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MODELING OF THE CTEx SUBCRITICAL UNIT USING MCNPX CODE

Avelino Santos[1], Ademir X. da Silva[2],Wilson F. Rebello[3], Victor L. Lassance Cunha[4]

[1] Divisão de Defesa Química, Biológica e Nuclear.
Centro Tecnológico do Exército - CTEx
Av das Américas, 28705-Guaratiba
Rio de Janeiro, RJ - Brasil - CEP: 23020-470
hiperav@gmail.com

[2] Programa de Engenharia Nuclear.
Universidade Federal do Rio de Janeiro - UFRJ
Centro de Tecnologia, Bloco G, Sala 206 Ilha do Fundão
Rio de Janeiro, RJ - Brasil - CEP: 21945-970 - Caixa-Postal: 68509
ademir@con.ufrj.br

[3] Seção de Engenharia Nuclear – SE/7
Instituto Militar de Engenharia - IME
Praça General Tibúrcio, 80 -Praia Vermelha
Rio de Janeiro – RJ- CEP: 22290-270
wilsonrebello@gmail.com

[4]Instituto de Engenharia Nuclear
Comissão Nacional de Energia Nuclear - CNEN
Rua Hélio de Almeida, 75 - Cidade Universitária - Ilha do Fundão
Rio de Janeiro - RJ – Brasil - CEP: 21941-614
lassance@gmail.com

ABSTRACT

The present work aims at simulating the subcritical unit of Army Technology Center (CTEx) namely ARGUS pile (subcritical uranium-graphite arrangement) by using the computational code MCNPX. Once such modeling is finished, it could be used in k-effective calculations for systems using natural uranium as fuel, for instance. ARGUS is a subcritical assembly which uses reactor-grade graphite as moderator of fission neutrons and metallic uranium fuel rods with aluminum cladding. The pile is driven by an Am-Be spontaneous neutron source. In order to achieve a higher value for k_{eff}, a higher concentration of U235 can be proposed, provided it safely remains below one.

1. INTRODUCTION

The study aimed to carry out computational modeling of the subcritical unit CTEx and perform the simulation of its operation to calculate its reactivity. The simulation was developed using the MCNPX, which is a code for calculating nuclear radiation transport based on the Monte Carlo method. With the estimated value for the neutron multiplication factor, $k_{eff,}$ in its initial composition, one can propose changes in this composition to achieve a k_{eff} close but under 1, condition for maintaining the condition of subcriticality.

2. ARRANGEMENT SUBCRITICAL

The ARGUS pile (subcritical uranium-graphite arrangement) is an experimental tool, made for obtaining relevant neutronic parameters necessary to design High Temperature Reactor

(HTR). The experiments are mainly intended to investigate the neutrons flux, either directly or indirectly.

The subcritical arrangement of the CTEx consists of graphite blocks of nuclear purity placed upright, working as the moderator of fission neutrons. The graphite blocks are arranged in a hexagonal shape on a concrete pedestal and held together by aluminum strips. The central graphite blocks are hollow in the core, where the fuel rods and instrumentation are introduced. The peripheral blocks are solids. The fuel rods are composed of an aluminum casing, filled with natural metallic uranium. The pile also has an external source of Am-Be, that when introduced, is responsible for providing a sufficient amount of neutrons to maintain the fission reactions and when removed, the reactions cease. This external neutron source is introduced halfway up by a pneumatic mechanism remotely controlled. When not inserted in the pile, it is housed in a borated paraffin shielding. The CTEx subcritical unit is shown in Figure 1.

Figure 1. CTEx subcritical unit

3. METHODS

The first objective of this study is to model the unit using the computational code MCNPX. To create the INP (input file) of this modeling, the surface cards were defined by macrobodies. This option was aimed at reducing the command lines required to describe the geometry. This reduction can be exemplified in the modeling of a cube, where you can use a single command line if you use macrobodies instead of six lines, each representing a plane. The modeling began by scaling the external source, then the shell of the source, and the graphite block where this source is introduced.

The detailed modeling can be seen in Figure 2 (cross section) and Figure 3 (longitudinal section) obtained by the Visual Editor. The next step was the characterization of two graphite blocks adjacent to an external source. In these blocks, four cavities were designed containing the fuel assembly, composed of the fuel itself (uranium) in the central part, covered with an aluminum tube and an air channel in the outer shell of this set. Soon after, the remaining cubes of graphite with central hole for the fuel introduction (uranium, aluminum tube and air

channel) were designed, where it was only necessary to define a single one of these elements, since they are identical. At a later stage they were be replicated. Continuing to define the card surface, eight blocks of solid graphite and the outer shielding of the external source internally composed of a graphite block were drawn, wrapped in a layer of borated paraffin and externally covered by wood. Finally, the concrete pedestal and the air box encompassing the entire structure were set up.

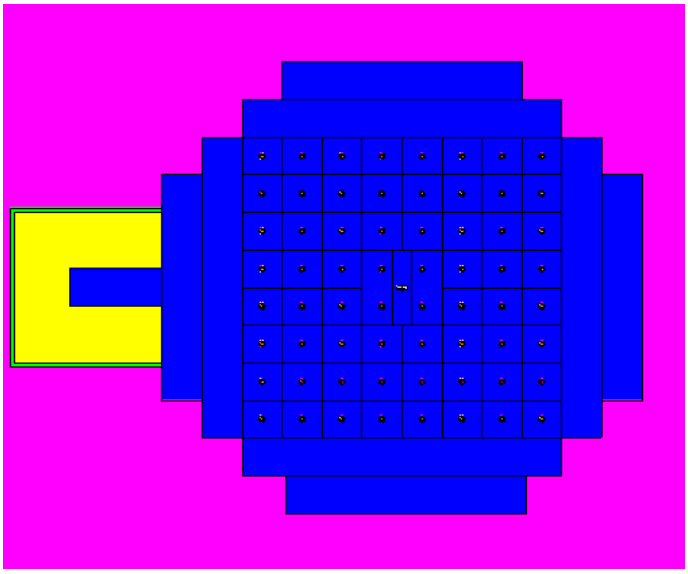

Figure 2. Cross section of the subcritical unit

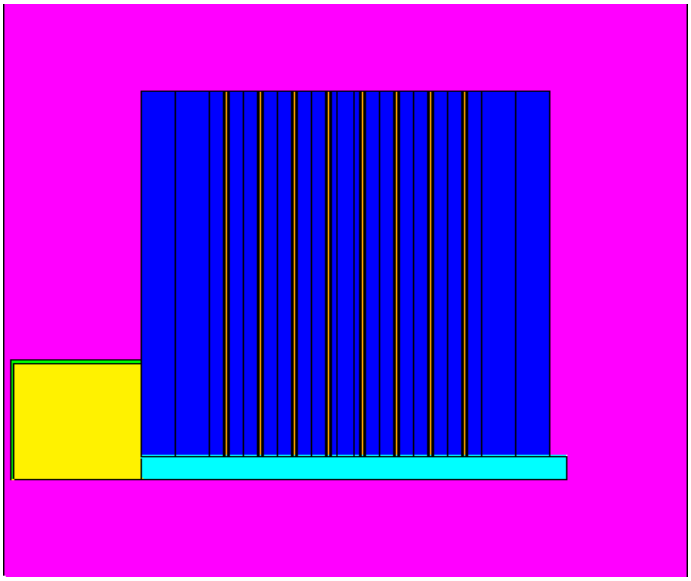

Figure 3. Longitudinal section of the subcritical unit

After the definition of the card surface, the cell cards were defined, following basically the same order shown above. It should be noted that for the production of these cards, you need to set a number for each material to be used later, the density of this material, and the relative importance to radiation or particles that should be followed in the simulations. The orientations of the previously defined surfaces are established, generating the solids. It is in this block of the input file (INP) that identical structures are replicated, where a single command line can copy complicated structures, just by varying the position of these structures. This is possible thanks to the concept called *universe-fill*. To use this feature it is necessary to first define the volumes that will be replicated.

In the end of the input file (INP) the simulation data block is set, consisting of the composition of all materials used and the isotopic abundance of its constituents. In this block it is also defined which particles or radiation are of interest. In this case, only neutrons were considered. Geometric and spectral data of the external source are defined. For k_{eff} calculations the latter won't be taken into account, since this estimation is not dependent on external source. The calculation of k_{eff} itself runs through the command KCODE, providing information on the number or neutrons per cycle, an initial estimate of the value of k_{eff}, number of initial cycles that will be disregarded (to converge distribution of the neutron fission sources throughout the geometry) and the total number of cycles studied in the simulation.

The first simulation conducted maintained all the original features of the Argus unit, i.e., the fuel consisting of natural uranium (metal), containing 0.7% of the isotope U-235. Different enrichments were also tested, always observing the k_{eff} limit (below 1.0) to keep the subcriticality character of the unit. The effective multiplication constant was also analyzed in the case where uranium dioxide, UO_2, was used instead of metal, since the latter has a lower production cost, especially at higher enrichments.

4. RESULTS

The parameters used in KCODE command in all simulations were: 200 neutrons per cycle, initial estimate value for k_{eff} equal to 0.4, 10 skipped initial cycles and the total number of cycles studied in the simulation was 3000. To simplify the problem no other uranium isotopes were considered in the fuel.

The first simulation was performed maintaining all the original characteristics. The calculated value of k_{eff} for the simulation with natural uranium metal with 0.7% U-235 was 0.61033 with standard deviation of 0.00089. It was the first achieved objective of the study. The other aim of this study is to simulate the increase in the fuel enrichment, making the unit more reactive but maintained the subcriticality. For that we used at first uranium metal with various concentrations of U-235. These results are presented in Table 1:

Table 1 – K_{eff} values simulating metal uranium for different enrichments

U-235 in the fuel	K_{eff}	Standard deviation
0,70%	0.61033	0.00089
1,00%	0.73116	0.00078
5,00%	1.14935	0.00147
3,00%	1.03866	0.00139
2,00%	**0.94385**	**0.00112**
2,50%	1.00623	0.00123
2,30%	0.97438	0.00118
2,40%	**0.99384**	**0.00129**

In a later stage the fuel was replaced by uranium dioxide, which is a more widely used fuel with enriched uranium. The results of k_{eff} are presented in Table 2:

Table 2 – K_{eff} values simulating UO_2 for different enrichments

U-235 in the fuel	K_{eff}	Standard deviation
0,70%	0.42938	0.00065
5,00%	1.03325	0.00148
3,50%	**0.94210**	**0.00127**
4,00%	0.97735	0.00119
4,20%	0.98464	0.00127
4,30%	**0.99387**	**0.00106**

5. CONCLUSIONS

The present study aims to propose changes in the subcritical unit for the development of a neutron channel to be used in various applications such as neutrongraphy, activation analysis of materials etc. The values presented in tables are sorted in chronological order were obtained, the approach of seeking a unit value for k_{eff}. Among the possible changes is the enrichment of the fuel used to make the battery more reactive, keeping the subcriticality. Thus, the increase in fuel enrichment was increased with the maintenance of its geometry. In a first set of simulations the fuel type was kept (metal uranium), varying the enrichment to obtain a value of k_{eff} very close to one. In this sense, the calculated enrichment of 2.40% was the maximum one before the unit became supercritical. According to established safe limits, the concentration of U-235 should be adjusted. If the maximum allowed value of k_{eff} is equal to 0.95, the enrichment value drops down to 2.0%. Similarly, if uranium dioxide is used, the

enrichment should not exceed 4.3%. In the same way, to obtain a maximum k_{eff} value equal to 0.95, the enrichment should drop to approximately 3.5%. This difference between the enrichment in metallic and dioxide uranium is explained by their different densities.

6. REFERENCES

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