# Modification of activation code ACAB to detect and prevent the possibility of an erroneous resolution of some cases

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## Introduction

**What is an activation code?**

It is a program which calculates the isotopic inventory of a material when it is irradiated. The two main process which form the activation paths are decay (e.g. ${}^{3}H \rightarrow {}^{3}He + \bar{\nu} + e^{-}$ ) and transmutation (e.g. ${}^{186}W + n \rightarrow {}^{187}W + \gamma$ ).

**Why they are relevant in fusion facilities?**

Activation codes perform radiation protection studies (e.g. operators' dose rates in maintenance activities), radiation waste management, radiation damage in materials and components.

**What is ACAB used for?**

Currently, it is used for activation studies in fusion facilities (ITER, DEMO) and particle accelerators (IFMIF-DONES). In addition, activation studies were done for NIF and Hylife-II facilities [1]. It is part of R2SUNED code (Rigourous-Two-Steps UNED).

## Description of the problem

It has been determined that there are some cases in which it is possible that an error in the results could be done. If the error happens ACAB doesn't inform to the user [2].

## Cause of the problem

The isotopes are characterized by their effective decay rate ($d = \lambda + \phi\sigma$) in ACAB.

In ACAB it is recommended that irradiation and cooling intervals be divided in time steps but it isn't defined clearly the way to do it.

For each time step ($\Delta t$) ACAB classifies the isotopes as short life isotope ($d > \frac{-\ln(0{,}001)}{\Delta t}$) or as long life isotope ($d \leq \frac{-\ln(0{,}001)}{\Delta t}$).

**It was determined that in some cases an error in isotopic concentration happens when there are isotopes with effective decay rates near or equal at the limit between short live isotopes and long live isotopes. These cases are very sensitive to user´s time step [2].**

This limit is named critical decay rate ($d_{crit} = \frac{-\ln(0{,}001)}{\Delta t}$).

## Resolution of the problem: time step generator

**Basis of the method**

For each time interval it is necessary to search the time steps whose related critical decay rate has the maximum distance to the effective decay rates of the isotopes. This property is determined with a relative difference called Safety Factor (SF).

$$SF = \frac{d_i - d_{crit}}{d_{crit}} \text{ if } d_i \geq d_{crit}$$

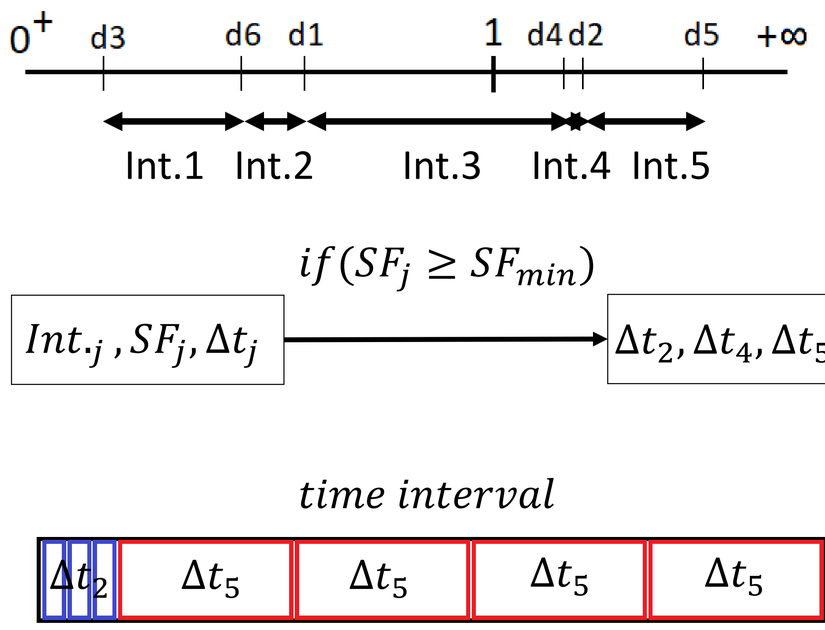
$$SF = \frac{d_{crit} - d_i}{d_i} \text{ if } d_{crit} \geq d_i$$

### Algorithm structure

1. For each time interval, the effective decay rates are arranged in descending order to form effective decay rates intervals.
2. For each interval $[d_i, d_{i+1}]$ the maximum common Safety Factor is achieved when $SF_i = SF_{i+1}$ and it is obtained a related time step $\Delta t_j$. The minimum value of SF will be defined and all the time steps $\Delta t_j$ with a SF greater than the minimum SF will be chosen.

$$d_{crit,j} = \sqrt{d_i d_{i+1}} \quad \Delta t_j = \frac{-\ln(0{,}001)}{d_{crit,j}} \quad SF_j = \sqrt{\frac{d_{i+1}}{d_i}} - 1$$

3. With these time steps the time intervals will be built.




## Alternative resolutions of the problem

The first one is an improvement of the actual solver of ACAB. The second one consists of change the actual solver for another such as LSODE (Livermore Solver for Ordinary Differential Equations) [3] or CRAM (Chebyshev rational approximation method) [4]. **Both could present the same problems as the current ACAB solver**. So a deep study must be done.

Since the time step generator doesn`t need to change the solver, it is the option chosen.

## Conclusions and Future Work

- Activation codes are programs which calculate the isotopic inventory of a material when it is irradiated. ACAB is one of them.
- A problem in some cases was identified in ACAB. Also this cause.
- To detect and prevent this situation a time step generator will be developed and implemented in ACAB. It will guarantee that the time steps used have a related critical decay rate far from the effective decay rates of the isotopes.
- It was considered other resolutions of the problem such as the solvers LSODE or CRAM.

## References

[1] Sanz, J., Cabelllos, O., Garcia-Herranz, N., *ACAB: Inventory code for Nuclear Applications. User's Manual 2008*, December 2008

[2] A.J. López-Revelles, *Neutron analyses and design of components for ITER*, PhD thesis, Universidad Nacional de Educación a Distancia, 2018

[3] K. Radhakrishnan and A. C. Hindmarsh, *Description and Use of LSODE, the Livermore Solver for Ordinary Differential Equations*, LLNL report UCRL-ID-113855, December 1993

[4] Pusa, M., Leppänen, J., *Computing the matrix exponential in burnup calculations*. Nucl. Sci. Eng. 164, 140–150, 2010