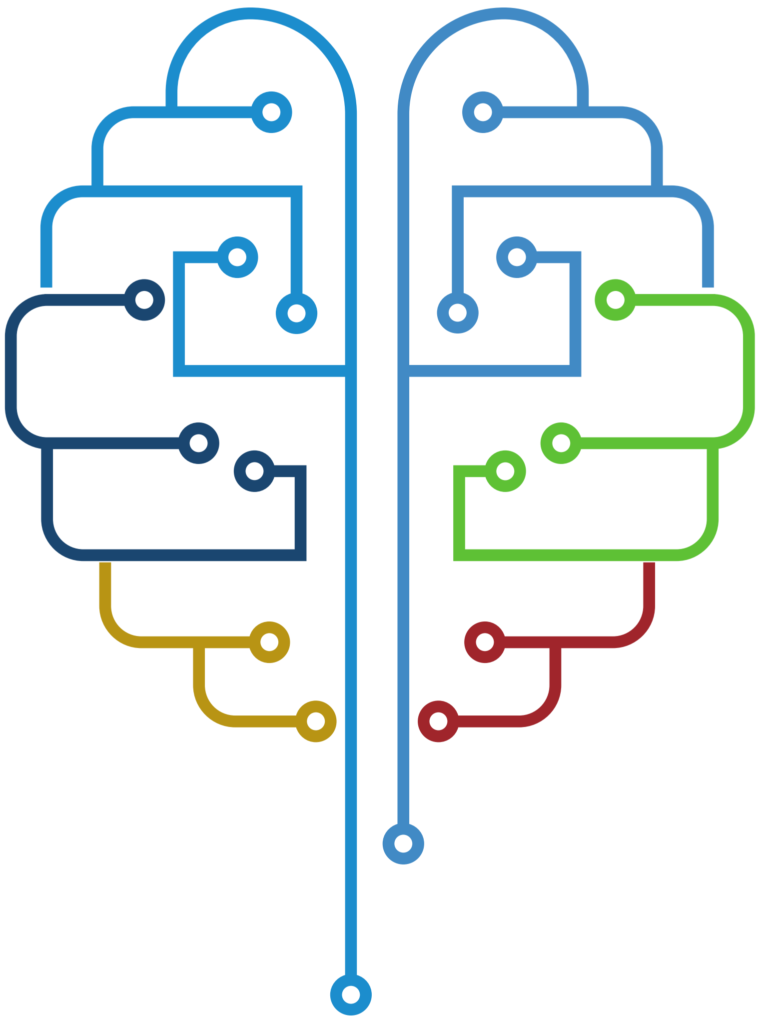
State-of-the-art method for many problems in science

Advantages

Yields spatial distributions of nuclides & residual dose rate

Disadvantages

Calculation times can be very long
Difficult to achieve sufficient statistics for thin layers



Hybrid (analytic & MC)

Combine the power of modern intranuclear-cascade models with analytical computation speed

Advantages

Very high statistical significance & short computation times
Analysis & reporting tailored to characterization

Disadvantages

Requires fluence spectra as input (→Monte Carlo)
Does not yield spatial information

Inventory Prediction – Simulation codes used

FLUKA

https://fluka.cern

- Multipurpose Monte Carlo code widely used and benchmarked in the RP domain.
- Since December 2019 new CERN distribution (FLUKA 4) aiming to ensure FLUKA's long-term sustainability and capability to meet the evolving requirements.
- Joint development & management team including CERN ATS & RP and ELI-Beamlines (Prague).
- Active user forum and official courses

ActiWiz 3

- Developed and maintained by CERN RP group.
- Calculate complete nuclide inventories and provide evaluations with respect to radiotoxicity, inhalation doses, Multiple of the Swiss clearance limits, Specific activity, operational & waste hazard factors and more.
- Pre-defined radiation environments (CERN accelerator complex) or user-defined via FLUKA particle spectra.

Inventory Prediction – ActiWiz - hybrid method

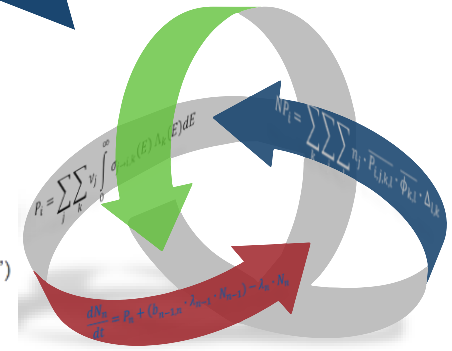
neutrons < 20 MeV:
JEFF 3.3

ActiWiz 3

neutrons > 20 MeV, p, pi+, pi-, photons up to 100 TeV: 100 CPU years of generic CERN FLUKA 4.4 calculations FLUKA

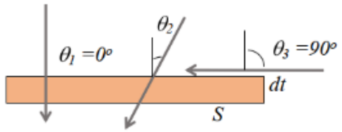
$R = \Sigma\Phi V$: number of reactions in a given time interval inside the volume V (where Φ is the fluence and the product $\Sigma\Phi$ is integrated over energy or velocity)

- $\Sigma[cm^{-1}] = 1/\lambda[cm]$: **macroscopic cross section**, *i.e.* probability of interaction per unit distance. It depends on the material, particle type and energy
- $\sigma = \frac{\Sigma}{N_0} = atom\ effective\ area$, $[barn = 10^{-24} cm^2]$: **microscopic cross section**, *i.e.*
  - the **area of an atom weighted with the probability of interaction** (hence the name "cross section")
  - or the **probability of interaction per unit length, with the length measured in atoms/cm²** (the number of atoms contained in a cylinder with a 1 cm² base)



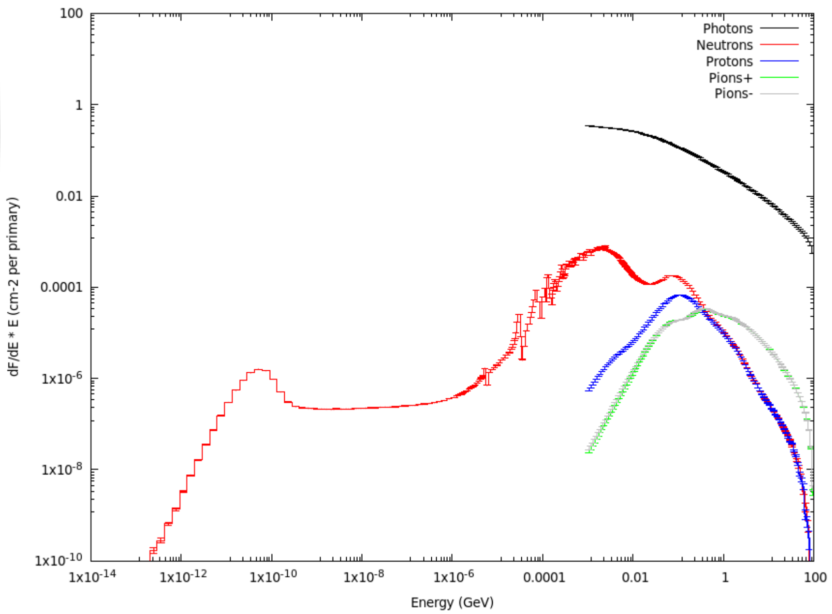
Surface crossing estimation

- Imagine a volume of surface *S* and infinitesimal thickness *dt*.
  A particle incident with an angle *θ* with respect to the normal of the surface *S* will travel a segment *dt/cosθ*.
- Therefore, we can calculate an **average surface fluence** by adding *dt/cos θ* for each particle crossing the surface, and dividing by the volume *S dt:*



$$\Phi = \lim_{dt \to 0} \frac{\sum_i \frac{dt}{\cos\theta_i}}{S\,dt}$$

Particle fluence spectra



Inventory Prediction – ActiWiz 3 overview

84 built-in radiation fields

CERN accelerators & LHC experiments

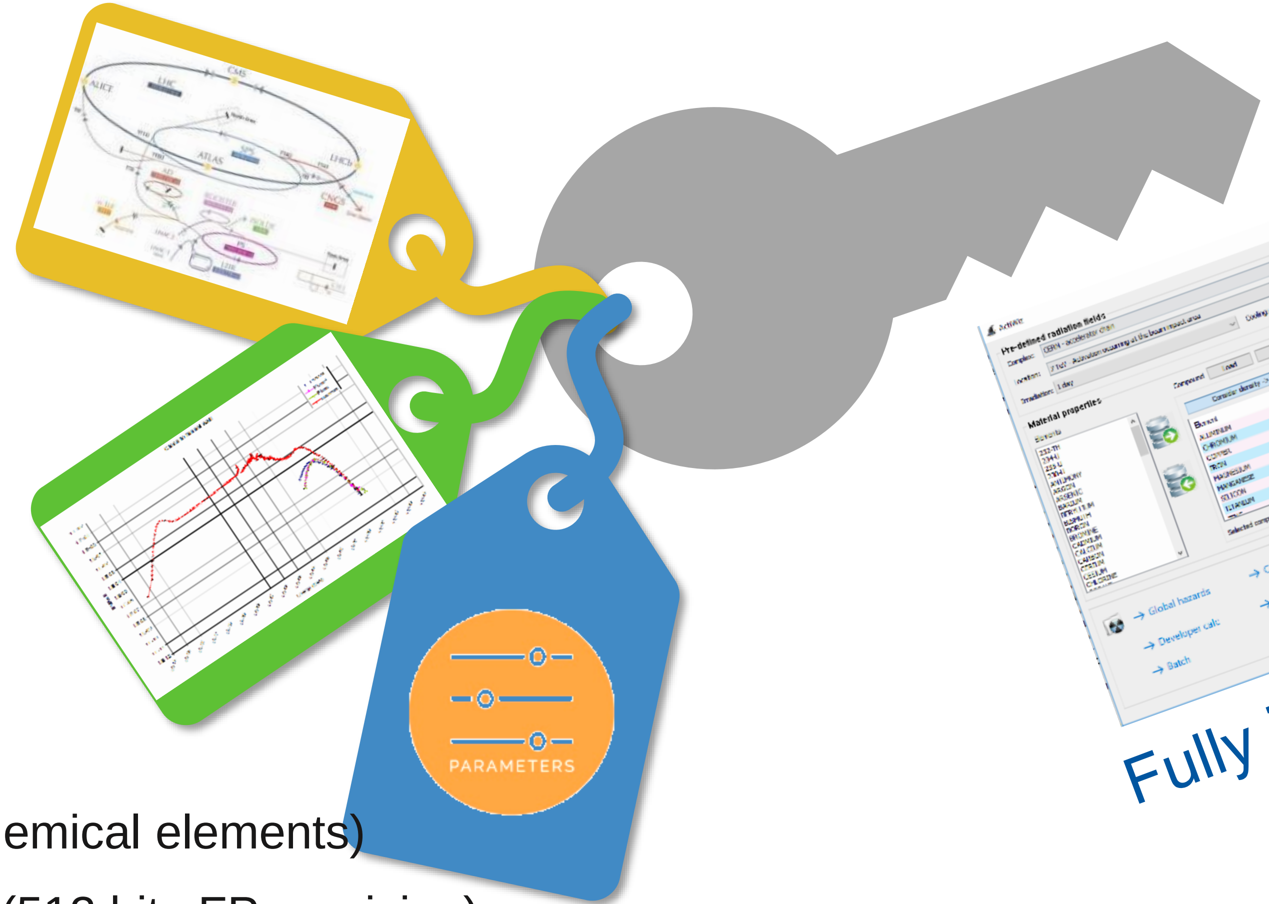
External radiation fields

Import via radiation environment files

Parameters

Arbitrary material compounds (85 chemical elements)

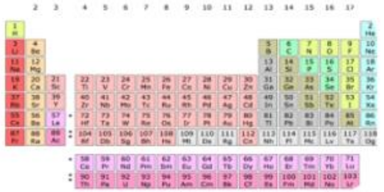
Arbitrary irradiation/cooling patterns (512 bits FP precision)



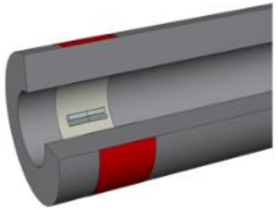
Fully integrated GUI

Radionuclide inventory prediction (Generic) – Method 1

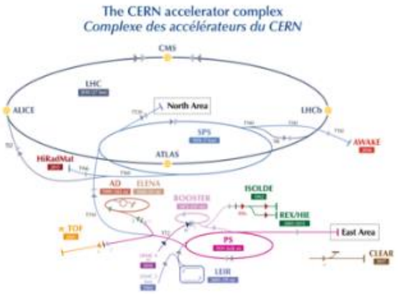
Activation parameters:



Material composition



Location in accelerator



Energy (machine)

Time
(irradiation & cooling time)

Source: ©2016-2020 CERN https://cds.cern.ch/record/2197559

Locations and energy → **E.g.: From 160 MeV (Linac 4) up to 7 TeV (LHC)**

Time → **E.g.: Irradiation times are fixed at 4 months up to 30 years**

Decay times are longer than 3 years

Material composition → **E.g.: Stainless Steel, Copper, Al,..**

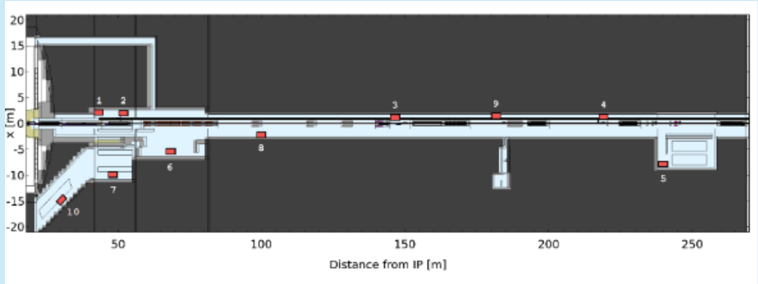
"All models are wrong, but some are useful" George BOX - Statistician

Radionuclide inventory prediction (Specific) – Method 2

FLUKA

Input example
Symmetric proton-proton collision at 160 μrad half crossing angle,
and $\sqrt{(s)}$=13.6 TeV centre-of-mass energy.

Output:
Particle fluence spectra

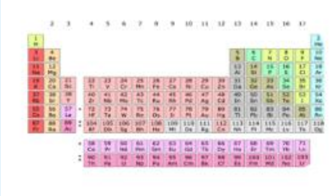


ActiWiz Creator 3
by C. Theis & H. Vincke
© 2019 CERN

ActiWiz 3

Input:
Particle fluence spectra
Material composition
Irradiation profile:
- Beam intensity
- Irradiation and cooling times

Output:
Radionuclide inventories and specific activities/ sum of LL fractions



Clearance: Criteria for clearance of radioactive materials

i. the **ambient dose equivalent** rate measured at 10 cm distance from the item surface is **lower than 0.1 µSv/h** after subtraction of the background,
AND

ii. the **specific activity** is below the **clearance limit* (LL)**, i.e. for a mix of radionuclides if:

$$\sum_{i=1}^{n} \frac{a_i}{LL_i} < 1$$

AND

iii. the **surface contamination** is below the surface **contamination limit (CS)**, i.e. for a mix of radionuclides if:

$$\sum_{i=1}^{n} \frac{c_i}{CS_i} < 1$$

* CERN clearance limits adapted from Swiss legislation:
Ordonnance sur la radioprotection (ORaP) du 26 Avril 2017 (état le 1 janvier 2018) réf. 814.501 (Suisse)
Clearance and exemption limits are introduced in safety standards documents: IAEA GSR Part 3, IAEA, RS-G 1.7, IAEA SRS44, EU RP120

Clearance: Establishing Nuclide Vector

Apply a characterization approach based on total gamma counting (TGC) and the leading nuclide correlation method (LNC) associated with conservative material nuclide vectors (fingerprints)

Construct Figure of Merit (FOM)

$$FOM_j = \frac{sumLL}{TGCsignal} = \frac{\sum A_{i,j}/CL_i}{\sum A_{i,j} \times LNC_i},$$

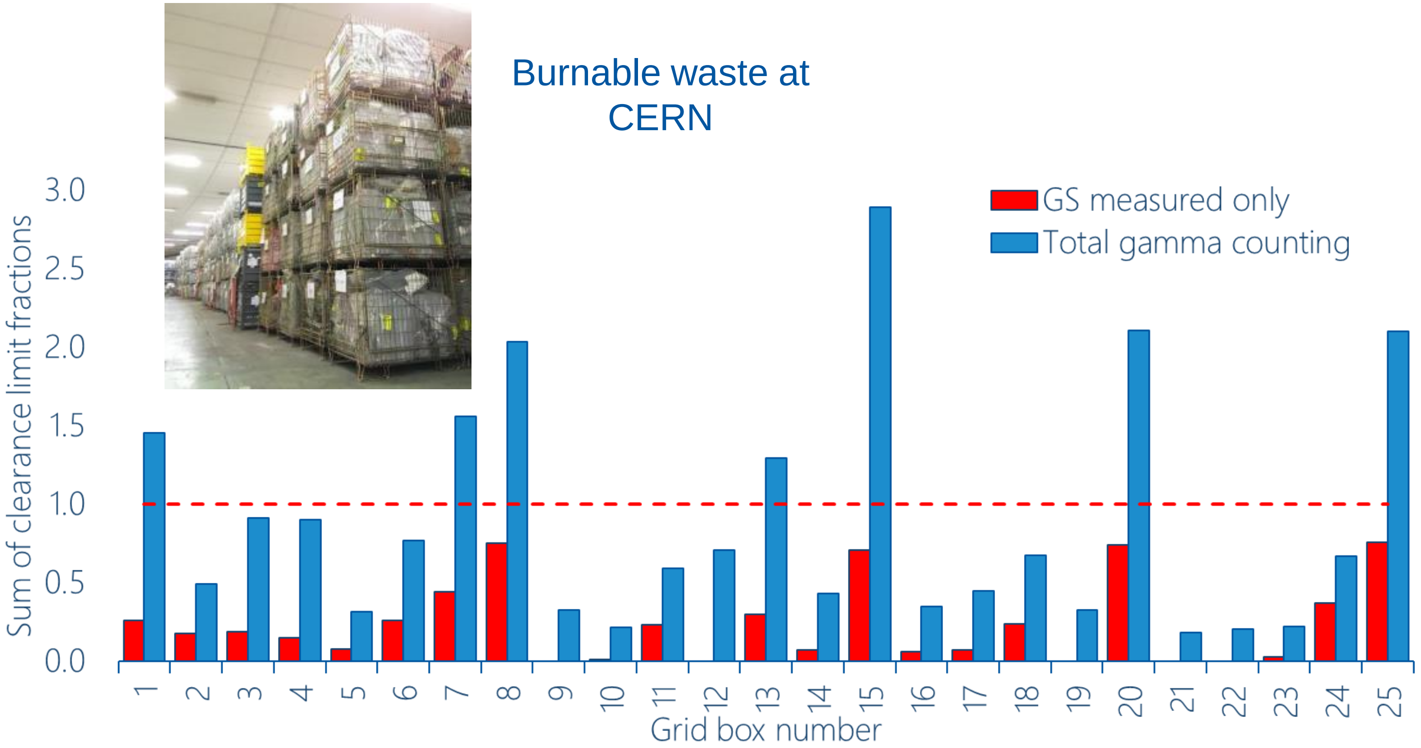
Nuclide vector → considered as the most conservative scenario defined by maximizing the sum of LL fraction (sumLL) of the Swiss clearance limit per TGC signal

Mirion Technologies RTM644Inc large area clearance monitor

"All models are wrong, but some are useful" George BOX - Statistician

Example – B-FREE pilot study

Burnable waste at CERN



TGC – clearance monitor

10% volume for Quality Control

g-spectrometry samples

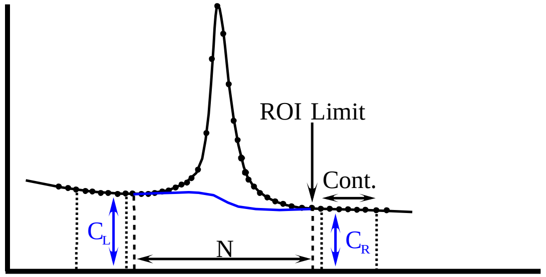
- 25 'grid boxes' filled with burnable waste produced at CERN
- fingerprint with 10y – 30y cooling used, DTM scaling based on Na-22 activity
- no result found where g-spectroscopy contradicted TGC with conservative fingerprint
- cases where g-spectroscopy alone remained unconclusive due to MDA

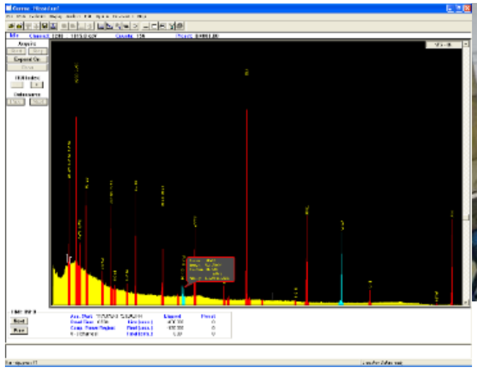
R. Harbron et al.,Clearance of burnable waste produced at CERN, presented at the 12th International Symposium on Clearance, Frankfurt, 2022

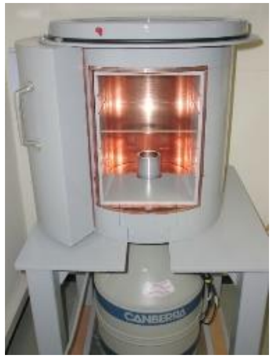
Gamma Spec – Nutshell view

- Acquire a spectrum: Detectors w/ MCA
- Perform the analysis:
  - Peak search
  - Peak area
  - Area correction: background correction
  - Efficiency calibration
  - NID with Interference correction. Cascade summing correction for close geometries!
  - MDA calculations → Lower MDA requires lower background and/or better E resolution → HPGe
- Report the activities with uncertainties given at 2σ

$$A = \frac{N_s}{\varepsilon(E).\Delta t} \times \frac{1}{I_\gamma}$$








```
********************** Radioprotection Group ****************************
*****   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      Halflife      Conf.  Weighted Mean Activity   MDA
                                              (Bq /g    )
    -------------------------------------------------------------------
      K<Ar-42     3.30E+001 Y   0.935  1.92E-002 ±  65.9%     4.6E-002
      Sc<Ti-44    6.00E+001 Y   0.973  1.05E-001 ±  17.2%     1.0E-002
      Mn-54       3.12E+002 D   0.992  2.31E-002 ±  31.9%     1.4E-002
      Co-60       5.27E+000 Y   0.978  3.21E-001 ±  11.1%     8.3E-003

      ? = 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  2.000 sigma
```

Denoted "Reported Activity Uncertainty": This is just part of the "actual" uncertainty

Uncertainties - Simplified

$$A = \frac{N_s}{\varepsilon(E).\Delta t} \times \frac{1}{I_\gamma}$$

A is the activity of a certain radioactive nuclide in the decay series;

N_s is the net peak area count subtract background of the sample;

$\varepsilon(E)$ is the absolute efficiency curve of the geometric model as a function of the gamma line energy;

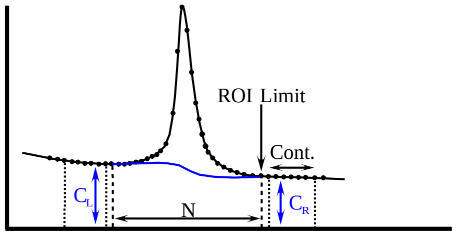
I_γ is the emission probability of a specific energy photo peak;

Δt is time for collecting the spectrum of the sample.

Neglecting correlations, Reported Activity Uncertainty is as follow:

$$\left(\frac{\partial A}{A}\right)^2 = \qquad + \qquad +$$

$$\left(\frac{\partial \varepsilon(E)}{\varepsilon(E)}\right)^2 = \left(\frac{\partial \varepsilon_{numeric}(E)}{\varepsilon_{numeric}(E)}\right)^2 + \left(\frac{\partial \varepsilon_{geometry}(E)}{\varepsilon_{geometry}(E)}\right)^2$$



N_s - due to the peak fit

I_γ - Refer to literature (nuclear databases)

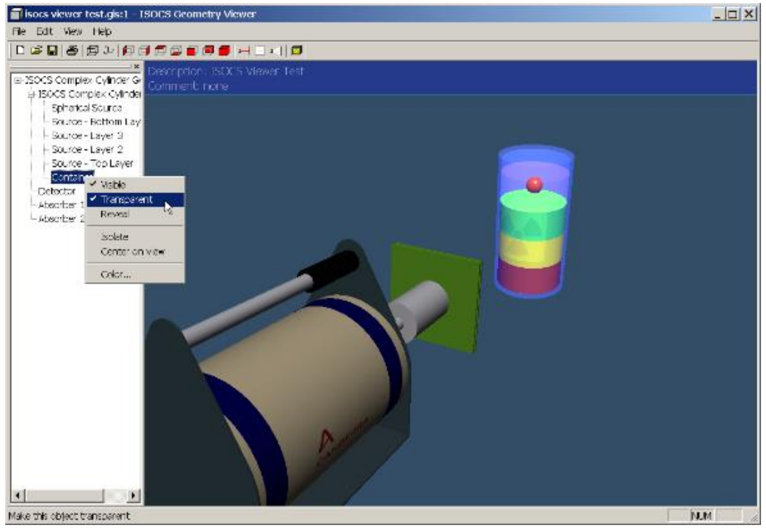
$\varepsilon(E)$ - due to the numerical approximation (vertex, deterministic interpolation) and the qualification of MC code (comparison calculation / experiment) => does not include geometric modeling

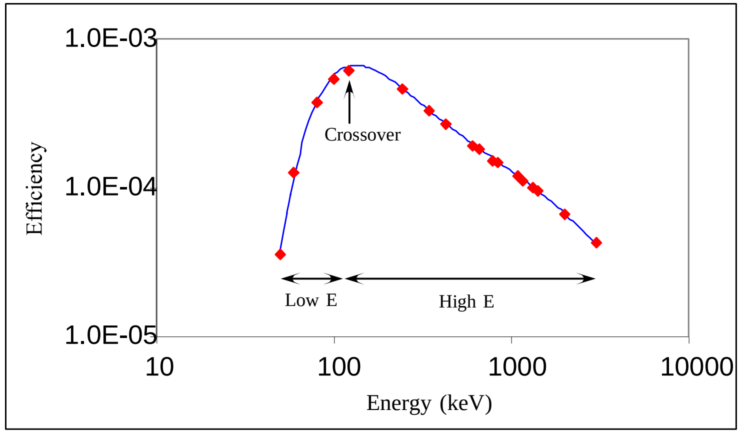
Mathematical Efficiency Calibration

- Mathematical Efficiency calibration have great advantage over source based.
  - Geometries cannot be easily emulated
  - Source(s) expensive to acquire, maintain, and remove from service.

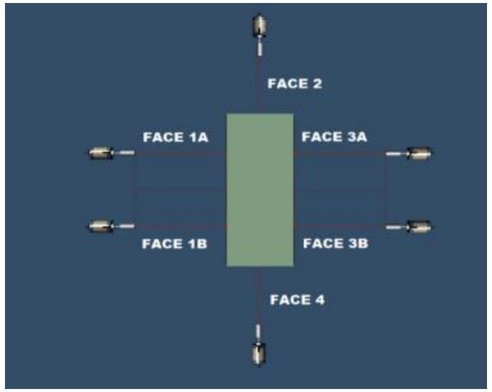
- Mathematical eff. Cal. results quality depends on accuracy of modeled geometry
  - ISOCS
  - FLUKA
  - MCNP or other…

- Detector can be carefully characterized in the factory using calibrated traceable sources (ISOCS)
- However, sample and counting geometry dimensions/parameters are often not well known
- Dominating uncertainty budget



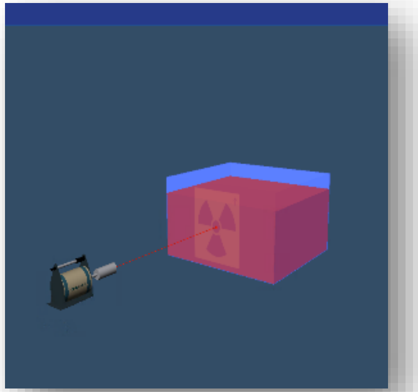


Gamma Spectrometry Countings - Examples

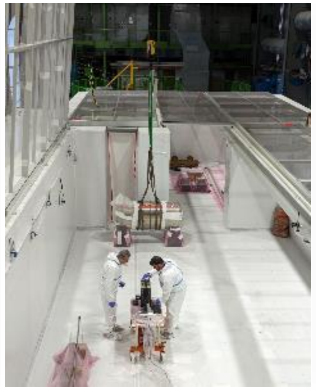



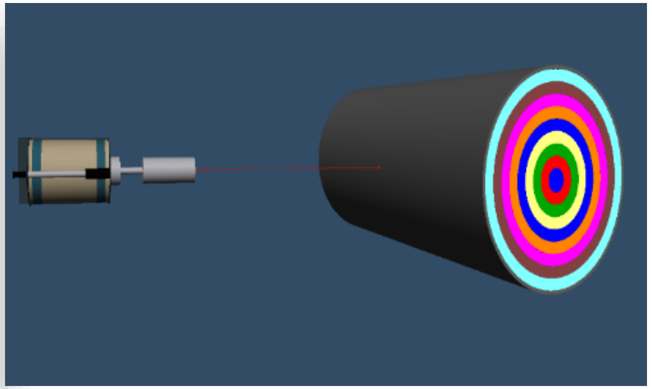
TFA Waste packages


Special items

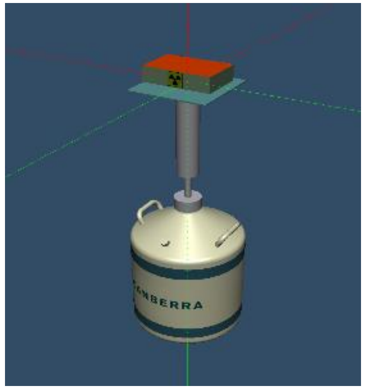



FMA-VC Waste packages for melting





FMA-VC Waste packages (special Items)

Laboratory Sample

Take-Home Messages

- CERN’s radioactive waste management has greatly evolved in the last decade.
- To achieve such results, CERN’s radioactive waste management is **centralized**.
- **Phases**: Production→ Reception→ Processing → Characterization→ Validation→ Disposal (Elimination)
- Characterization → development of realistic statistical studies for reasonably conservative Scaling Factors and Nuclide Vectors.
- Following the infrastructure renovation and the provision of the main equipment, the next phase to further develop the radioactive waste management at CERN is the opening of the **complex pathways**, the **standardization** and the **coordination** of the waste treatment and disposal with an increasing **number of elimination pathways**.

1. CERN introduction
2. Radioactive Waste management at CERN
3. Radioactive waste produced
4. Radioactive waste classification and Elimination pathways
5. Radioactive waste Reception and Processing
6. Radioactive waste characterization
7. Conclusion
8. Questions/answers
9. Career opportunities at CERN

Career opportunities at CERN

Internships, summer/technical/doctoral student programs

Opportunities for graduates:

- Origin program: early-career professional, <2 years' experience,
- Quest program: MSc 2-6 years experience, or PhD <2 years' experience.

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Thank you!

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