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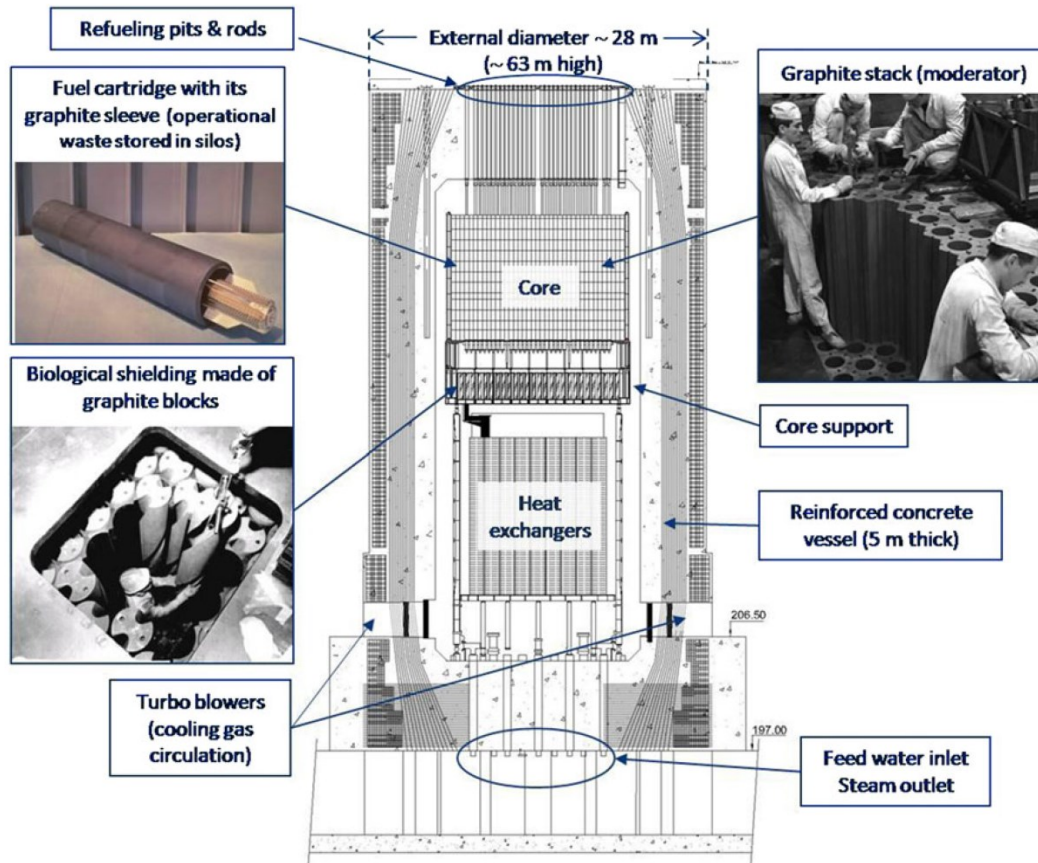


# **A reverse method for the determination of the radiological inventory of irradiated graphite at reactor scale**

- **UNGG reactors and activated graphite waste**
- **A specific physical problem of radiological inventory determination**
- **The proposed reverse method**
- **Output results and physical analysis**
- **Further work**

# EDF - UNGG reactors and activated graphite

- Uranium Natural Graphite Gas (Graphite-moderated, gas-cooled (air or CO<sub>2</sub>))

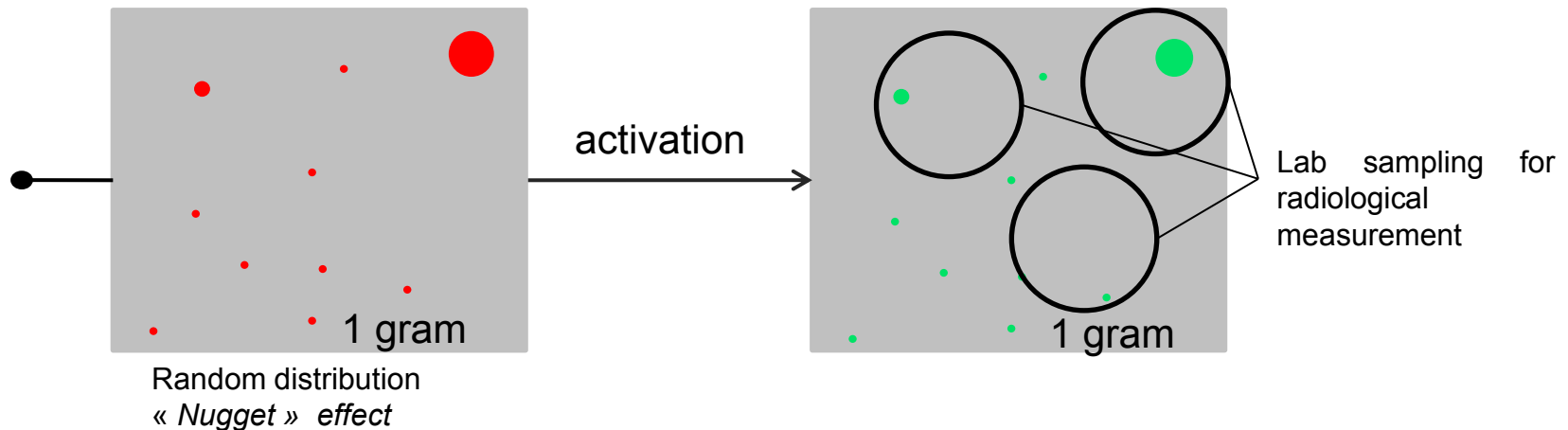


~17000 tons of activated graphite in 6 UNGG reactors of EDF

Graphite activated waste are Low-Level Long-Lived waste (<10<sup>6</sup>Bq/g, >100y)

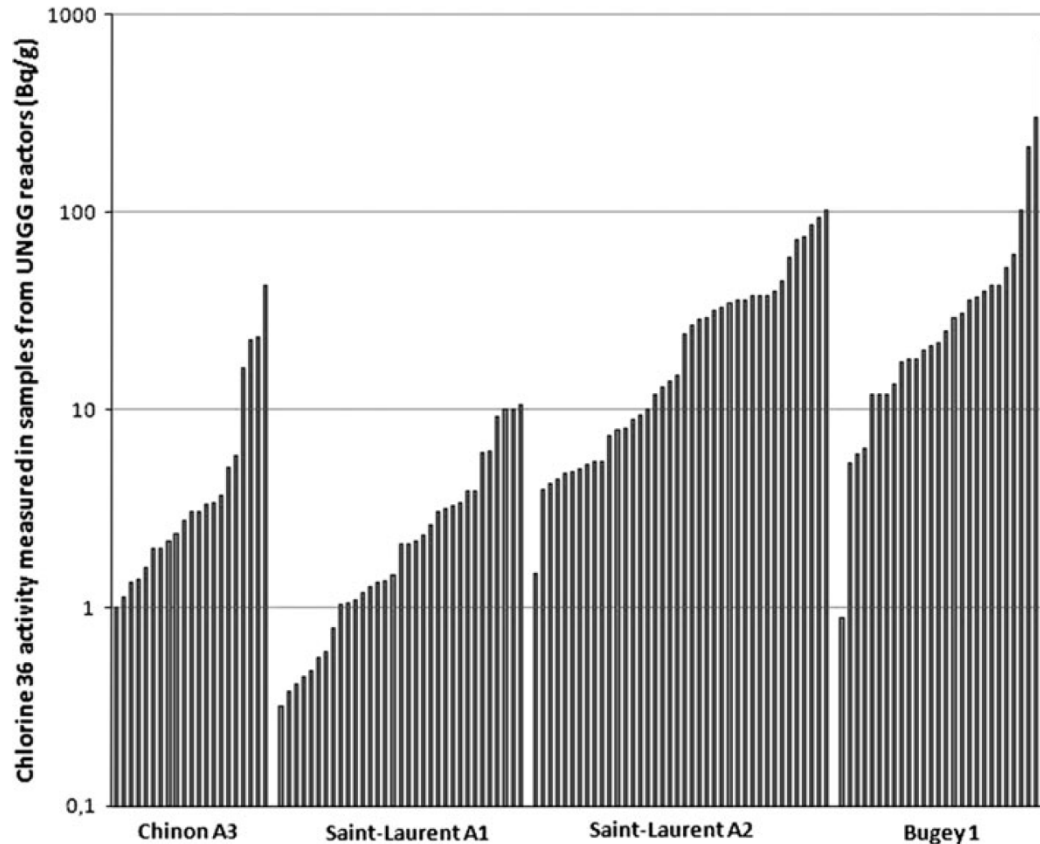
# A specific physical problem of radiological inventory determination

- Radioactivity comes from activation of  $^{13}\text{C}$  isotopic content in graphite (1%) + impurities at trace levels, far below ppm



**For many radionuclides, radiological measurements exhibit high discrepancies (2-3 orders of magnitude) that do not correlate with the neutron flux variation (1 order of magnitude), or the temperature variation (280-530°C)**

# Example of $^{36}\text{Cl}$ activity measurements



Considering only the highest values is not reasonable for disposal designing

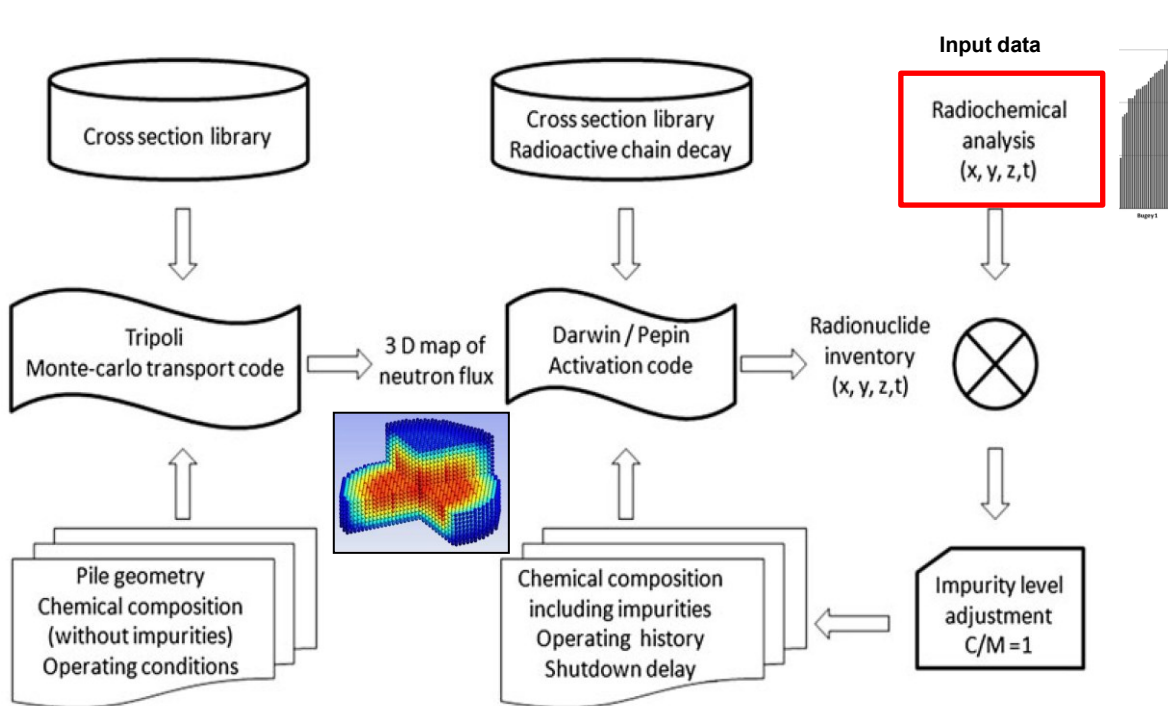
A geometric or arithmetic average should not be representative of the physical process of the activation of impurities

Activation calculation is needed but impurities content is not known

A reverse method to find the best set of impurities content is needed, using all the available radiological measurement

# The reverse method in details

52 impurities (k) are considered to find 144 radionuclides (i) which are measured (j) ~30 times



For each of the  $j$  local measures  $M_{ij}(x_j, y_j, z_j, t_j)$  of a radionuclide  $i$ , a local activation matrix  $A_j$  is analytically built using the calculated local neutron flux.

It links the local content of an impurity  $X_{kj}$  to the local activity concentration after activation of a radionuclide  $C_{ij}$

$$X_{kj} \cdot (a_{ki})_j = C_{ij}$$

Then the quantity  $X_{kj}$  is adjusted by iterations to minimize the cost function:

$$\sum_i \mu_i^2 = \sum_i \left( \frac{1}{N_i} \sum_{j=1}^{j=N_i} \ln \frac{C_{ij}}{M_{ij}} \right)^2$$

A vector of adjusted impurity content is therefore obtained for each of the  $j$  prelevement.

An average is performed on all these vectors to get the average impurity content of all the pile  $\langle X_k \rangle$ .

A final activation is performed using this vector as input data to get the radiological inventory of all the pile.

# Output results to analyse

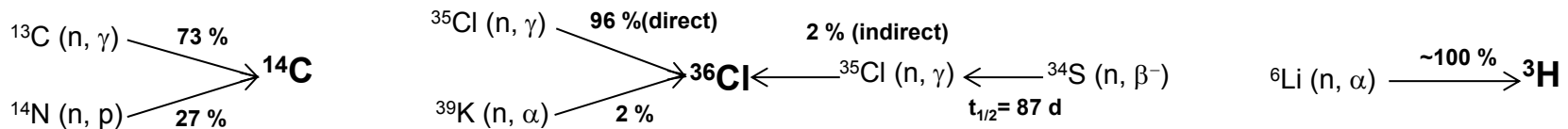
## 1- IMPURITIES CONTENT

$^{35}\text{Cl}$  (precursor of  $^{36}\text{Cl}$ ) is evaluated to **81 mg/t on Bugey 1 reactor**

$^{35}\text{Cl}$  (precursor of  $^{36}\text{Cl}$ ) is evaluated to **83 mg/t on Saint Laurent A2 reactor**

This similarity is promising.

## 2- ACTIVATION SCHEMES AT THE REACTOR SCALE



These schemes are obtained at reactor scale at the end of a justment process. They need to be compared from a reactor to another (further work) to assess that the method is not reactor-dependant.

# Output results to analyse

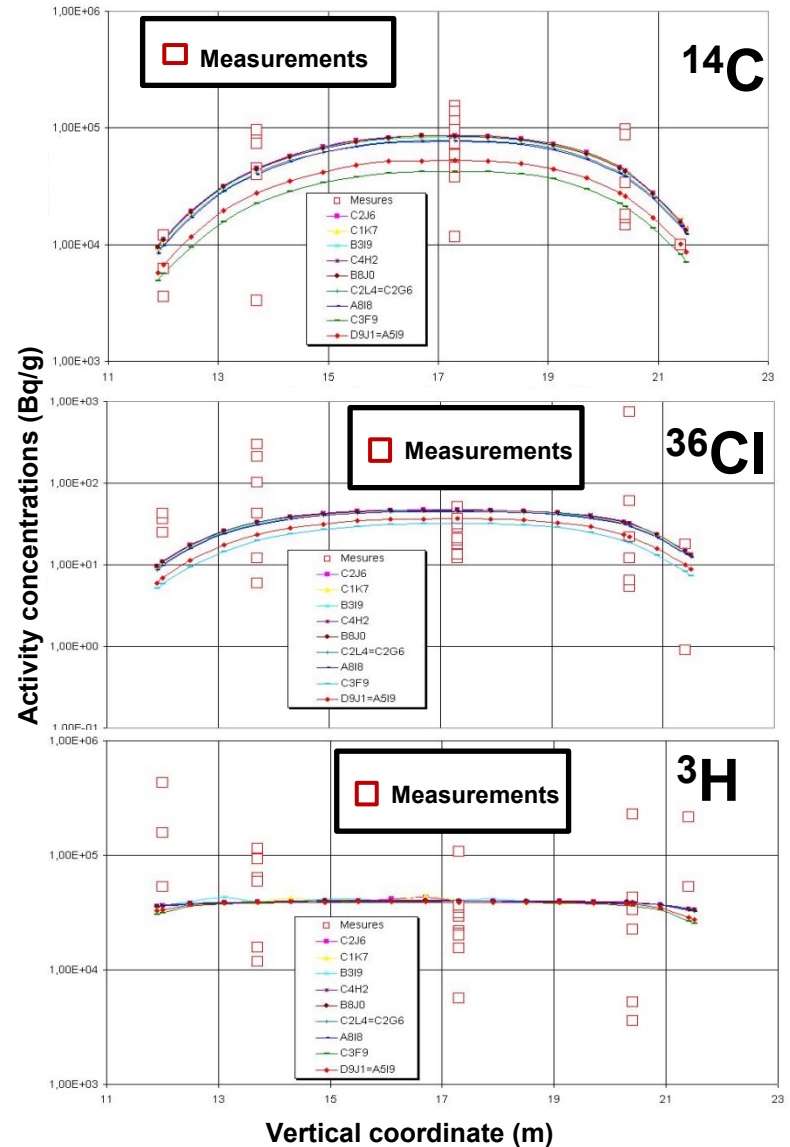
## 3- CALCULATED ACTIVITY CONCENTRATION PROFILE

There is a strong correlation between the shape of neutron flux and the profile of calculated activity concentration taken into account the neutron capture cross section of the precursors:

- $\sigma_{\text{capt}}$  of the  $^{13}\text{C} (n, \gamma) ^{14}\text{C}$  reaction is  $10^{-3}$  barn
- $\sigma_{\text{capt}}$  of the  $^{35}\text{Cl} (n, \gamma) ^{36}\text{Cl}$  reaction is 43 barns
- $\sigma_{\text{capt}}$  of the  $^6\text{Li} (n, \alpha) ^3\text{H}$  reaction is 940 barns

A very dependant to the neutron flux profile of  $^{14}\text{C}$  activity concentration distribution, and a flat profile of  $^3\text{H}$  (saturation) are very physical results regarding to  $\sigma_{\text{capt}}$

Moreover « sursaturation » measurement of  $^3\text{H}$  may come from contamination by tritium produced by ternary fissions (to study)





# Conclusion and further work

**The reverse method gives some physical and coherent results on Bugey 1 reactor.**

**The declination of this method on the 6 EDF UNGG reactors is ongoing (EDF).**

**Intercomparison and interpretation of impurity contents, activation schemes, activity concentration profiles will be used for the physical validation of this mathematical method (IRSN).**

**In case of satisfying level of validation, radiological inventories will be calculated with a narrow uncertainty range, compared to measurements variability.**