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A Simplified Mathmethical Calculation for Radwaste Effluent with Fuel Defect Rate

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Abstract

It is necessary to calculate radwaste effluent due to change in the fuel defect rate to see the overall change in radwaste effluent and, at present, for this type of calculation DAMSAM code is being used. However, often, one can not access easily to this code with many reason and so we have chosen this case, in this paper, to show a very simplified but quite accurated calculation method without the solving equations. The physical meanning of the parameters in the equations used in DAMSAM have been reviewed to simplify the equations and the result calculated with this method have been compared with that of DAMSAM.

1. Introduction

Often we find ourselves in limited situations where the neccessary tools are not immediately available to us and, specially, it is true when we need to work on the simulation. From time to time, it is very difficult to obtain the code we needed and, in many cases, it can be time consuming and numerous work if we try to solve the equations. Even most cases the equations we try to solve do not have exact solutions and, therefore, in this case the best we can do is a guess or to simplify the mathematical equations by eliminating the parameters with their physical role in the equations.

In this paper, we show an example and compare the results obtained from this simplified method and the actual DAMSAM code calculation. Surprisingly, the agreement between the two results are excellent.

2. Maximum Fission Product Activities in Reactor Coolant

Maximum fission product activities in reactor coolant is important because it will be used as design basis source terms for shielding and facilities design and for calculating the consequences of postulated accidents.

The concentration of nuclides in the reactor coolant system is determined with the appropriate mathematical model. The fission product inventory is determined in the two separate regions, the fuel pellet region and the reactor coolant region and the equations can be obtained by applying a mass balance without considering the fuel plenum and gap region. The equation for the fuel pellet region is given as;

$$\frac{dN_{p,i}}{dt} = (F\,Y_i P) + (f_{i-1}\,\lambda_{i-1})\,N_{p,i-1} + \sigma_j \varphi\,N_{p,j} - (\lambda_i + D\,v_i + \sigma_i \varphi)\,N_{p,i} \qquad (1)$$

The equation for the reactor coolant region is following:

$$\frac{dN_{c,i}}{dt} = (D\,V_i\,N_{p,i}) + (f_{i-1}\,\lambda_{i-1})\,N_{c,i-1} + (\sigma_j \varphi CVR)\,N_{c,j} - \left(\lambda_i + \frac{dQ/dt}{W}\,\eta_i + \frac{(1-\eta_i)dC/dt}{C_o - (dC/dt)t} + \frac{L}{W}\right) N_{c,i} \qquad (2)$$

where the subscripts are

i = i^{th} nuclide

$i-1$ = precursor to i^{th} nuclide for decay

j = precursor to i^{th} nuclide for neutron activation

p = pellet region

c = coolant region

and where the parameters are

λ = Decay constant (sec^{-1})

σ = Microscopic capture cross section (cm^2)

φ = Thermal neutron flux ($neutron/cm^2 \cdot s$)

η = Resin efficiency of CVCS ion exchanger and gas stripper efficiency

υ = escape rate coefficient (s^{-1})

f = Branching fraction

t = time (s)

N = Populations (atoms)

F = Average fission rate (fissions/Mwt· s)

Y = ^{235}U fission yield of nuclide, fraction

P = Core power (Mwt)

D = Defective fuel cladding, fraction

W = Reactor coolant system mass during power operation (lbm)

C_o = Beginning of core life boron concentration (ppm)

L = Leakage or other feed and bleed from the reactor coolant (lbm/s)

CVR = Core coolant volume to reactor coolant volume ratio, fraction

dQ/dt = CVCS purification flow rate during power operation (lbm/s)

dC/dt = Boron concentration reduction rate because of feed and bleed (ppm/s)

In those equations, escape rate coefficients, the empirical values[1] are used to represent the overall release from the fuel pellets to the coolant.

3. Discussion and result

Although a fuel defective cladding term is in the last term of equation (1), ($\lambda_i + D\upsilon_i + \sigma_i\varphi$), its change in the fuel defect rate can be neglected as the first term, λ_i, is dominant in this term. Overall contribution of the last term to the equation (1) can be neglected since $(F\ Y_i P)$ in the expression dominate. Therefore we can safely assume that there is no significant change in the fuel pellet region. But this fuel cladding term play major role in equation (2) since it is multiplied to the dominant term, the first term, $(D\ V_i\ N_{p,i})$. However, aparting from this, all other terms are exactly the same as before. Furthermore, it is reasonable by nature of the corrosion products to assume that they are not effected by the change in the fuel defect rate. Therefore, calculation for any change in the fuel defect rate is possible in easy way if we have a reference result calculated with DAMSAM.

The two results based on 3993MWt, Continuous Gas Stripping, one calculated with the method described above and another calculated with the actual DAMSAM code are presented in table 1 and they are remarkably in good agreement.

4. Conclusion

In this paper, we showed that a simplified mathematical method can be served well enough for our need by analysing the mathematical equations with their physical meannings. Although we apply this method for only one case this type of methodology can be applied in various physical cases giving rough ideas for our expectations even if we do not have proper tools. However, one need to be careful with the physical meanning of parameters when the assumptions are made since they can give the unreasonable results.

Table 1. The two calculated results, one from the simplified method and another one from DAMSAM

	Nuclide	Activity (μCi/cc)		
		DAMSAM		Simplified Calculation
		1% FFR	0.1%FFR	0.1%FFR
CP	^{16}N	2.25E+02	2.25E+02	2.25E+02
	^{51}Cr	1.36E-02	1.36E-02	1.36E-02
	^{54}Mn	1.34E-03	1.34E-03	1.34E-03
	^{59}Fe	2.52E-04	2.52E-04	2.52E-04
	^{58}Co	4.84E-03	4.84E-03	4.84E-03
	^{60}Co	4.50E-04	4.50E-04	4.50E-04
	^{84}Br	2.01E-02	2.01E-03	2.01E-03
	^{85m}Kr	7.31E-01	7.31E-02	7.31E-02
	^{87}Kr	1.52E-02	1.52E-03	1.52E-03
	^{88}Kr	7.42E-01	7.42E-02	7.42E-02
	^{88}Kr	1.81E+00	1.81E-01	1.81E-01
	^{89}Sr	2.77E-03	2.77E-04	2.77E-04
	^{90}Sr	1.39E-04	1.39E-05	1.39E-05
	^{91}Sr	4.54E-03	4.54E-04	4.54E-04
	^{91m}Y	2.60E-03	2.60E-04	2.60E-04
	^{91}Y	3.95E-04	3.95E-05	3.95E-05
	^{93}Y	1.09E-04	1.09E-05	1.09E-05
	^{95}Zr	4.35E-04	4.35E-05	4.35E-05
	^{95}Nb	4.31E-04	4.31E-05	4.31E-05
	^{99}Mo	2.46E-01	2.46E-02	2.46E-02
	^{99m}Tc	1.31E-01	1.31E-02	1.31E-02
	^{103}Ru	1.48E-04	1.48E-05	1.48E-05
	^{106}Ru	5.90E-05	5.90E-06	5.90E-06
	^{129m}Te	5.07E-03	5.07E-04	5.07E-04
	^{129}Te	5.81E-03	5.81E-04	5.81E-04
	^{131m}Te	2.51E-02	2.51E-03	2.51E-03
	^{131}Te	1.06E-02	1.06E-03	1.06E-03
	^{132}Te	1.70E-01	1.70E-02	1.70E-02
	^{131m}Xe	1.56E-01	1.56E-02	1.56E-02
	^{133m}Xe	4.20E-02	4.20E-03	4.20E-03
	^{133}Xe	2.06E+01	2.06E+00	2.06E+00
	^{135m}Xe	5.96E-01	5.96E-02	5.96E-02
	^{135}Xe	3.07E+00	3.07E-01	3.07E-01
	^{137}Xe	1.41E-01	1.41E-02	1.41E-02
	^{138}Xe	5.08E-01	5.08E-02	5.08E-02

Nuclide	Activity		
	DAMSAM		Simplified Calculation
	1% FFR	0.1%FFR	0.1%FFR
^{131}I	2.12E+00	2.12E-01	2.12E-01
^{132}I	6.39E-01	6.39E-02	6.39E-02
^{133}I	3.21E+00	3.21E-01	3.21E-01
^{134}I	4.23E-01	4.23E-02	4.23E-02
^{135}I	1.90E+00	1.90E-01	1.90E-01
^{134}Cs	2.29E-01	2.29E-02	2.29E-02
^{136}Cs	4.04E-02	4.04E-03	4.04E-03
^{137}Cs	3.01E-01	3.10E-02	3.10E-02
^{137m}Ba	2.92E-01	2.92E-02	2.92E-02
^{140}Ba	3.42E-03	3.42E-04	3.42E-04
^{137}La	1.06E-03	1.06E-04	1.06E-04
^{141}Ce	1.28E-04	1.28E-05	1.28E-05
^{143}Ce	3.73E-04	3.73E-05	3.73E-05
^{144}Ce	3.45E-04	3.45E-05	3.45E-05

FFR = Fuel Failure Rate

CP = Corrosion Product

Reference

[1] J.D.Eichenberg, "Effects of Irradiation on Bulk UO_2", WAPD-183 Oct 1957

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[3] TID-14844, "Calculation of distance Factord for Power and Test Reactors"

[4] NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants", U.S. Nuclear Regulatory Commission

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[6] T. Chandrasekaran, J.Y. Lee, and C.A. Willis, "Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactor, NUREG-0017 Rev. 1, 1985