Visualization Technique for Nuclear Materials using ACTYS

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Introduction

In nuclear devices as well as conceptual power plants, neutron induced activation calculations play an important part in the research into materials. Activation codes simulate neutron induce reactions and calculate a variety of radiological quantities. A key constraint for fusion structural materials is to have minimal long term environmental impact. Therefore, designing and fabricating low activation materials is of high priority [1].

A novel method has been developed as an aide to the activation codes to reach optimized concentrations of elements for a material without iterative calculations. To further help the cause innovative visualization techniques are developed. These graphs provide a spectrum independent behavior of isotopes or elements contributing towards a radiological response. Thus removing such isotopes/elements would facilitate the selection of materials based on radiological requirement.

METAA

The transmutation-decay of any isotope Ni is governed by Bateman equation. The solution of equation is:

$$\vec{N}(t) = e^{\mathbf{A}t}\vec{N}(0) \Rightarrow \vec{N}(t) = \mathbf{T}\vec{N}(0) \qquad (1)$$

where $e^{\mathbf{A}t}$ is written as matrix $\mathbf{T}$. Now, any radiological response calculated at time 't' can be written as:

$$R = \vec{G}\vec{N}(t) \Rightarrow R = \vec{G}\mathbf{T}\vec{N}(0) \Rightarrow R = \mathbf{F}\vec{N}(0) \qquad (2)$$

This implies that, any radiological response can be evaluated in terms of initial atomic concentration of isotopes or elements. For any isotope 'j', contribution C_j, towards a radiological quantity 'R' and the contribution factor CF_j can be expressed as:

$$C_j = \frac{F_j * N_j(0)}{R} \quad and \quad CF_j = \frac{C_j}{af_j} \qquad (3)$$

where af_j is the atomic concentration of isotope 'j'. Such quantities are helpful in material optimization based on the initial elemental or isotopic composition [2]. By changing the initial atomic fraction the final responses of the material can be minimized.

Visualization Technique

The above radilogical contributions and contributing factors can be evaluated for any radiological quantity. To illustrate the importance of these quantities in material optimization various visualization techniques are developed. The EDC, ECF and Margin plots are obtained for Contact dose rate of SS316L(N). The parents of dominant isotopes for dose rate is calculated for each delta spectra of $1.0E12nm^{-2}s^{-1}$ and is plotted along a line parallel to the time axis at an energy corresponding to the energy group containing the neutrons. The technique is integrated with indegenously developed activtaion code ACTYS [3].

Elemental Dose Contribution

EDC or Elemental Dose Contribution is defined as:

$$EDC = \sum_{isotopes} \sum_{radionuclides} (\frac{d_j}{D} * N_j(0)) \qquad (4)$$

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where d_j is the dose contribution of isotope 'j' to the total dose D. The contribution from all radioactive daughters of each isotope of the element is summed together to evaluate EDC. The plot shows elements with highest

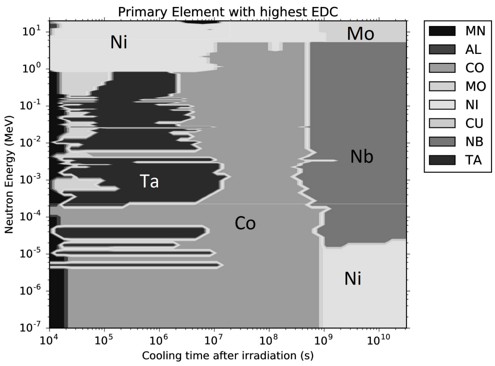

FIG. 1: Spectrum independent EDC plot of SS316

dose contribution factors(EDC) as a function of cooling time. As seen from the plot Nb and Ni are the most dose contributing elements after 31 years(1E9 secs). Reducing these would reduce dose at later cooling periods. Further if we can reduce the high energy flux effects of Nb could be minimized. Consequently if concentration of Ni can be reduced then the overall dose after 31 years could be reduced significantly.

Elemental Contributing Factor

ECF or Elemental contributing Factor is defined as:

$$ECF = EDC/wf \tag{5}$$

where wf is the weight fraction of the element contributing EDC. ECF determines the impact of reduction of the element on the total dose. Major isotopes whose quantities if reduced, would affect dose are Ta, Co and Nb. Since only 3 elements needs to be minimized, if neutrons are not very energetic(less than 1MeV), this narrows down the task of material optimization.

Margin Plot

Margin is the allowable limits within which element can be tailored in a material. This

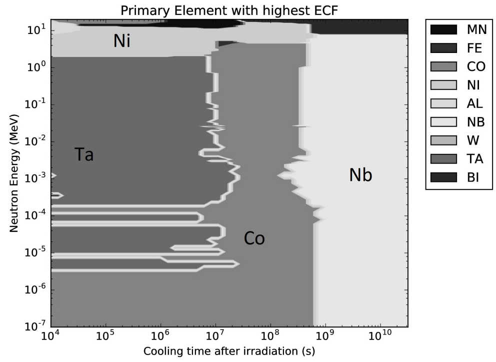

FIG. 2: Spectrum independent ECF plot of SS316

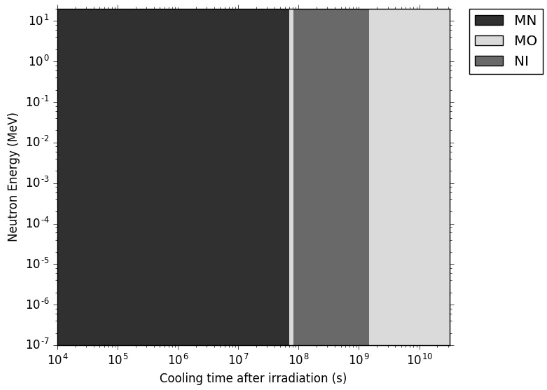

FIG. 3: Spectrum independent Margin plot of SS316

plot represents the elements with highest allowable range for tailoring that have high ECF values. Only three elements are represented in the plot for entire cooling period which indicates the simplicity of the graph. Reducing these elements are possible , and would result in decreased values of the radiological quantity in question.

References

[1] M. Gilbert et. al., CCFE-PR(14)44
[2] T.S. Chaitanya et. al., Nuclear Science and Engineering (ACCEPTED)
[3] T.S. Chaitanya et. al., Annals of Nuclear Energy 107C (2017) 7181.