THE EVALUATION OF SET OF CRITICALITY PARAMETERS USING SCALE SYSTEM

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ABSTRACT

In evaluating the criticality safety of the nuclear fuel facility, it is important to apply a consistent methodology, which consider every aspects concerning various types of criticality parameters. Usually, the critical parameters are compiled and arranged into handbooks, and these handbooks are based on experience with nuclear facilities, experimental data from criticality safety research facilities, and theoretical studies performed using numerical simulations. Most of criticality safety evaluation can be addressed using the criticality parameters data directly from handbook, but some critical parameters for a specific chemical mixtures and/or enrichment are not be available. Consequently, not available parameters has to be evaluated. This work present the methodology to evaluate a set of critical parameters using SCALE system for various types of mixtures present at nuclear fuel cycle facilities for two different level of enrichment, the results are verified in the independent calculation using MCNP Monte Carlo Code.

1. INTRODUCTION

The basic principle of criticality safety analysis is to prevent criticality for all situations where technically are conceivable. The safety analysis has to consider design stage, fabrication and construction stages, and operational procedures conducted at facilities under normal and abnormal conditions. The criticality safety evaluation methodology applied at CTMSP and IPEN consider all the nuclear criticality safety standards applicable and accepted by the license authority[1-9].

The first step of the evaluation consider the enrichment and fissile mixtures processed at facilities, followed by detailed study of the process taken place under normal and abnormal operation, in addition the size, geometry and capacity of equipment involved during the operation. The second step of the evaluation consider the criticality parameters applicable to the safety analyses, the most important ones are: critical volume, critical mass, critical cylinder diameter, critical slab thickness and critical sphere diameter. Whenever the criticality parameters are available in the criticality safety handbooks[10-11], those parameters are assessed to verify the single existent equipment as first approach of the safety analyses. Most of the parameters available into the handbooks are from critical measurement facilities, where different experiments were performed to determine critical dimensions of individual units for various geometry[12-15].

The criticality control by means of equipment shape and dimensions is always recommended where practicable and economically tolerable. Although, the geometry control is recommended some cautions must be addressed, specially to prevent transferring from safe form equipment to unsafe form equipment, so an administrative practices has to be established.

2. CRITICAL PARAMETERS

Whenever experimental data are not available to establish critical parameters for a given system, it may be necessary apply a computational scheme to obtain the parameters. The criticality parameters of a fissionable material depend on the concentration of fissionable material and the degree of the moderation. The degree of the moderation is associated to the presence of the moderator material in the system, if a system contains more moderator, the system is designate as overmoderated and opposite case it is an undermoderated system. The system where moderation degree is designated as optimum gives a minimum of the critical parameters. These minimum values of criticality parameters play an important role since they are the smallest critical parameters, since with smaller masses, volumes, dimensions, concentrations under the same reflector conditions a critical state cannot occur.

The criticality analysis consider the critical parameters with a safety factors, which consider calculational uncertainties, how accurately will be the construction of the equipment (tolerances), the operational procedures involved according to the facility.

The methodology developed at CTMSP and IPEN to evaluate a critical parameters is based on SCALE system[16], and additionally the MCNP[17] Monte Carlo code was utilized to verify the obtained results as independent way.

Table 1 present a sequence available and correspondent modules to perform different calculations. The specific sequence applied to the criticality safety is denominated CSAS (Criticality Safety Analysis Sequence), which has different combinations of the functional modules depending of the purpose of the analysis.

Table 1. Calculational Sequence Available in the SCALE4.4a

Sequence	Search	Associated Modules
CSASI	No	BONAMI→NITAWL-II→ICE
CSASIX	No	BONAMI→NITAWL-II→XSDRNPM→ICE
CSASN	No	BONAMI→NITAWL-II
CSAS1X	No	BONAMI→NITAWL-II→XSDRNPM
CSAS25	No	BONAMI→NITAWL-II→KENO-V.a
CSAS2X	No	BONAMI→NITAWL-II→XSDRNPM→KENO-V.a
CSAS4	Yes	BONAMI→NITAWL-II→KENO-V.a→MODIFY
CSAS4X	Yes	BONAMI→NITAWL-II→XSDRNPM→KENO-V.a→MODIFY

The approach adopted in this work to obtain the critical parameter has two steps, one to obtain a mixture concentration which gives highest reactivity, and another step to perform a search for critical dimension considering concentration obtained in previous step.

The first step of the evaluations starts using the CSAS1X sequence, which gives the infinite neutron multiplication factor of the given system (cell calculation). The CSAS1X sequence is considered for each different fissile mixture in order to obtain the infinite multiplication factor as function of moderation ratio (density). The results gives the optimum moderation ratio for a specific mixtures, the Fig. 1 shows the behavior of the infinite neutron multiplication factor as function of density, and the maximum of the curve represents the optimum degree of moderation, which gives the highest infinite neutron multiplication factor.

The second step of the evaluation consider the previous results obtained from infinite multiplication factor calculations, which the density of the mixtures were determined. The CSAS4 sequence were performed to search a specific critical dimensions for each one of the mixture considered, the critical dimension is obtained by an iterative and successive calculations starting from an arbitrary dimension of the system, which gives the correspondent neutron multiplication factor and it is compared to the critical multiplication factor (k_{ef}=1.0000), depending on the neutron multiplication factor obtained, subsequent calculation will be performed changing automatically the dimension, others successive calculations were performed up to reach a critical dimension.

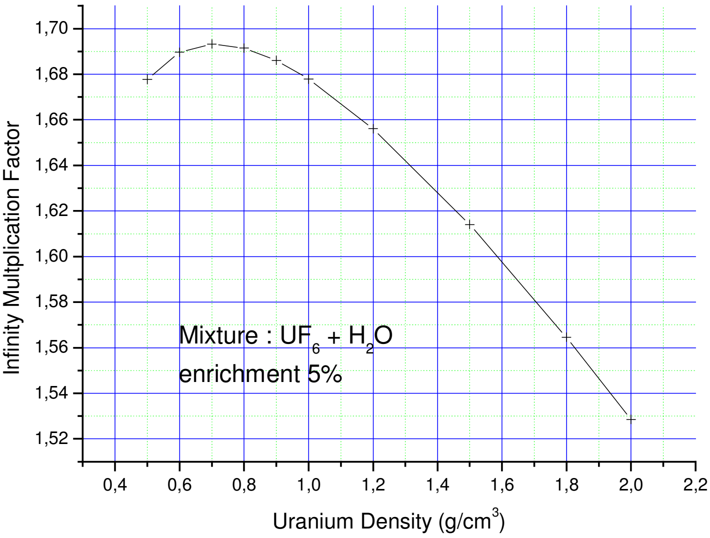

Figure 1 – Infinite Neutrin Multiplication Factor of the UF_6 + H_2O Mixture

The KENO-Va[18] module is a multigroup Monte Carlo code used to determine K_{eff} of the system with specific geometry, all calculations taken to search a critical dimension were performed considering 30.0 cm of the ordinary water as reflector. The cross section library considered in the all evaluations was 44GROUPNDF5.

3. RESULTS

The Table 2 present the critical parameters obtained using a methodology described previously, six different mixtures with two different enrichment were considered. The critical parameters obtained were: mass, spherical volume, diameter of infinite cylinder and thickness of infinite slab. Commonly, the safety parameters are used in criticality safety assessment for a single unit, those parameters are obtained multiplying the critical parameter by specific safety factor.

Table 2 – Critical parameters for different mixtures considering 5% and 20% of ^{235}U enrichment

Mixture	Enrich(%)	m_c (kg)	V_c (liter)	D_c (cm)	L_c (cm)
UO_2	5	37.10	27.80	25.70	12.20
	20	5.24	10.85	18.13	7.60
UF_6	5	44.70	54.30	32.30	16.10
	20	5.64	14.88	20.24	8.63
UO_2F_2	5	40.70	39.90	29.10	14.20
	20	5.42	12.70	19.12	8.00
$UO_2(NO_3)_2$ $6H_2O$	5	75.90	82.30	38.20	20.30
	20	6.16	15.75	20.80	9.12
$(NH_4)_4 UO_2 (CO_3)_3$	5	130.40	114.5	43.30	24.10
	20	6.60	14.50	20.35	9.00
U_3O_8	5	38.50	33.00	27.20	13.00
	20	5.32	11.60	18.60	7.70

V_c = Sphere volume
D_c = Diameter of infinite cylinder
L_c= Thickness of infinite slab

Additional calculations were performed as independent verification of the results obtained. The MCNP Monte Carlo code was used to obtain an effective neutron multiplication factor considering the critical dimension obtained from the SCALE system.
Since, each geometry with correspondent dimension was obtained as critical (k_{eff}=1.0000), and using same concentrations, a series of Monte Carlo calculations were performed. The MCNP calculation should reproduce the k_{eff} close to unit. The geometric modelling adopted were an infinite cylinder, sphere and infinite slab with 30.0 cm of ordinary water as reflector. The Table 2 shown the results obtained for each mixture with two different enrichment level.

Table 3 – MCNP-4C results for different mixtures considering 5% and 20% of ^{235}U

Mixture	Enr(%)	Sphere	Cylinder	Slab
UO_2	5	0.99500 ± 0.00017	0.99493 ± 0.00016	0.99442 ± 0.00015
	20	0.99351 ± 0.00019	0.99493 ± 0.00018	0.99848 ± 0.00017
UF_6	5	1.00057 ± 0.00016	0.99715 ± 0.00016	0.99903 ± 0.00015
	20	0.99760 ± 0.00018	0.99751 ± 0.00018	0.99744 ± 0.00017
UO_2F_2	5	0.99635 ± 0.00017	0.99514 ± 0.00016	0.99739 ± 0.00015
	20	0.99540 ± 0.00018	0.99537 ± 0.00018	0.99604 ± 0.00017
$UO_2(NO_3)_2$ $6H_2O$	5	0.99221 ± 0.00015	0.99280 ± 0.00015	0.99587 ± 0.00014
	20	0.99393 ± 0.00018	0.99442 ± 0.00017	0.99599 ± 0.00016
$(NH_4)_4 UO_2 (CO_3)_3$	5	0.99751 ± 0.00013	0.99667 ± 0.00013	0.99809 ± 0.00012
	20	0.99598 ± 0.00017	0.99603 ± 0.00017	0.99305 ± 0.00016
U_3O_8	5	0.99487 ± 0.00015	0.99338 ± 0.00016	0.99423 ± 0.00015
	20	0.99430 ± 0.00018	0.99667 ± 0.00018	0.99460 ± 0.00017

4. CONCLUSIONS

The methodology of critical parameters evaluation was developed based on SCALE system and independent verification was performed using MCNP Monte Carlo code. The critical parameters for typical fissile mixtures commonly existent at fuel cycle facility were obtained and consequently, critical safety parameters can be obtained considering an appropriate safety factor. From the critical parameters (dimensions) obtained, MCNP calculations performed shown a good agreement and trend to underestimate when compared to the SCALE results. Firstly, the SCALE cross section library was 44GROUPNDF based on ENDF/B-V basic nuclear data libraries and MCNP cross section library is based on ENDF/B-VI. The results of the MCNP code systematically underestimate the k_{eff}, with an exception of $U(5\%)F_6$ mixture in the sphere geometry.

The critical parameters as function of two level of enrichment obtained in this evaluation can be applied in the design stage of the equipment, criticality safety analysis for a single unit. Nevertheless, the neutronic interaction between single units and possible existing reflector material, as well as operational procedures involved has to be evaluate properly in order to prevent any criticality accident.

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