HSE

Radiation Protection

Machine learning and transfer functions to characterise radioactive waste for particle accelerators

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CERN

... an accelerator complex with 11 machines

During their operation, beam losses lead to the inevitable activation of material.

When machines are upgraded or dismantled, radioactive waste is generated.

Radioactive waste

…generated at CERN is collected at a dedicated treatment center.

It is then split in categories and characterized …

…in order to be eliminated to final repositories in France and Switzerland.

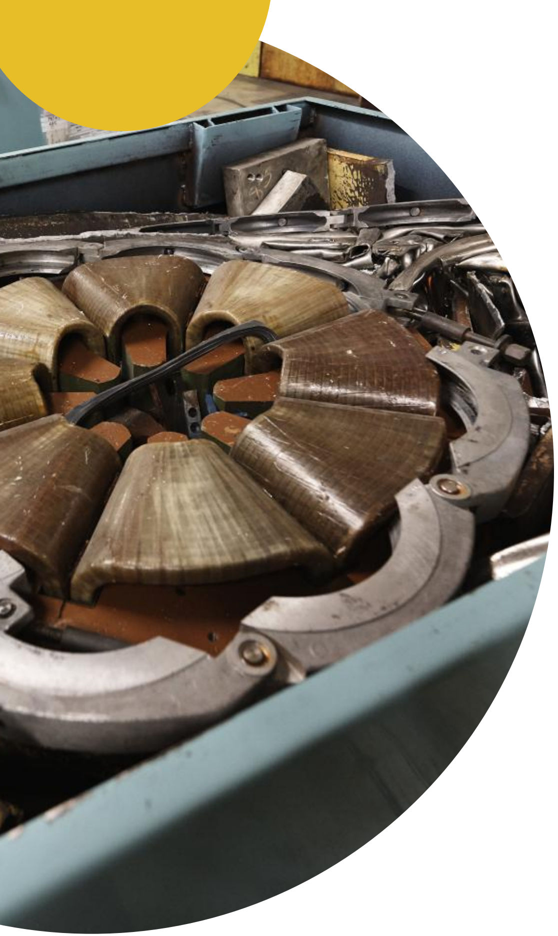
What does it mean

to characterize radioactive waste?

To confirm the acceptability of waste in the final repository…

…we need to know the nuclides present in the waste and their activity

Then we can calculate a figure of merit depending on the elimination path



Irradiated material

conventional

Cleared from regulatory control

FOM : LL (clearance limit)

radioactive

Very low activity

Low & medium activity

FOM : IRAS (radiotoxicity)

* More info at backup slides

What does it mean
to characterize radioactive waste?

In order to extract the nuclides and their activity…

…we need to perform measurements on the waste.

Typical examples : Gamma spectrometry or chemically analyzing samples

What does it mean

to characterize radioactive waste?

But….

Is there another way to do it?

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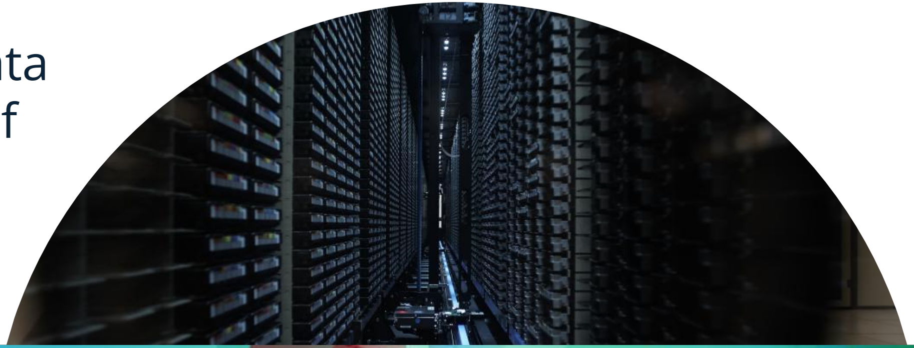
Machine learning

...when a computer mimics human behavior and learns from data

We “show” the computer a lot of data and it identifies underlying patterns and correlations

It can use models to connect data points, identify similar groups of data points, find relations between parameters, etc…

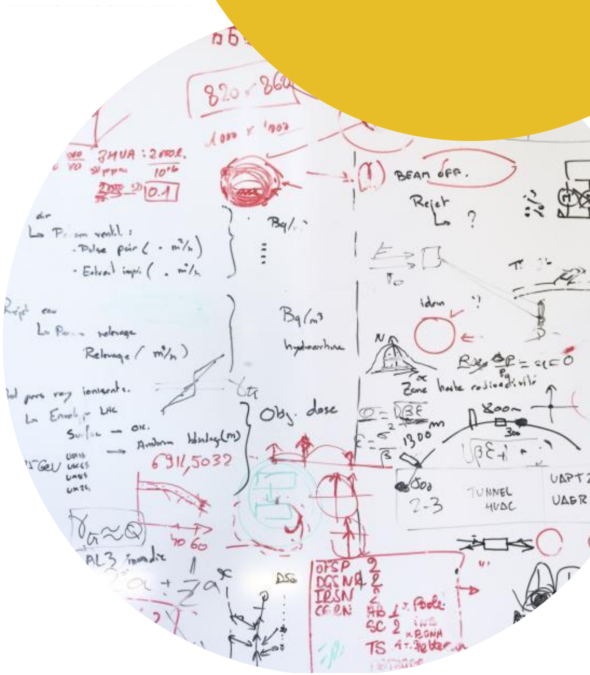


But what about statistics?

We are used to working with statistical models,
why do we need machine learning?

With statistics, we use data to set parameters so we can build a model that describes a population

With machine learning, we identify patterns and can make predictions about individuals



So how can we employ it?

We need data…

…representative enough of our waste so the computer can find patterns…

…and apply them to create models and predictions for individual waste

How do we create data?

At CERN we have two powerful tools

TREC: Traceability system for potentially radioactive equipment

ActiWiz: A software calculating irradiation results based on input parameters

* More info at backup slides

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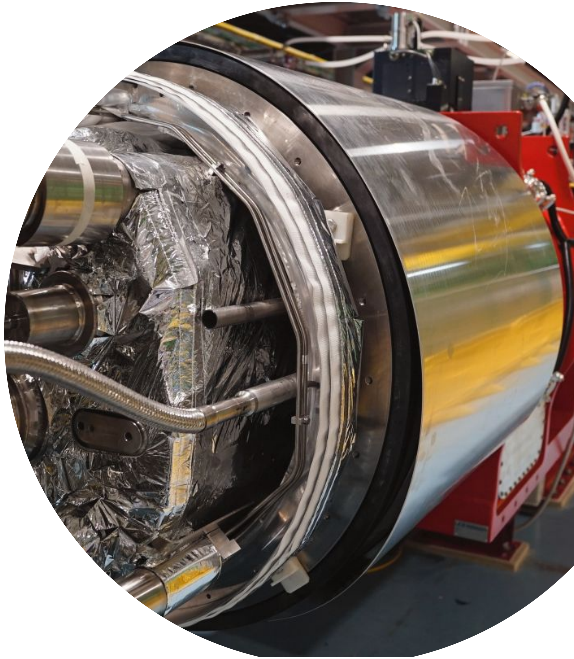
The massive items case

Some of the waste generated at CERN consists of bulky items such as magnets and shielding blocks.

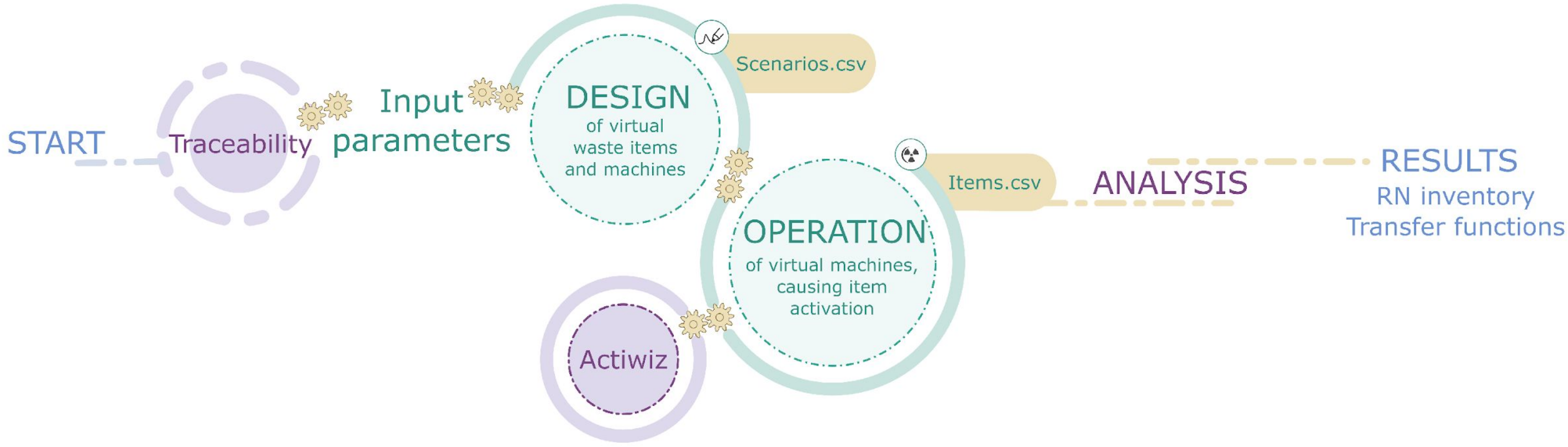
Characterization via g-spec : Technically and practically complex

Alternative : Characterize based on the dose rate instead



The massive items case

Our workflow:



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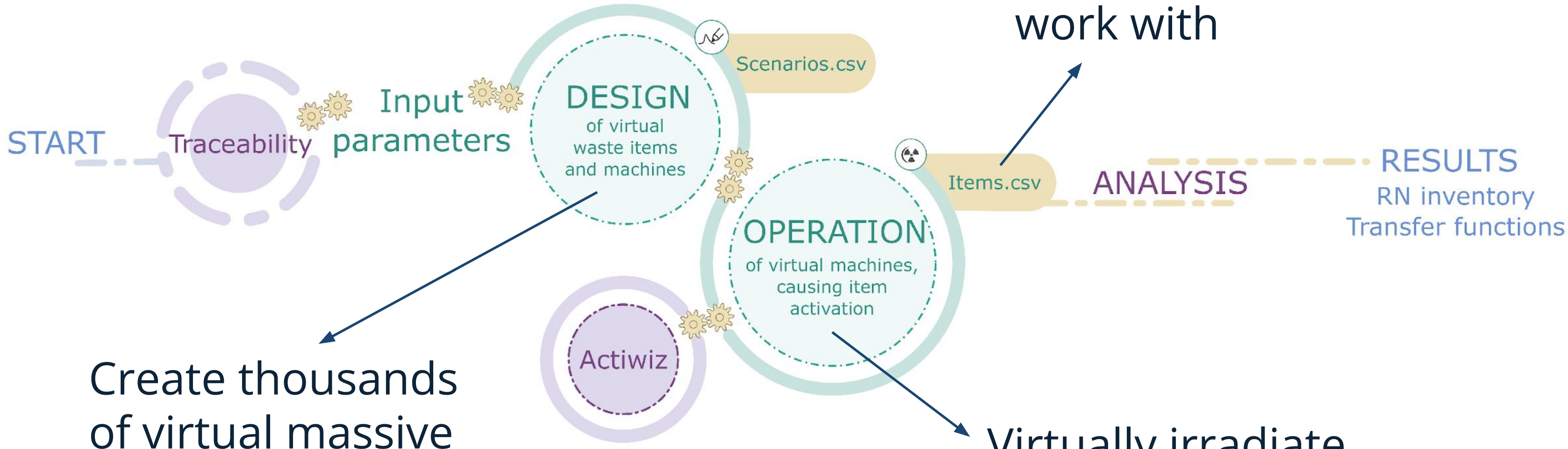


Dataset of thousands of massive waste pieces to work with

Create thousands of virtual massive waste items

Virtually irradiate them with ActiWiz

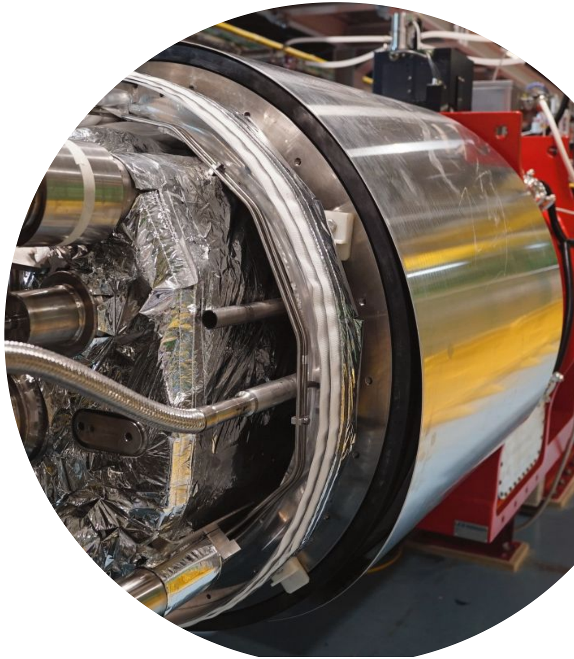
* More info at backup slides

The massive items case

Aim: Translate an item’s dose rate to RN inventory

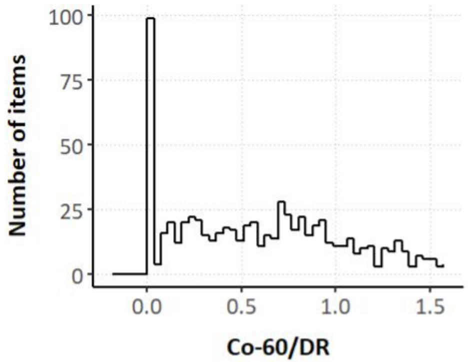
Data: Virtual waste items created with ActiWiz
Data contain each item’s dose rate and RN inventory

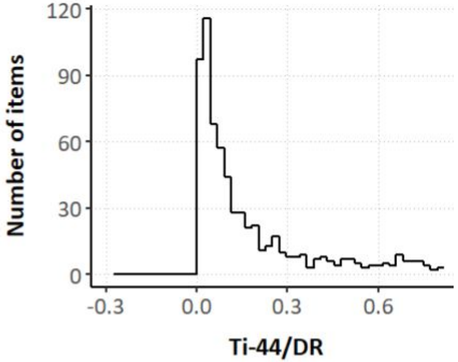
Path: Study the relationship between item dose rate and each nuclide’s activity



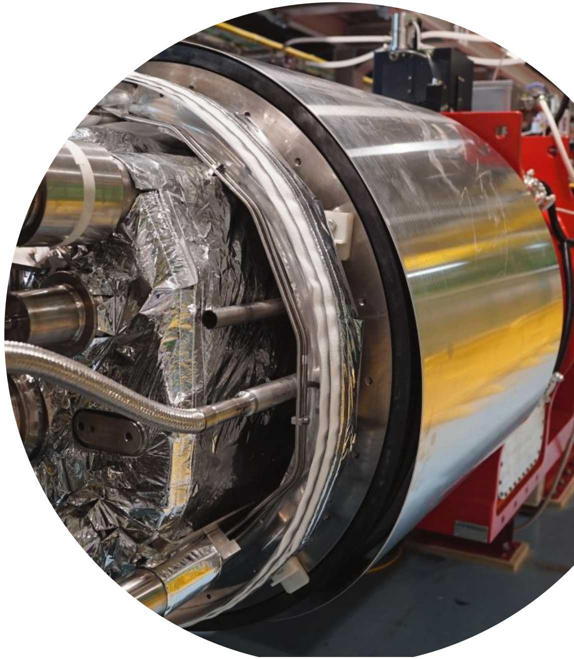
The massive items case

Path: Study the relationship between item dose rate and each nuclide's activity





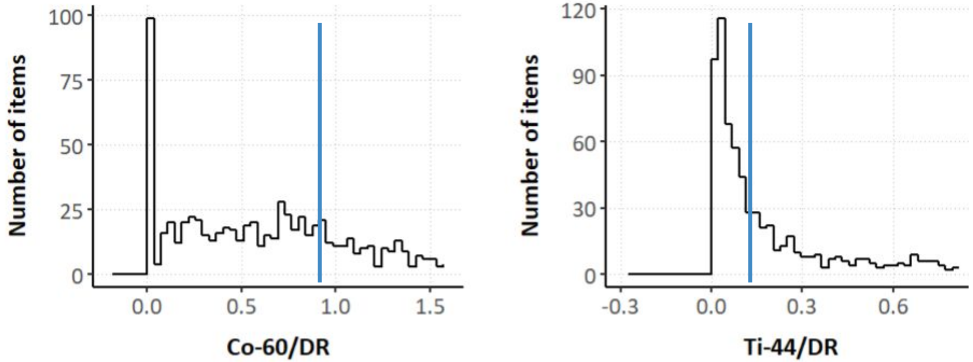
Distribution of ratio between nuclide activity and dose rate for 10000 items for two example nuclides, Co-60 and Ti-44



The massive items case

Path: Study the relationship between item dose rate and each nuclide's activity

Representative value: 75th percentile



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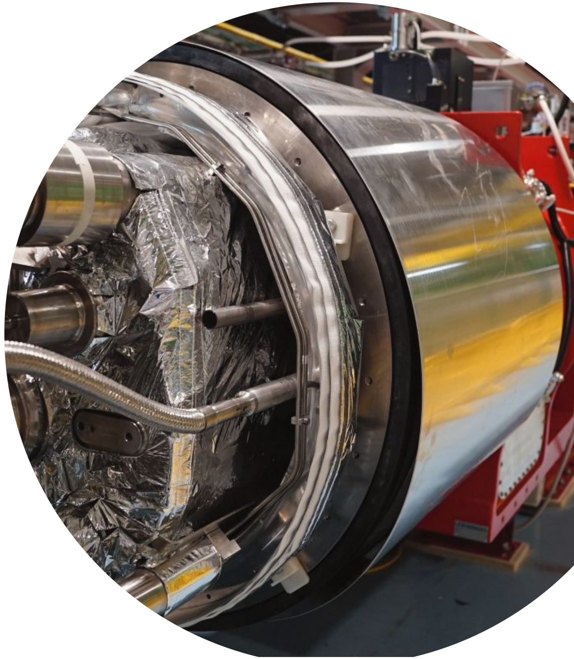
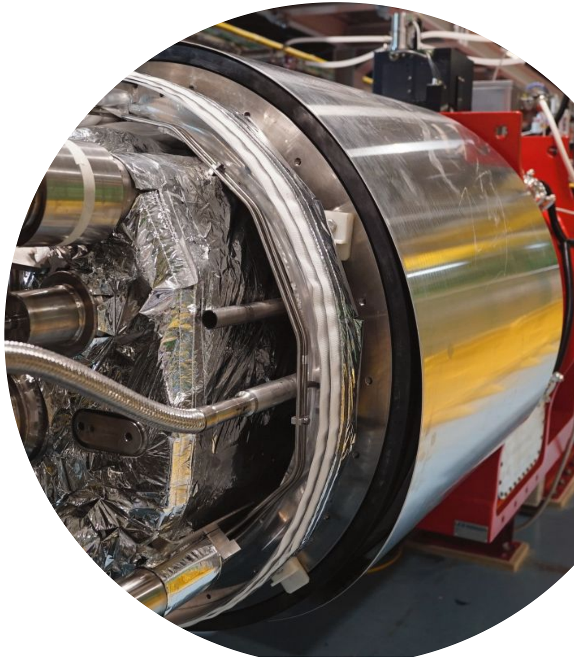


The massive items case

We call this value the “transfer function” and use it to translate an item’s dose rate to radionuclide activities



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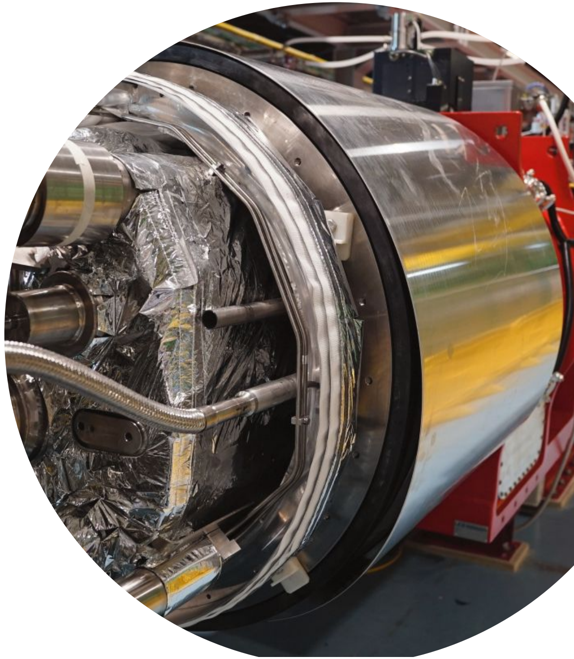
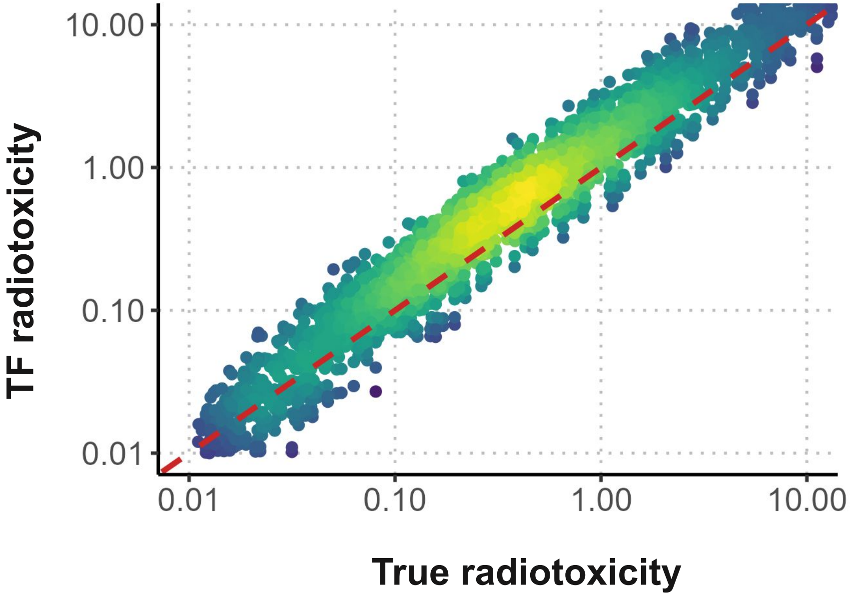


How do we know it works?

Virtual items advantage : We created them, we know their details.
We can create an independent “test” dataset and compare!

The massive items case



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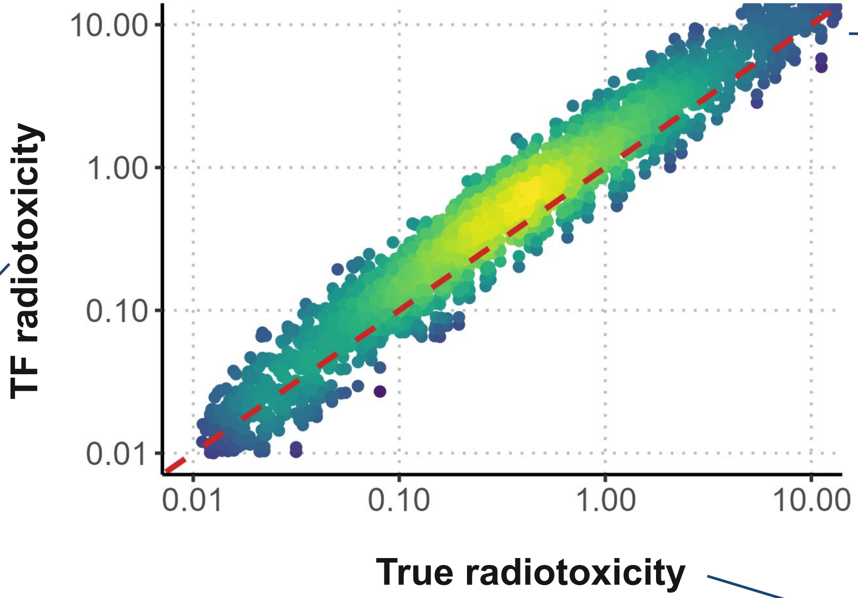
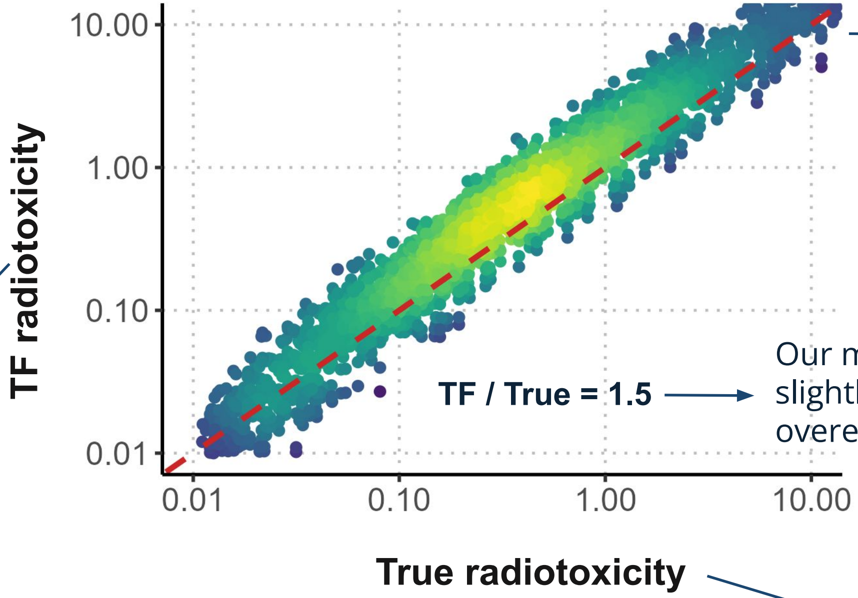


True radiotoxicity = TF radiotoxicity

As we calculate it with our transfer functions

As it comes from the simulations

The massive items case



True radiotoxicity = TF radiotoxicity

As we calculate it with our transfer functions

Our method is slightly overestimating

Conservative = good in radioactive waste context!

As it comes from the simulations

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What are we doing?

Launching a new methodology in radiological characterisation by employing the advantages of machine learning

This large-scale approach helps us spot trends with more confidence and reduces the influence of random variations.

In the massive items case, replacing gamma-spec measurements with dose-rate mapping reduces complexity

What's next

Dive deeper into machine learning!

Use other methods of machine learning and computational techniques such as clustering, modelling, principal component analysis, etc. not only in the characterisation methodologies but also in quality control.

Thank you for your attention!

Contact me:
maria-elisso.stamati@cern.ch

Find us:
https://radiological-characterization.web.cern.ch/

All images: CERN

Backup slides

CERN’s waste

Since 2011, ~8000 m3 of waste have been produced and ~11000 m3 (eq. before treatment) have been disposed of.

Some waste families:

- Metals
- Inert
- Cables
- Sources / Targets
- Burnable

CERN's regulatory framework

CERN is an international organisation and, as such, it has a right to establish its own rules and regulations.

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 CERN and its host states (FR and CH) authorities according to a "Tripartite Agreement" of 2010.

CERN’s regulatory framework

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

The waste study of the organisation 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.

Cleared
Low & Medium activity

Very low activity
Low & Medium activity : Short half-life

Characterisation FOMs

Clearance conditions:

- Surface contamination (CS) level: CS is defined as the sum of the non fixed activity which can be removed from a surface by wiping or washing + the fixed activity which can be removed during future use. Condition: CS < or = to the defined CS limit.

- Specific activity level: It should be lower than or equal to the clearance limit / limite de liberation (LL).

- Dose rate level: The dose rate (D) is an operational quantity used to estimate the exposure of a person to radiation. The ambient equivalent D at 10cm from the material surface should be lower than 0.1μSv/h.

Characterisation FOMs

Radioactive waste:

- IRAS = Indice Radiologique d'Acceptabilité en Stockage, defined by the French National Agency for Radioactive Waste Management (ANDRA)

$$IRAS = \sum_i \frac{a_i}{AL_i},$$

with a_i the activity of isotope i and AL_i a coefficient expressing the radiotoxicity of isotope i

All isotopes with activities surpassing an established declaration threshold must be included in the IRAS calculation

ActiwWiz

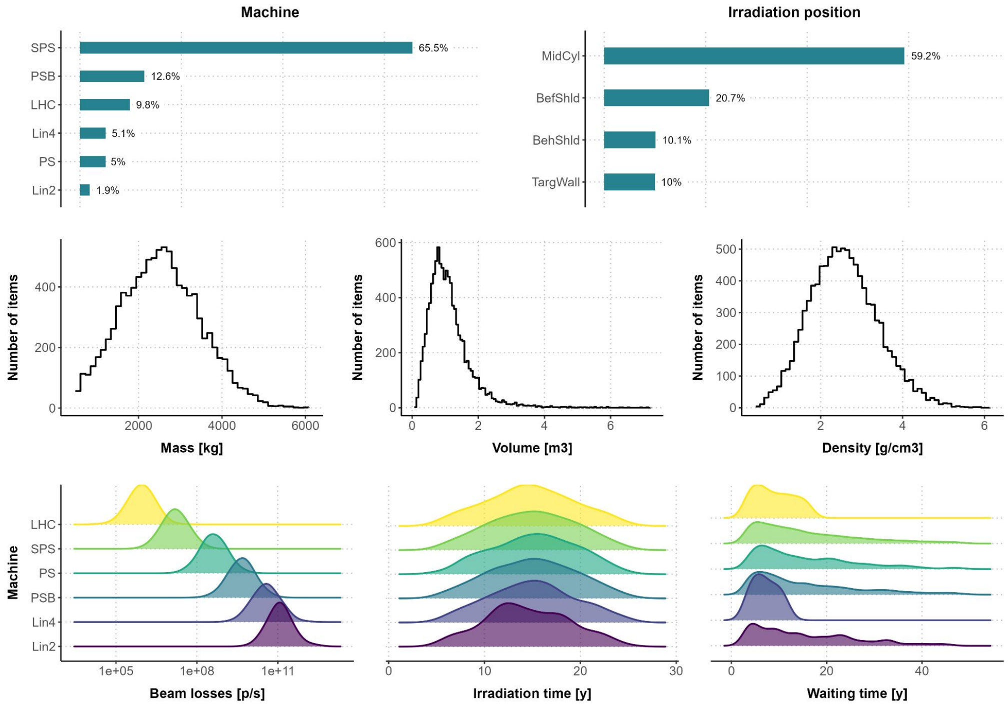
ActiWiz | Knowledge Transfer
ActiWiz 3 – un code déterministe pour la caractérisation radiologique Chris Theis et Helmut Vincke

ActiWiz is an analytical code developed at CERN in 2011. It is based on simulated particle fluence spectra together with a dedicated decay engine, combined with user-defined input parameters. The aim of ActiWiz is to compute quantities related to the activation of an object inside a CERN accelerator.

The basis of ActiWiz is the definition of a scenario that specifies the physical characteristics of an item as well as its radiological history parameters. It can then calculate the induced activity values for all radionuclides present in the item, as well as the item's average dose rate at a user-defined distance.

Massive items parameters

In order for our virtual items to be as representative as possible, we sample their parameters from probability distributions based on our knowledge of CERN's radioactive waste



Massive items parameters

To confirm that the parameters are representative, we can simulate specific items whose parameters are known to us thanks to TREC and compare with the general study