LA-UR-15-24384
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Title: Reflector Worth of Dry Chemical and Powder Fire Extinguishing Agents

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Intended for: ANS National Meeting: 2015 Winter Meeting and Technology Expo, 2015-11-08/2015-11-12 (Washington, District Of Columbia, United States)

Issued: 2016-01-06 (rev.2)

Reflector Worth of Dry Chemical and Powder Fire Extinguishing Agents

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INTRODUCTION

In criticality safety, firefighting can introduce different reflector materials that must be accounted for in analysis of the original operation. Thus, it is important to understand the differences in reactivity worth for different firefighting materials that may be present in a facility. This study compares the reactivity increase of dry chemical fire extinguishing agents with the reactivity increase of reflection by water. Typical firefighting materials that are commercially available include graphite, silicon dioxide (SiO_2) or sand, magnesium oxide (MgO), MET-L-X®, FORAY® and water. These materials can be produced in a variety of densities which also creates extra considerations that need to be accounted for when evaluating these materials.

This study investigates the reactivity effects produced by the various firefighting agents, over a range of thicknesses from 1 – 30 cm, at manufacturer specified densities. Water was bounding of all the firefighting agents over the range investigated with the exception of FORAY®, which was more reactive over the range of 1 – 4 cm.

DESCRIPTION OF CALCULATIONAL STUDY

This study evaluated the reactivity effects of various reflectors/firefighting agents on a 4500 g sphere of plutonium. The plutonium sphere was reflected by close fitting firefighting agents over a range of thicknesses from 1 – 30 cm. The study presented represents a calculation-based investigation to expand upon the understanding of the reactivity effects of sparingly characterized reflector materials.

The analysis performed consists of a parametric study utilizing the neutron transport code MCNP6, with ENDF/B-VII.1 continuous energy cross-section sets to calculate system k_{eff} of plutonium spheres reflected by various commercially available firefighting materials. The firefighting agents evaluated and the manufacturer specified densities they were evaluated at can be found in Table I.

Table I. Material Densities

Material	Density(g/cc)
Graphite	0.561
	0.875
	1.000
	1.200
SiO_2	1.889
FORAY®	1.649
Water	1.000
MgO	1.900
MET-L-X®	2.067

FORAY® is a mixture of ammonium sulfate, ammonium phosphate and magnesium aluminum sulfate (fuller's earth). MET-L-X® is composed of magnesium distearate, sodium chloride and other components not reported. As such MET-L-X® was only modeled as magnesium distearate and sodium chloride. Table II shows the atomic composition and weight fractions used for modeling these materials.

Table II. FORAY® and MET-L-X® Composition

Material	Composition	Weight Fraction
FORAY®	Hydrogen	0.053
	Nitrogen	0.134
	Oxygen	0.546
	Magnesium	0.002
	Aluminum	0.003
	Silicon	0.006
	Phosphorus	0.221
	Sulfur	0.039
MET-L-X®	Hydrogen	0.003
	Carbon	0.032
	Nitrogen	0.008
	Oxygen	0.022
	Sodium	0.346
	Magnesium	0.004
	Aluminum	0.005
	Silicon	0.010
	Chlorine	0.572

The k_{eff}'s of the various reflectors over the range of thicknesses were then compared against each other to determine if any firefighting agent would be bounding of the others, with the goal of simplifying future analyses.

RESULTS

Figure 1 displays a comparison of the k_{eff} results for each of the firefighting agents. In general as the density of the material increases so does the reactivity of the system. Two significant exceptions to this were MET-L-X® and FORAY®. As the thickness of MET-L-X® increases the reactivity additions from reflection effects are not as significant as similarly dense material. This behavior can be attributed to the presence of sodium and chlorine in MET-L-X®, both of which have relatively larger absorption cross sections when compared against the other materials evaluated. FORAY® contains a significant amount of hydrogen which allows for increased moderation of reflected neutrons increasing the reflector worth to a level similar to water.

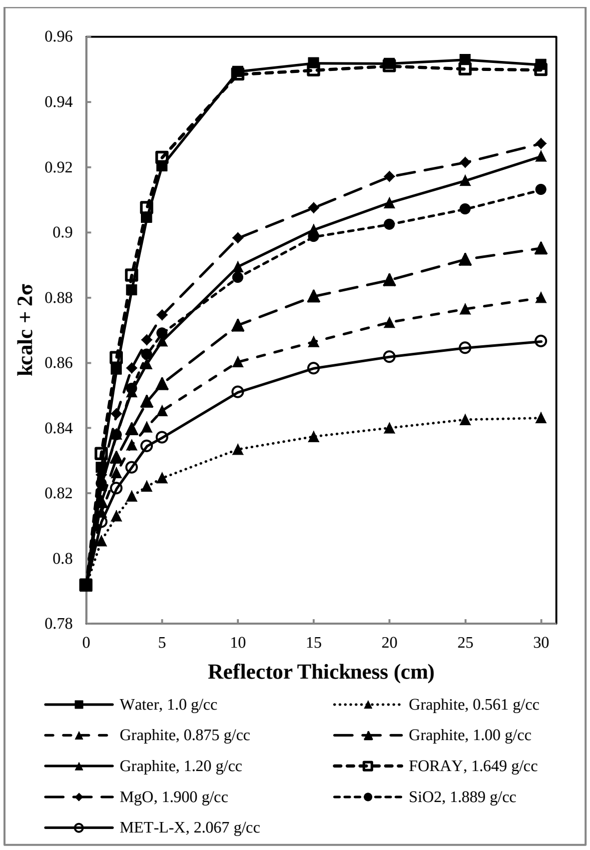

Fig. 1. Firefighting agent comparison

As illustrated in Figure 1, water is bounding of or statistically equivalent, at the 95% confidence level, to the firefighting agents with the exception of FORAY®. FORAY® follows a similar trend throughout the range of thicknesses but is not bounded by or statistically equivalent to water at thicknesses from 1 – 4 cm.

The data in Table III shows that FORAY® is slightly more reactive than water for reflector thicknesses from 1 – 4 cm. From 5 – 30 cm, water and FORAY® are statistically equivalent at the 95% confidence level.

Table III. FORAY®/Water Comparison

Thickness (cm)	Water		FORAY®	
	k_{calc}	σ	k_{calc}	σ
1	0.8268	0.0005	0.8309	0.0006
2	0.8569	0.0006	0.8604	0.0005
3	0.8811	0.0006	0.8854	0.0007
4	0.9032	0.0007	0.9062	0.0006
5	0.9189	0.0007	0.9214	0.0007
10	0.9478	0.0007	0.9470	0.0007
15	0.9503	0.0008	0.9482	0.0007
20	0.9500	0.0008	0.9494	0.0008
25	0.9514	0.0008	0.9486	0.0007
30	0.9499	0.0008	0.9484	0.0007

Additional numerical values for Figure 1 can be found in Table IV.

This publication provides criticality safety practitioners with practical and applicable data for analyses where water reflection has been considered. In these simple geometries, all but one of the firefighting agents studied can be bound by water over a wide range of reflector thicknesses. However, caution must be taken regarding the additional effects of moderation when dealing with complex shapes or multiple fissionable material items as this study does not consider these scenarios.

Table IV. Firefighting Agent Worth

Thickness (cm)	Graphite ρ = 0.561 g/cc		Graphite ρ = 0.875 g/cc		Graphite ρ = 1.00 g/cc		Graphite ρ = 1.20 g/cc		Water ρ = 1.0 g/cc		FORAY® ρ = 1.649 g/cc	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
0	0.79078	0.0005	0.79078	0.0005	0.79078	0.0005	0.79078	0.0005	0.79078	0.0005	0.79078	0.0005
1	0.80445	0.00048	0.81321	0.0005	0.81642	0.00048	0.8213	0.00054	0.82676	0.00053	0.83088	0.00058
2	0.81212	0.00048	0.82519	0.00054	0.82987	0.00055	0.83714	0.0005	0.85688	0.00055	0.8604	0.00054
3	0.81806	0.00052	0.8338	0.00048	0.83861	0.00054	0.85009	0.0005	0.8811	0.00057	0.88538	0.00068
4	0.8211	0.00051	0.83924	0.00054	0.84704	0.00053	0.85868	0.00052	0.9032	0.00067	0.90621	0.00063
5	0.82358	0.00056	0.84432	0.00049	0.85248	0.00053	0.86553	0.00055	0.91888	0.00072	0.92144	0.00071
10	0.83242	0.00051	0.85921	0.00052	0.87033	0.00058	0.88825	0.00059	0.94781	0.00073	0.94695	0.00073
15	0.83629	0.00054	0.8653	0.00058	0.87917	0.00059	0.89963	0.00057	0.95033	0.00076	0.94824	0.00073
20	0.83899	0.00052	0.87121	0.00058	0.88438	0.00049	0.90792	0.00056	0.95003	0.00083	0.94944	0.00076
25	0.84146	0.00056	0.87542	0.00054	0.8905	0.00059	0.91477	0.00056	0.9514	0.00075	0.94859	0.00073
30	0.84198	0.00056	0.8789	0.00055	0.89399	0.00057	0.92203	0.00065	0.94985	0.00076	0.9484	0.0007

Thickness (cm)	Silicon Dioxide ρ = 1.889 g/cc		Magnesium Oxide ρ = 1.900 g/cc		MET-L-X® ρ = 2.067 g/cc	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
0	0.79078	0.0005	0.79078	0.0005	0.79078	0.0005
1	0.82023	0.00134	0.82451	0.00052	0.81011	0.00052
2	0.83501	0.0014	0.84333	0.00051	0.82047	0.00049
3	0.84956	0.00126	0.8573	0.00054	0.82685	0.0005
4	0.85954	0.00151	0.8659	0.00055	0.83345	0.00048
5	0.86618	0.00142	0.87353	0.00054	0.83599	0.00053
10	0.88323	0.00144	0.89718	0.00053	0.84975	0.00061
15	0.89561	0.0015	0.90632	0.00059	0.85722	0.00052
20	0.89927	0.00155	0.91587	0.00059	0.86064	0.00057
25	0.90429	0.00141	0.92023	0.00058	0.86345	0.00055
30	0.90978	0.00162	0.92601	0.00058	0.86547	0.00055