Waste Encapsulation Storage Facility (WESF) – concrete gamma dose damage

Joint Tank Waste Committee and Health, Safety and Environment Committee meeting

Dirk Dunning, PE

Oregon Department of Energy

February 13, 2013

Issue Manager Framing Introduction

OREGON DEPARTMENT OF ENERGY

What happened? ONC Report

August 1, 2012 - WESF facility declared a positive Potential Inadequacy in the Safety Analysis (PISA) determination related to potential radiation deterioration of concrete in the WESF pool cell.

- **There has been significant gamma radiation exposure from cesium capsules to the lower portions of the pool cell divider walls during 37 years of capsule storage.**

OREGON DEPARTMENT OF ENERGY

What happened? ONC Report

August 1, 2012 - WESF facility declared a positive Potential Inadequacy in the Safety Analysis (PISA) determination related to potential radiation deterioration of concrete in the WESF pool cell.

- **There has been significant gamma radiation exposure from cesium capsules to the lower portions of the pool cell divider walls during 37 years of capsule storage.**
- **At the radiation levels seen in the lower section of the pool cell divider walls, studies indicate there could be a reduction in concrete strength.**

OREGON DEPARTMENT OF ENERGY

What happened? ONC Report

August 1, 2012 - WESF facility declared a positive Potential Inadequacy in the Safety Analysis (PISA) determination related to potential radiation deterioration of concrete in the WESF pool cell.

- **There has been significant gamma radiation exposure from cesium capsules to the lower portions of the pool cell divider walls during 37 years of capsule storage.**
- **At the radiation levels seen in the lower section of the pool cell divider walls, studies indicate there could be a reduction in concrete strength.**
- **Because there is no discussion of radiation deterioration of concrete in the WESF DSA and no estimate of the potential lifetime exposure levels experienced or anticipated, this issue was declared a positive PISA.**

OREGON DEPARTMENT OF ENERGY

What happened?

August 27, 2012 - Plant Review Committee determined a positive Unreviewed Safety Question.

- The safety class pool cell divider walls are credited with retaining structural integrity during a design basis earthquake.
- **The bottom three feet of the pool cell divider walls has received gamma radiation exposure that has exceeded the accepted threshold for degradation of concrete.**

OREGON DEPARTMENT OF ENERGY

What happened?

August 27, 2012 - Plant Review Committee determined a positive Unreviewed Safety Question.

- The safety class pool cell divider walls are credited with retaining structural integrity during a design basis earthquake.
- The bottom three feet of the pool cell divider walls has received gamma radiation exposure that has exceeded the accepted threshold for degradation of concrete.
- **Radiation degradation of the pool cell concrete divider walls is not currently addressed in the DSA.**

OREGON DEPARTMENT OF ENERGY

Why the problem wasn't found

- **The original hazard analysis for the WESF Safety Basis did not consider radiation as a potential source of degradation.**

Why the problem wasn't found

- The original hazard analysis for the WESF Safety Basis did not consider radiation as a potential source of degradation.
- **Annual reviews and updates did not consider this hazard, as there was no information to trigger a review.**

OREGON DEPARTMENT OF ENERGY

Why the problem wasn't found

- The original hazard analysis for the WESF Safety Basis did not consider radiation as a potential source of degradation.
- Annual reviews and updates did not consider this hazard, as there was no information to trigger a review.
- **No occurrence reports or lessons learned have been generated in the DOE complex to indicate this hazard should be considered.**

OREGON DEPARTMENT OF ENERGY

Why the problem wasn't found

- The original hazard analysis for the WESF Safety Basis did not consider radiation as a potential source of degradation.
- Annual reviews and updates did not consider this hazard, as there was no information to trigger a review.
- No occurrence reports or lessons learned have been generated in the DOE complex to indicate this hazard should be considered.
- **Safety basis development documents do not call out radiation as a hazard to be considered for structural integrity.**

Why the problem wasn't found

- The original hazard analysis for the WESF Safety Basis did not consider radiation as a potential source of degradation.
- Annual reviews and updates did not consider this hazard, as there was no information to trigger a review.
- No occurrence reports or lessons learned have been generated in the DOE complex to indicate this hazard should be considered.
- Safety basis development documents do not call out radiation as a hazard to be considered for structural integrity.
- **Consequently, personnel believed that the existing analysis addressed all potential hazards that could affect structural integrity.**

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**
- **Annual reviews and updates did not consider or find it.**

OREGON
DEPARTMENT OF
ENERGY

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**
- **Annual reviews and updates did not consider or find it.**
- **No occurrence reports or lessons learned across DOE complex.**

OREGON DEPARTMENT OF ENERGY

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**
- **Annual reviews and updates did not consider or find it.**
- **No occurrence reports or lessons learned across DOE complex.**
- **The safety culture neither identified the hazard, nor sought out unknown hazards.**

OREGON DEPARTMENT OF ENERGY

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**
- **Annual reviews and updates did not consider or find it.**
- **No occurrence reports or lessons learned across DOE complex.**
- **The safety culture neither identified the hazard, nor sought out unknown hazards.**
- **Once found, focus on showing why this wasn't a problem, relying on extremely limited data.**

OREGON
DEPARTMENT OF
ENERGY

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**
- **Annual reviews and updates did not consider or find it.**
- **No occurrence reports or lessons learned across DOE complex.**
- **The safety culture neither identified the hazard, nor sought out unknown hazards.**
- **Once found, focus on showing why this wasn't a problem, relying on extremely limited data.**
- **No apparent effort to gather additional field data.**

Major Policy Concerns

- **The original hazard analysis did not consider a major risk factor as a potential source of degradation.**
- **Annual reviews and updates did not consider or find it.**
- **No occurrence reports or lessons learned across DOE complex.**
- **The safety culture neither identified the hazard, nor sought out unknown hazards.**
- **Once found, focus on showing why this wasn't a problem, relying on extremely limited data.**
- **No apparent effort to gather additional field data.**
- **The safety basis allows the existence of accident scenarios that cannot be responded to or resolved.**

OREGON DEPARTMENT OF ENERGY

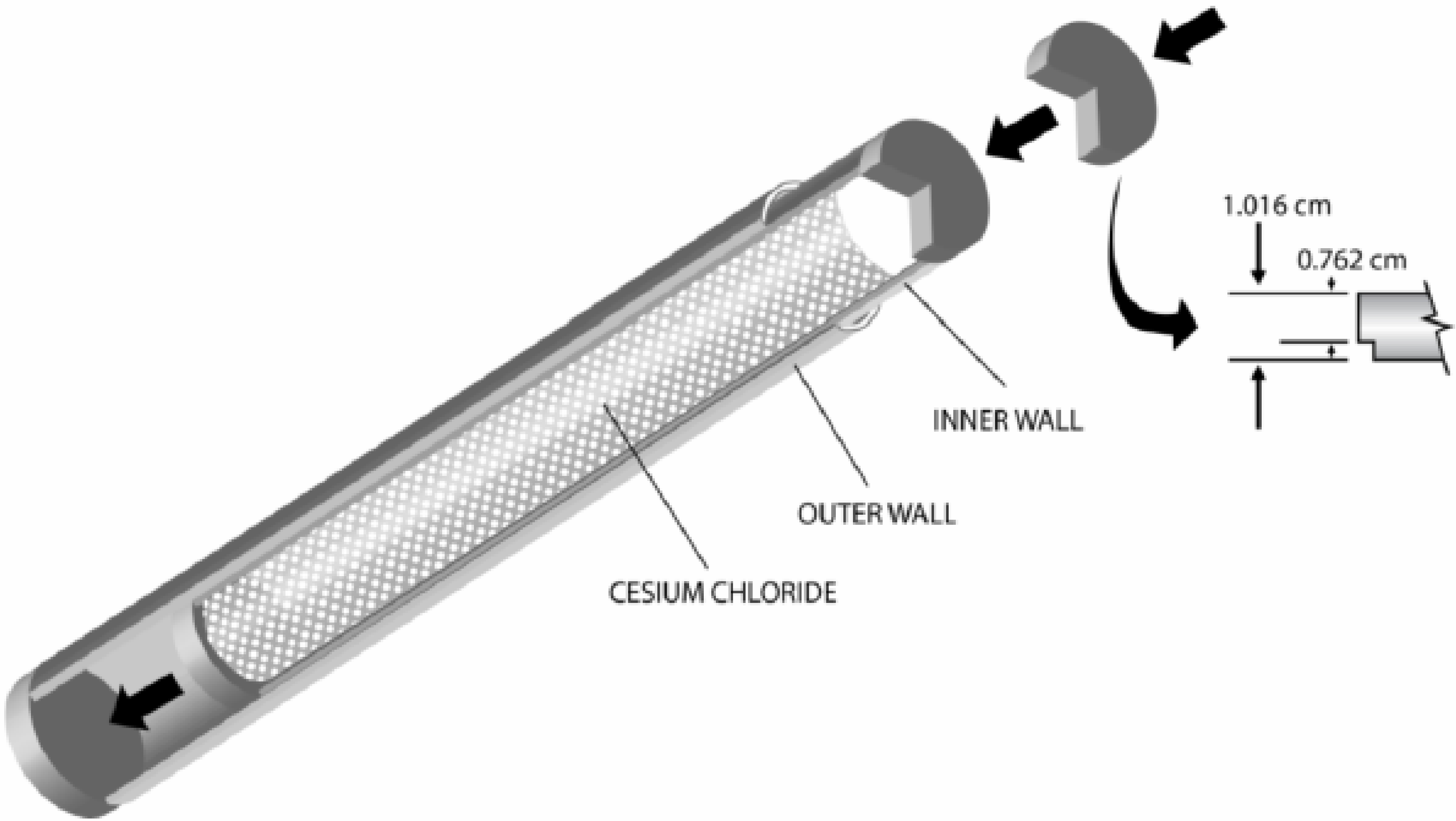


Figure 3 - Hanford Site Waste Encapsulation and Storage Facility Capsule [SRNL representation based on Knight's image (1974)].

SRNL-STI-2011-00202, Characterizing DOE Hanford Waste Site Waste Encapsulation Storage Facility Cells using Radball™
Figure 3, Page 6

B Plant and WESF

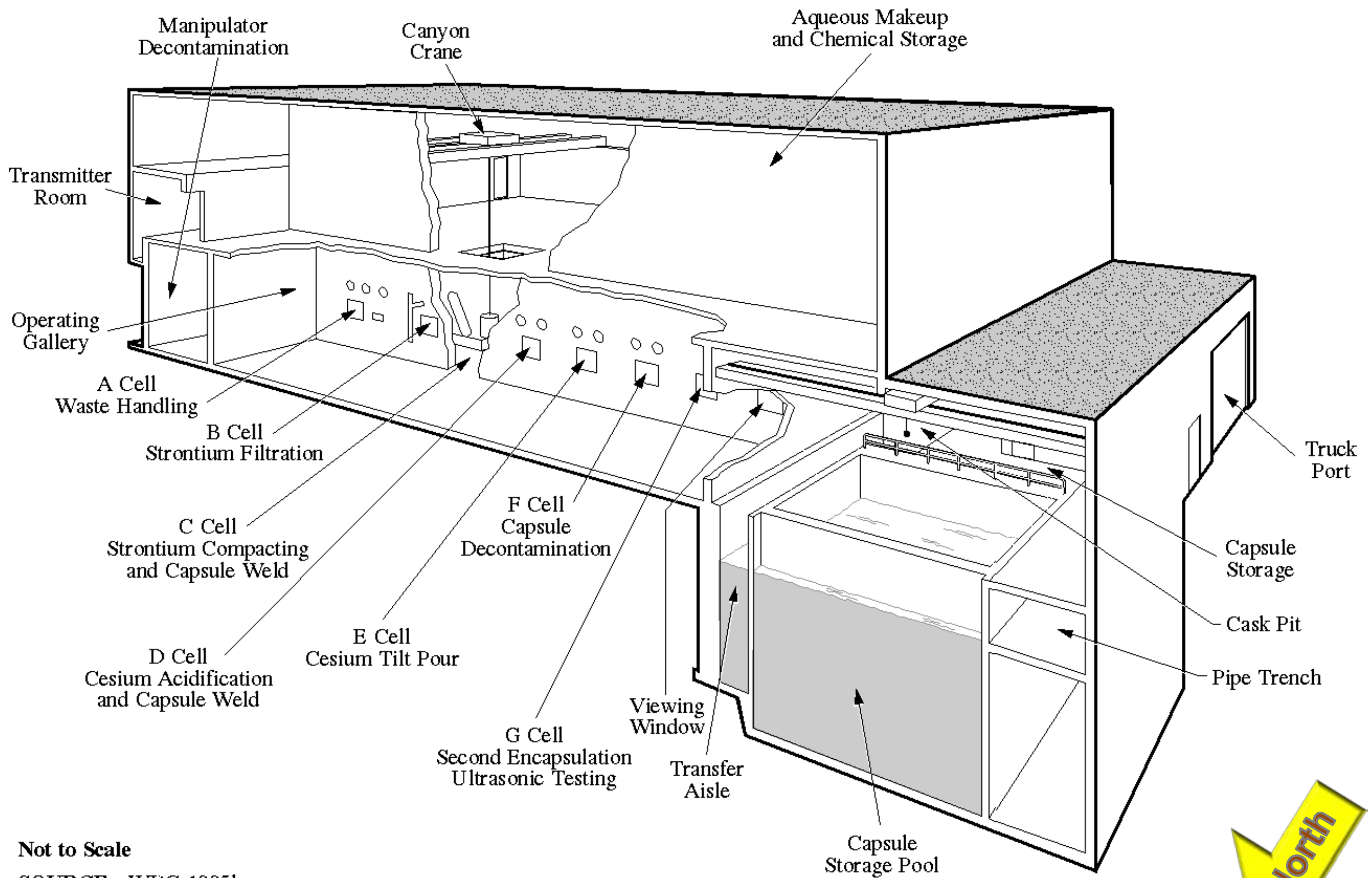
OREGON DEPARTMENT OF ENERGY

B Plant and WESF

OREGON
DEPARTMENT OF
ENERGY

Waste Encapsulation Storage Facility

Figure B.4.2.1 Waste Encapsulation and Storage Facility



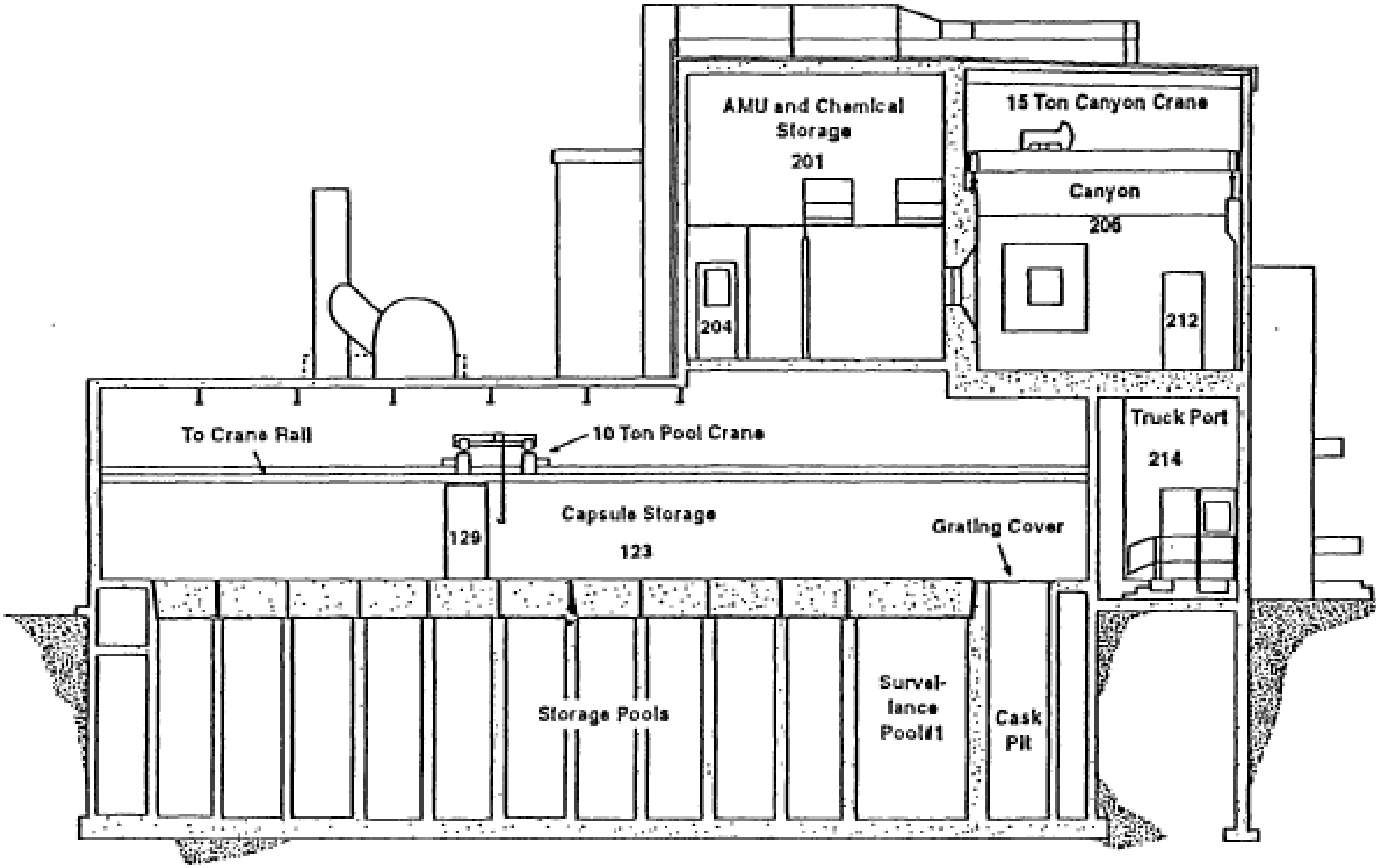
Not to Scale

SOURCE: WHC 1995h

919/K471-74.CDR

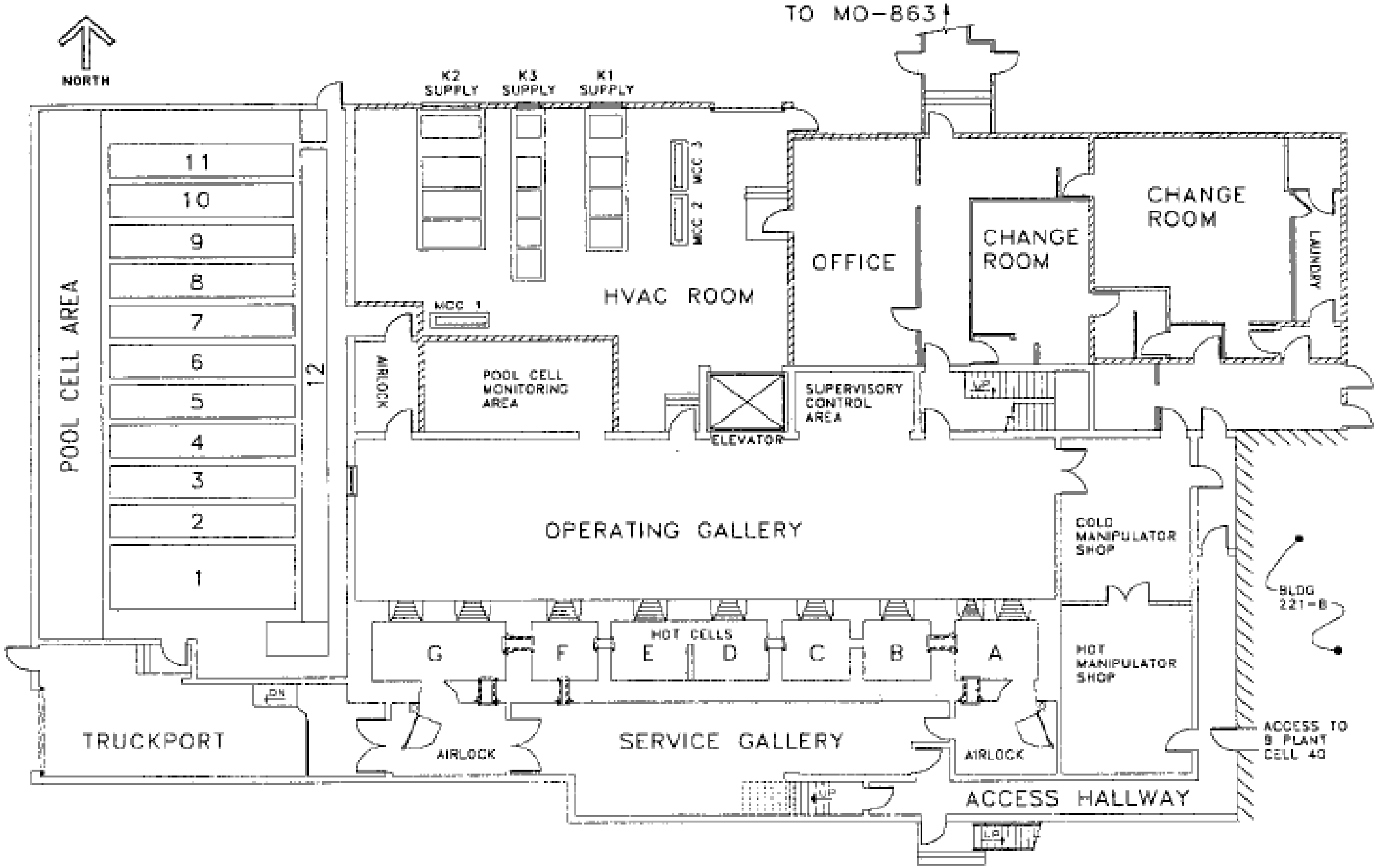
OREGON DEPARTMENT OF ENERGY

Waste Encapsulation Storage Facility



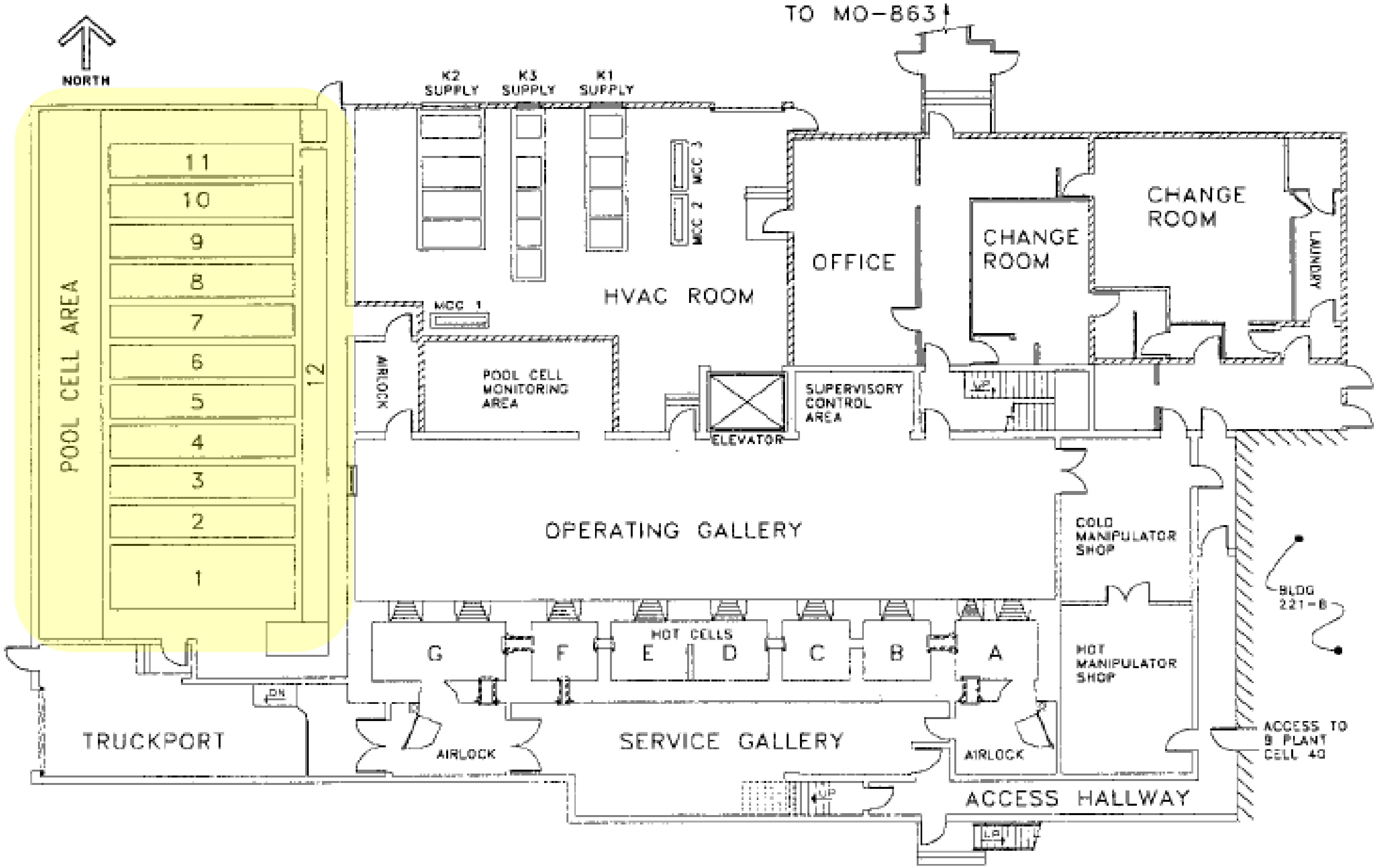
WHC-SD-WM-ES-313 rev 0, B Plant - WESF isolation study 1994,
Page 12 – Cross Section view of the capsule storage pools

OREGON DEPARTMENT OF ENERGY



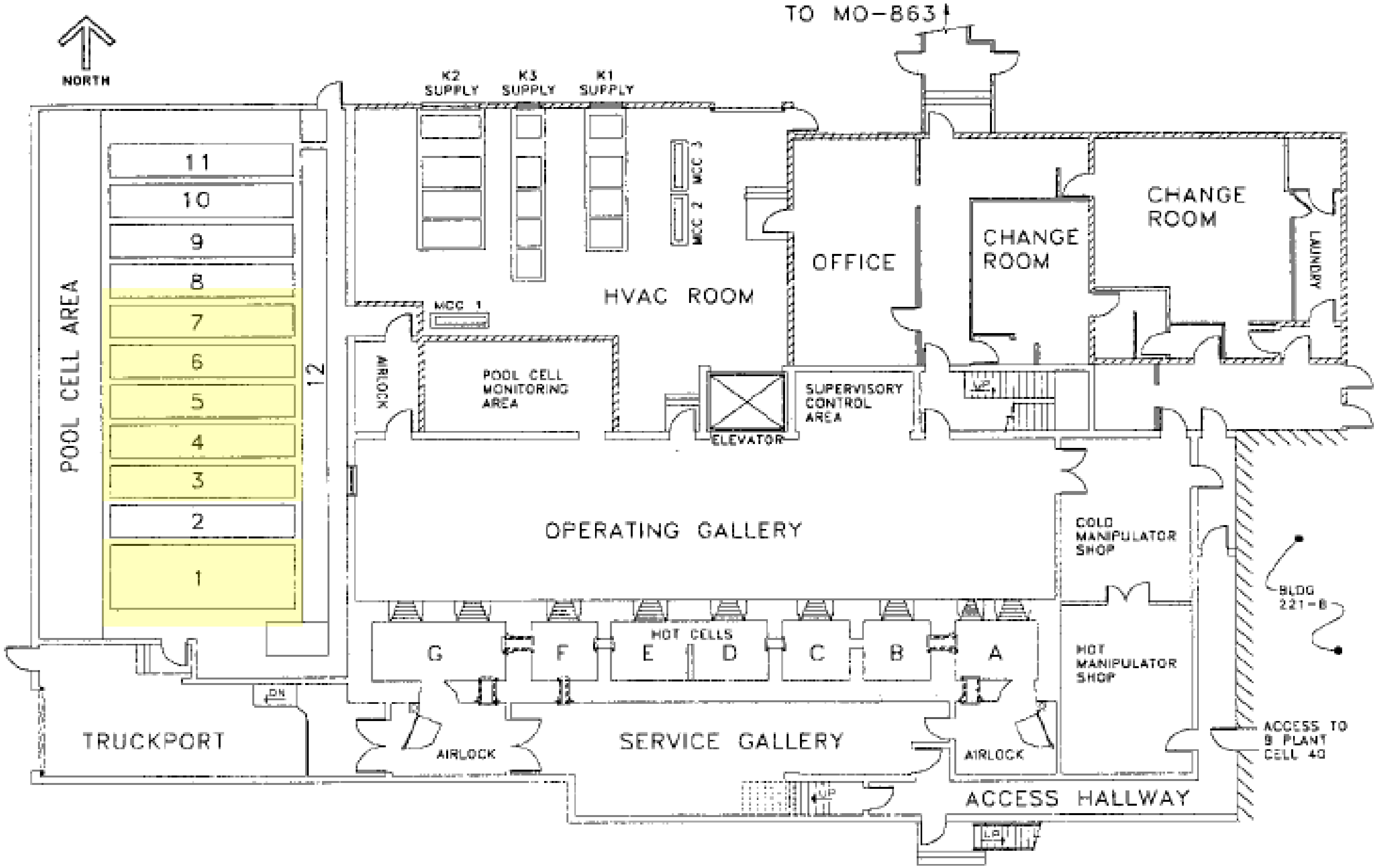
HNF-SD-WM-BIO-002, Revision 1, WESF Basis for Interim Operation
Figure 204, Page 2-10, plan view of the capsule storage pools

OREGON DEPARTMENT OF ENERGY



HNF-SD-WM-BIO-002, Revision 1, WESF Basis for Interim Operation
Figure 204, Page 2-10

Pool areas that have seen high dose.



HNF-SD-WM-BIO-002, Revision 1, WESF Basis for Interim Operation
Figure 204, Page 2-10

OREGON DEPARTMENT OF ENERGY

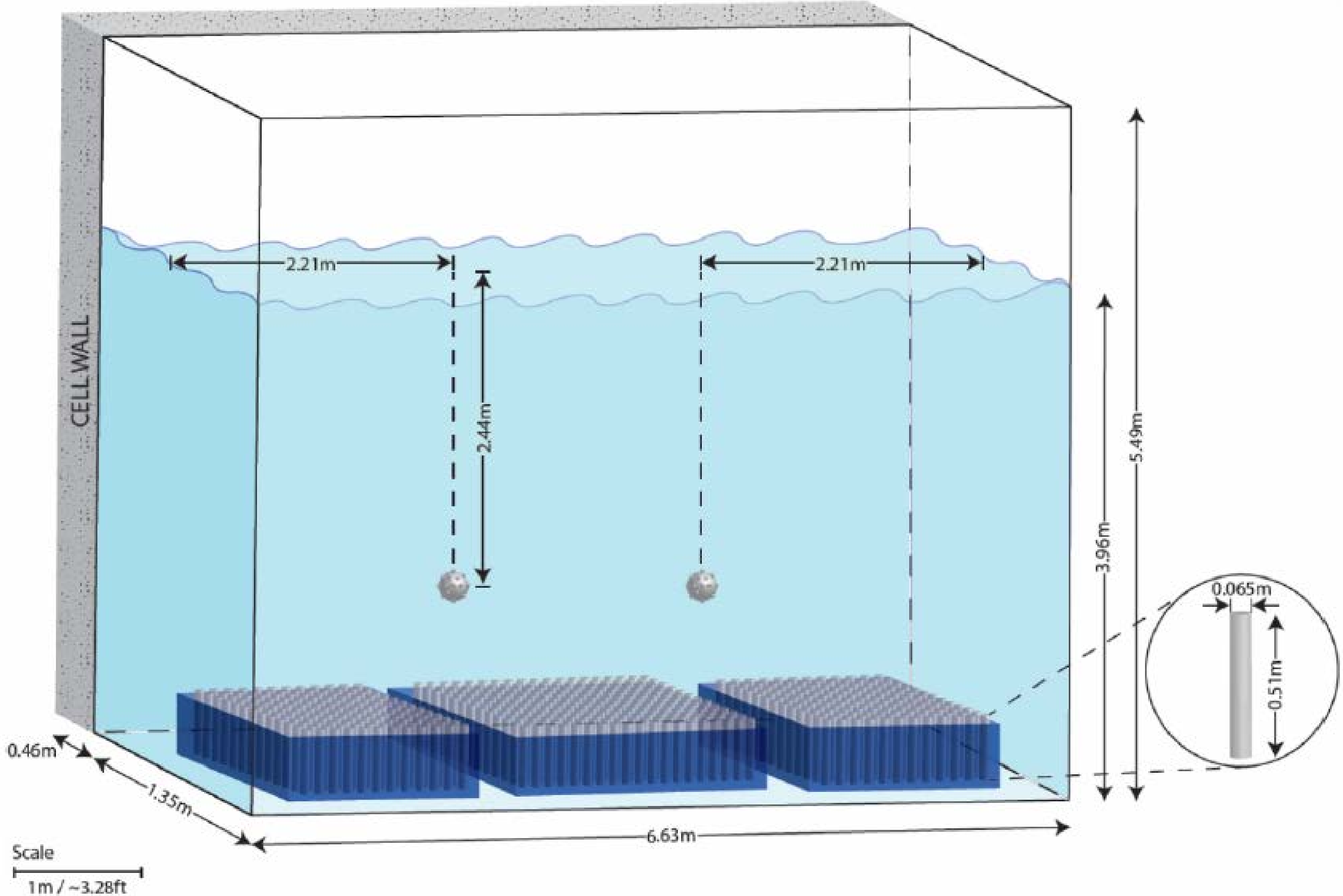


Figure 7 - Representation of the N-52-3 and N-52-4 RadBall™ deployments in Cell 6.

SRNL-STI-2011-00202, Characterizing DOE Hanford Waste Site Waste Encapsulation Storage Facility Cells using Radball™ Figure 7, Page 15

OREGON DEPARTMENT OF ENERGY

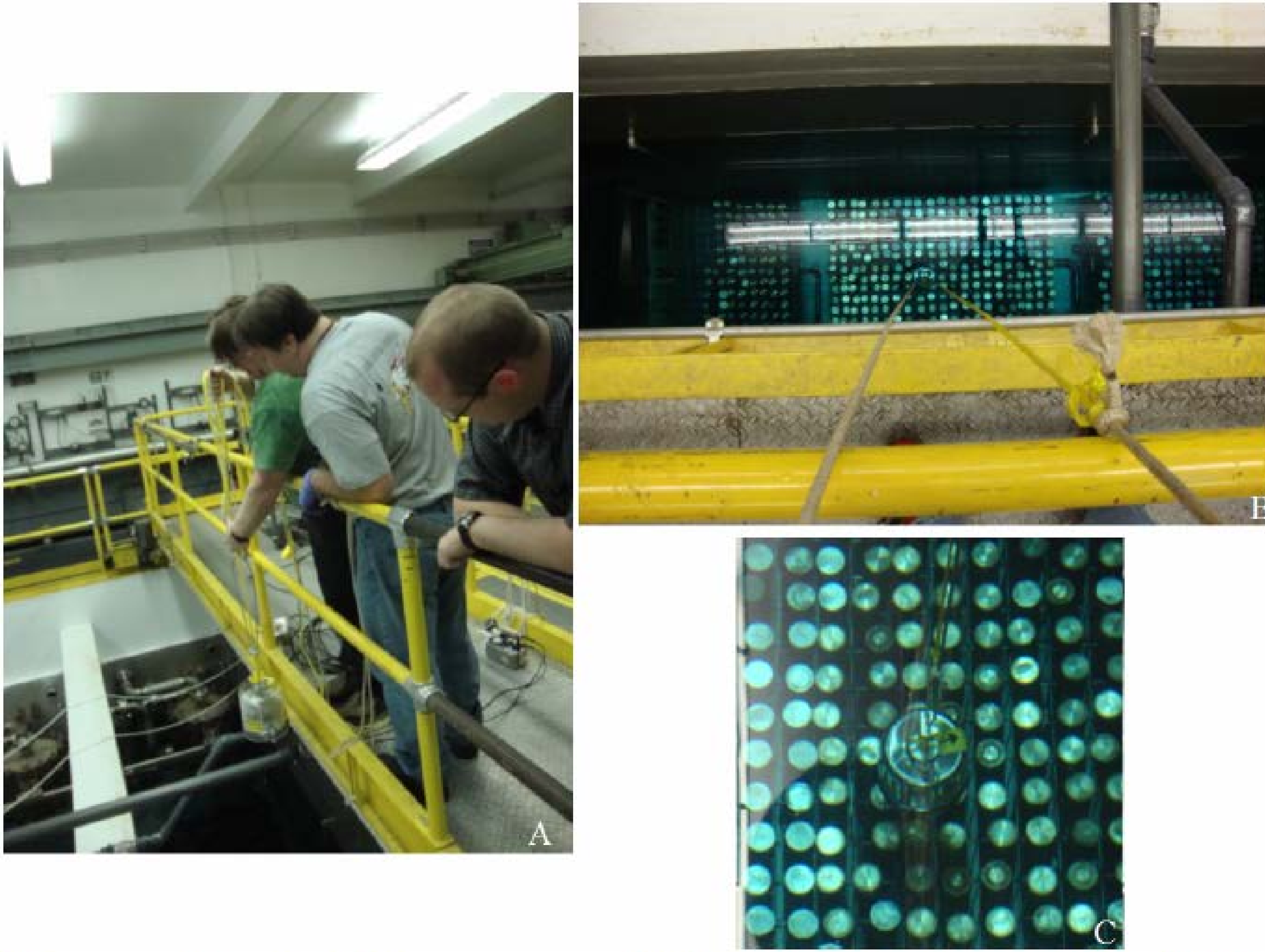


Figure 6 - **A**) RadBall^{TM} deployment into WESF Cell 7. **B**) Submerged RadBall^{TM}. **C**) Directionality indicated by the black arrow on the airtight RadBall^{TM} container.

SRNL-STI-2011-00202, Characterizing DOE Hanford Waste Site Waste Encapsulation Storage Facility Cells using Radball^{TM}
Figure 6, Page 12

OREGON DEPARTMENT OF ENERGY

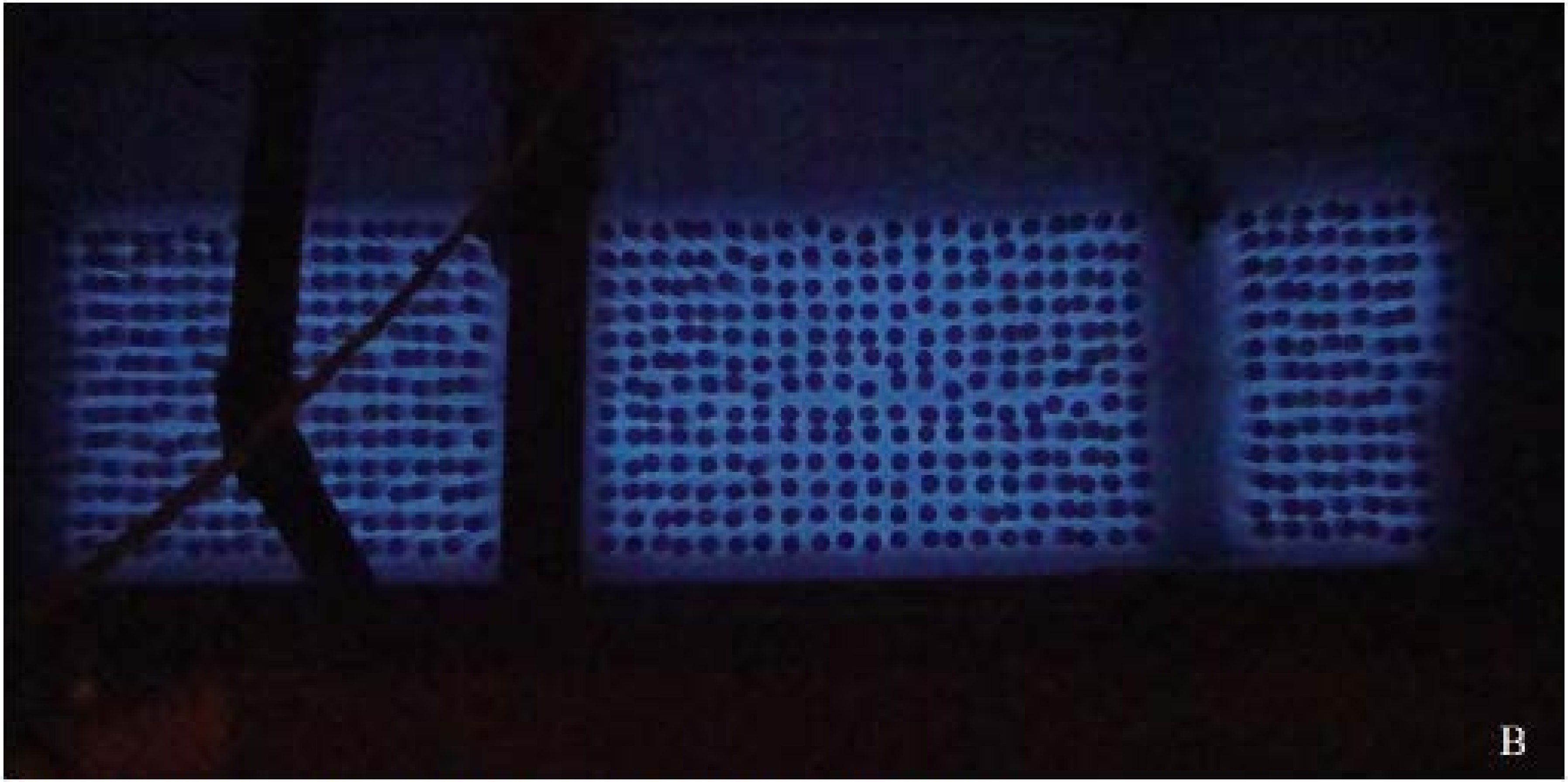


Figure 13 - Cherenkov radiation glow: A) Cell 6. B) Cell 7.

SRNL-STI-2011-00202, Characterizing DOE Hanford Waste Site Waste Encapsulation Storage Facility Cells using Radball^{TM}
Figure 13, Page 23, Cell 7

OREGON DEPARTMENT OF ENERGY

Loss of Water from a single pool

However, the immediate hazard from this event is direct radiation exposure due to loss of shielding water. Analyses documented in Hey (2000) indicated that the dose rate due to the direct gamma-ray shine at a receptor 100 m (328 ft) from the nearest WESF outside wall would be 20 mSv/h (2 rem/h). This dose rate would exceed the 0.01 Sv (1 rem) threshold for declaration of a SITE AREA Emergency within a half-hour. Dose field estimates (documented in Hey, 2000) at various locations in and around WESF, that could hamper recovery activities are provided in HNF-SD-WM-BIO-002, Table 3-32.

The loss of water in a single pool cell creates fatal dose fields within the Pool Cell Area and a field of approximately 120 R/h immediately outside the 225-B structure. Currently there is no control that could be relied upon to terminate this event once capsules have been uncovered. Thus, facility control is effectively lost. Continued progression of the event leads to a gradual evaporative loss of water in the remaining pool cells and thermally induced failure of uncovered capsules. Even though relatively little in the way of airborne release would be expected from capsules initially failed in the single pools, the loss of facility control indicates that this event is a potential initiator to the more severe consequences of loss of water from all pool cells.

HNF-SD-WM-BIO-002, Revision 1, WESF Basis for Interim Operation
Page 32

Loss of Water from a single pool

However, the immediate hazard from this event is direct radiation exposure due to loss of shielding water. Analyses documented in Hey (2000) indicated that the dose rate due to the direct gamma-ray shine at a receptor 100 m (328 ft) from the nearest WESF outside wall would be 20 mSv/h (2 rem/h). This dose rate would exceed the 0.01 Sv (1 rem) threshold for declaration of a SITE AREA Emergency within a half-hour. Dose field estimates (documented in Hey, 2000) at various locations in and around WESF, that could hamper recovery activities are provided in HNF-SD-WM-BIO-002, Table 3-32.

The loss of water in a single pool cell creates fatal dose fields within the Pool Cell Area and a field of approximately 120 R/h immediately outside the 225-B structure. Currently there is no control that could be relied upon to terminate this event once capsules have been uncovered. Thus, facility control is effectively lost. Continued progression of the event leads to a gradual evaporative loss of water in the remaining pool cells and thermally induced failure of uncovered capsules. Even though relatively little in the way of airborne release would be expected from capsules initially failed in the single pools, the loss of facility control indicates that this event is a potential initiator to the more severe consequences of loss of water from all pool cells.

Technical issues?

- Very little data on how concrete behaves in response to radiation dose.
  - Strong differences in response based on composition
  - Temperature history confuses the issue, as concrete responds very badly to high heat.
  - Data starts in the 1940s and 50s. The first full graphs on how concrete responds, like today's exist by the 1960s.
  - Other data (e.g. X10 reactor concrete excluded)
  - Wet versus Dry

OREGON DEPARTMENT OF ENERGY

Technical issues?

- Very little data on how concrete behaves in response to radiation dose.
  - Strong differences in response based on composition
  - Temperature history confuses the issue, as concrete responds very badly to high heat.
  - Data starts in the 1940s and 50s. The first full graphs on how concrete responds, like today's exist by the 1960s.
  - Other data (e.g. X10 reactor concrete excluded)
  - Wet versus Dry
- Safety basis for WESF did not consider radiation dose.

OREGON DEPARTMENT OF ENERGY

UNCLASSIFIED

AEC RESEARCH AND DEVELOPMENT REPORT

HW-56195

23

RADIATION DAMAGE TO CONCRETE

R. G. CLARK

MARCH 31, 1958

ORNL-2195
Physics and Mathematics

A STUDY OF THE NUCLEAR AND PHYSICAL PROPERTIES OF THE ORNL GRAPHITE REACTOR SHIELD

T. V. Blosser
G. W. Bond
L. A. Lee
D. T. Morgan
J. F. Nichols
R. C. Reid
A. B. Reynolds
T. O. P. Speidel
D. W. Vroom
M. A. Welt

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

INEEL/EXT-04-02319

Literature Review of the Effects of Radiation and Temperature on the Aging of Concrete

D. L. Fillmore, Ph.D.

September 2004

Vol. 114 (2008) ACTA PHYSICA POLONICA A No. 2

Proceedings of the 7-th National Meeting of Synchrotron Radiation Users

Effect of Gamma Irradiation on Cement Composites Observed with XRD and SEM Methods in the Range of Radiation Dose 0–1409 MGy

A. Łowińska-Kluge[a,*] and P. Piszora[b]

[a]Institute of Structural Engineering, Poznań University of Technology
Piotrowo 5, PL-60-965 Poznań, Poland
[b]Department of Materials Chemistry, Faculty of Chemistry
Adam Mickiewicz University, Grunwaldzka 6, PL-60-780 Poznań, Poland

Determining the Effects of Radiation on Aging Concrete Structures of Nuclear Reactors - 10243

Cristian E. Acevedo[1] and Michael G. Serrato[2]

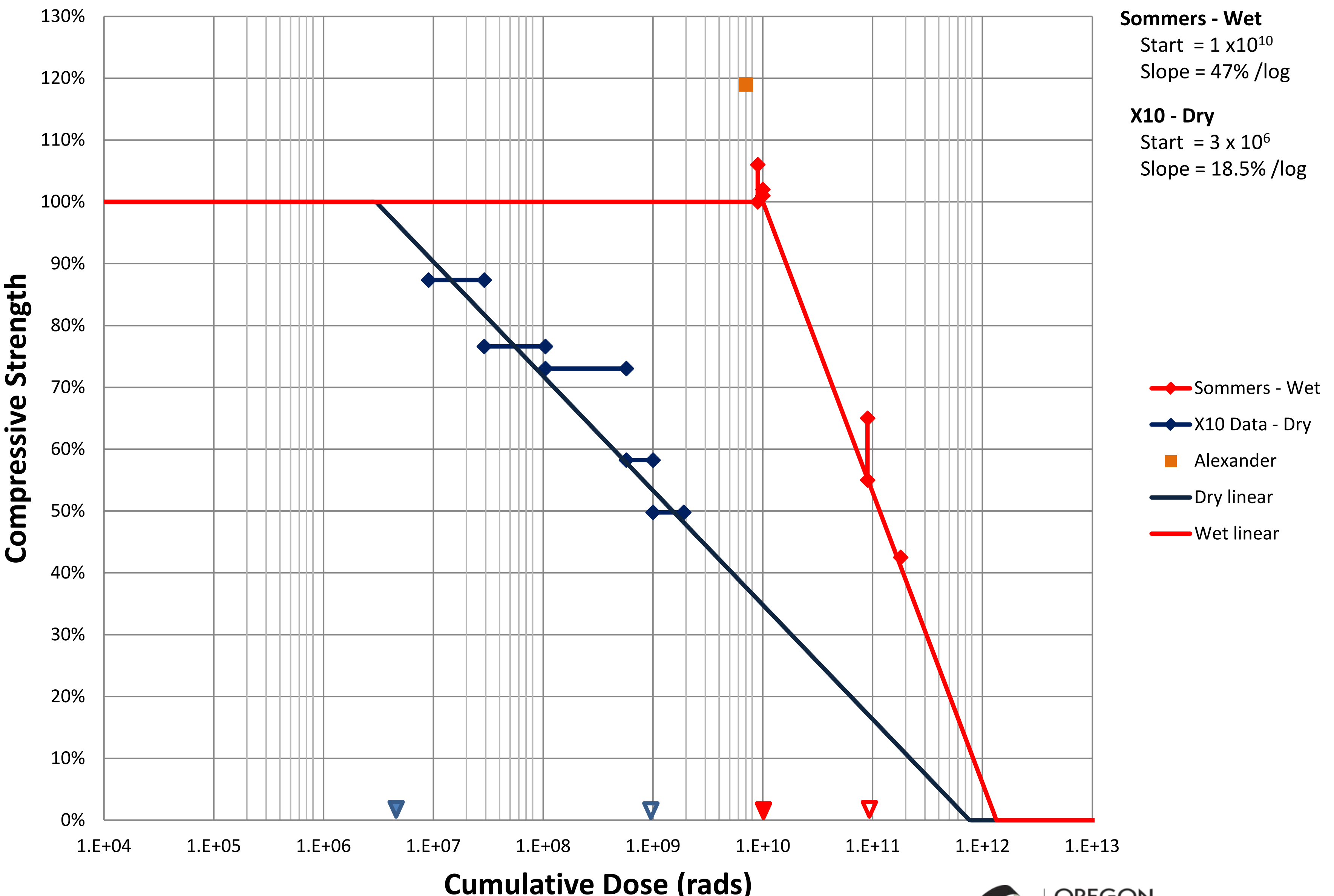
[1]Florida International University
Miami FL 33174

[2]Savannah River National Laboratory, Savannah River Nuclear Solutions, LLC
Savannah River Site, Aiken SC 29808

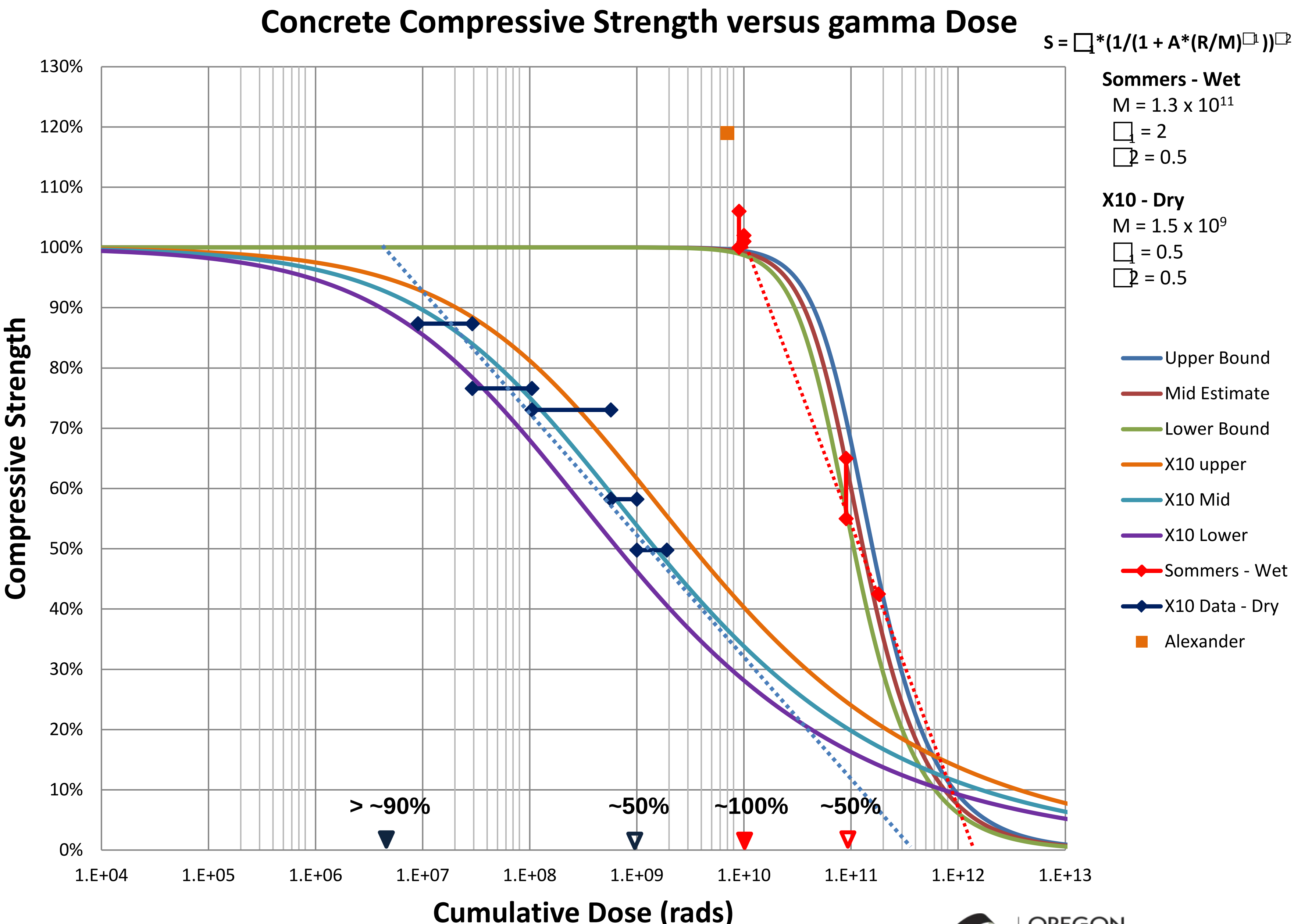
ABSTRACT

The U.S. Department of Energy Office of Environmental Management (DOE-EM) is responsible for the Decontamination and Decommissioning (D&D) of nuclear facilities throughout the DOE Complex. Some of these facilities will be completely dismantled, while others will be partially dismantled and the remaining structure will be stabilized with cementitious fill materials. The latter is a process known as In-Situ Decommissioning (ISD). The ISD decision process requires a detailed understanding of the existing facility conditions, and operational history. System information and material properties are needed for aged nuclear facilities. This literature review investigated the properties of aged concrete structures affected by radiation. In particular, this review addresses the Savannah River Site (SRS) isotope production nuclear reactors. The concrete in the reactors at SRS was not seriously damaged by the levels of radiation exposure. Loss of composite compressive strength was the most common effect of radiation induced damage documented at nuclear power plants.

Concrete Compressive Strength versus gamma Dose

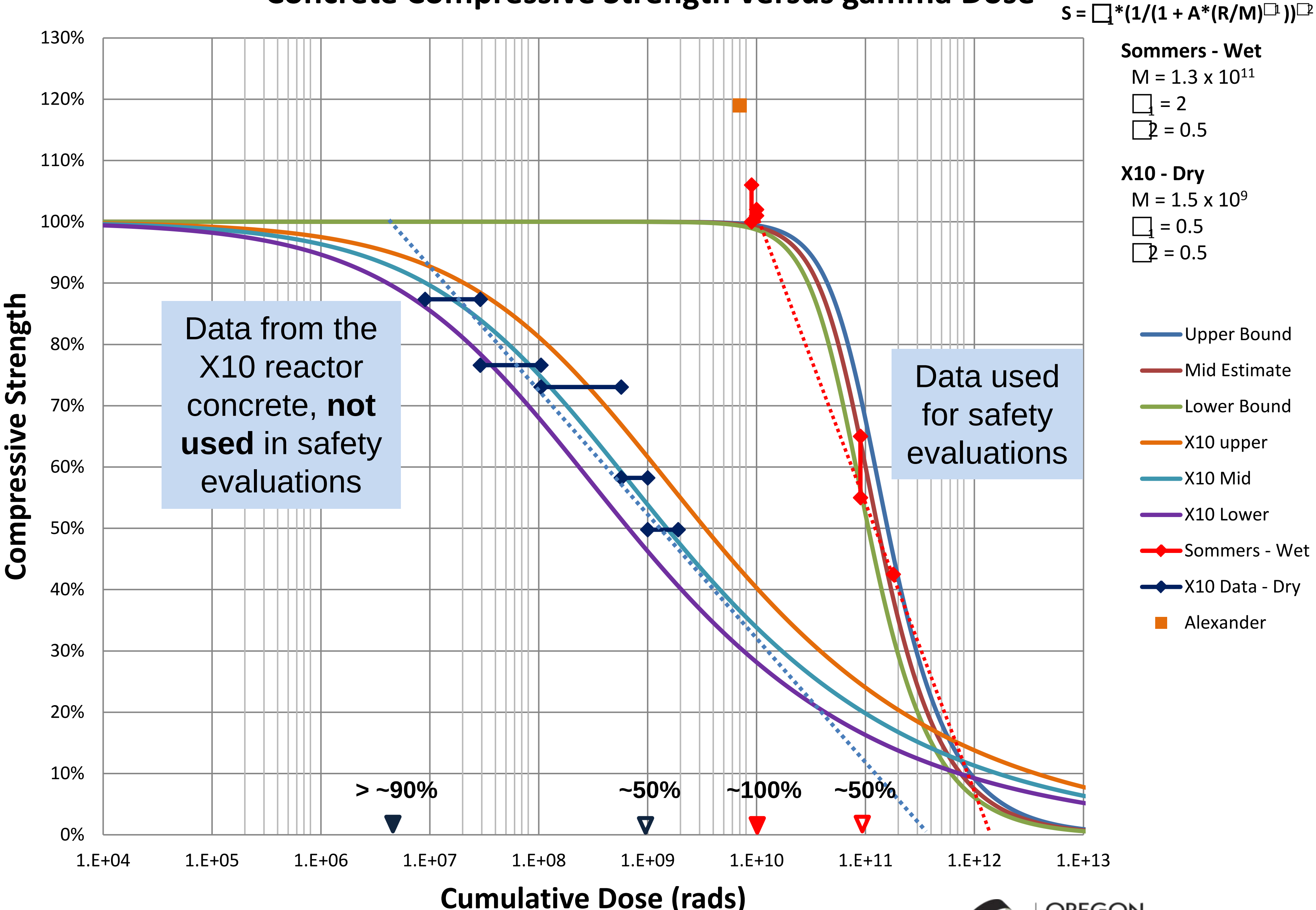


OREGON DEPARTMENT OF ENERGY

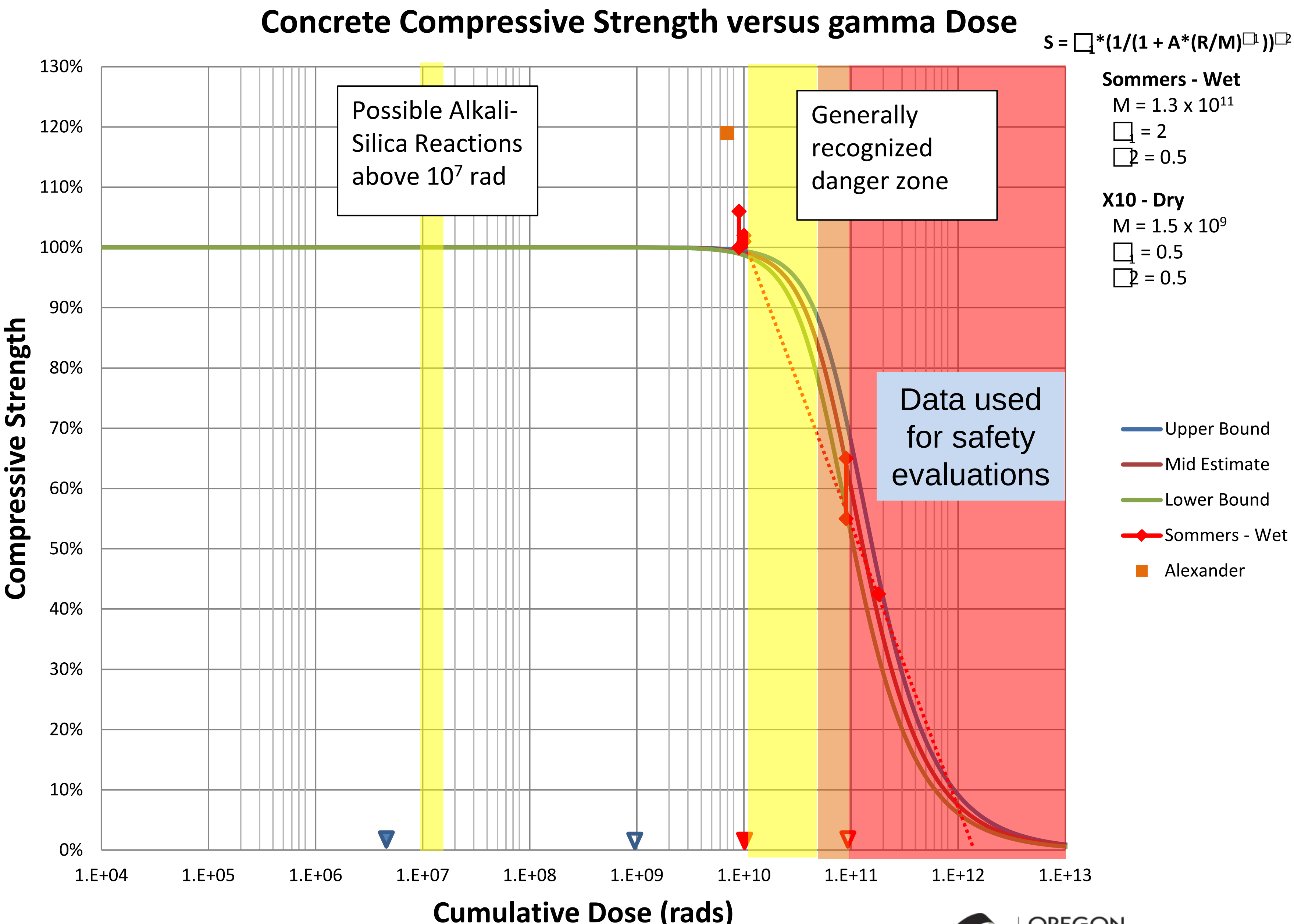


OREGON DEPARTMENT OF ENERGY

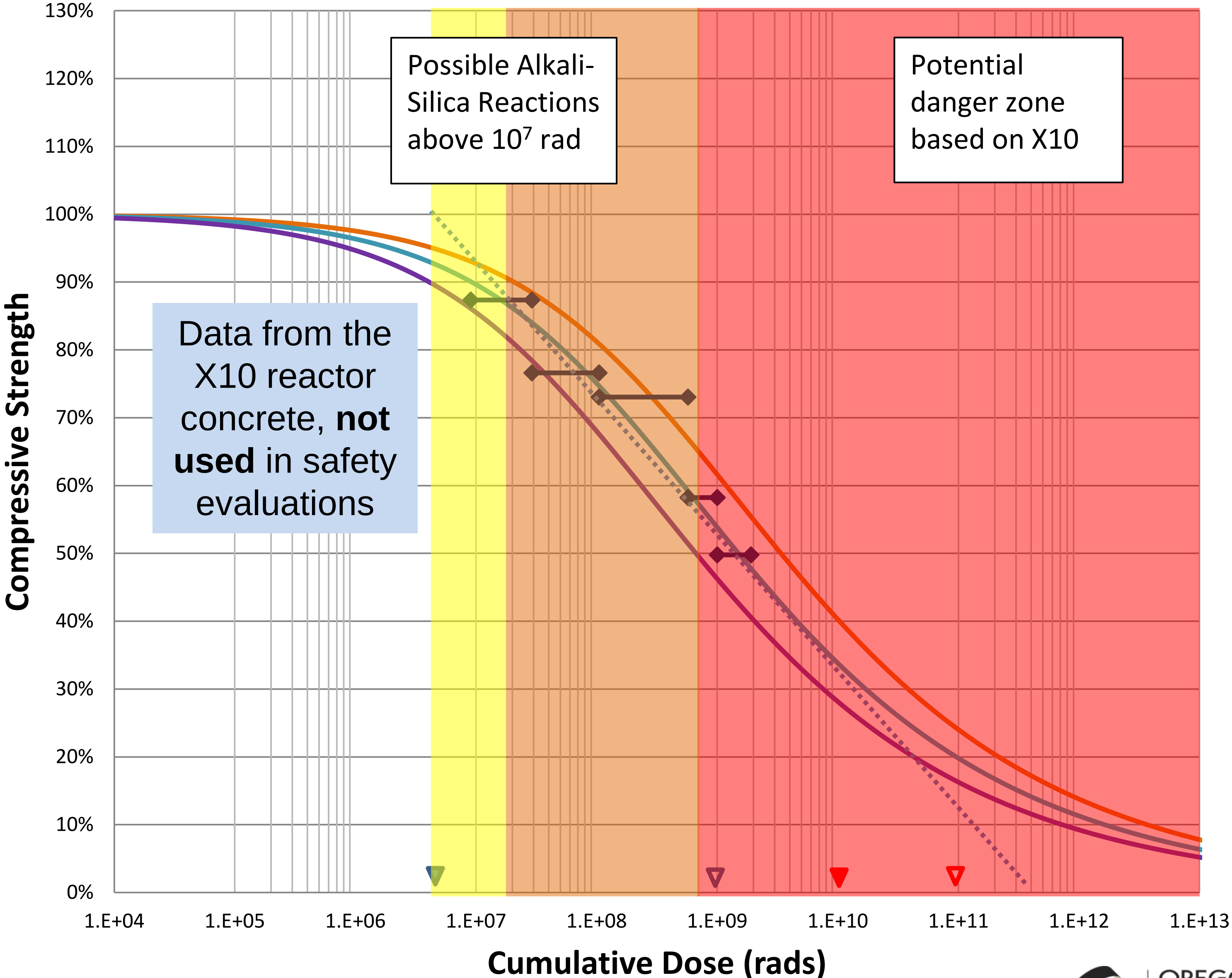
Concrete Compressive Strength versus gamma Dose



OREGON
DEPARTMENT OF
ENERGY


Concrete Compressive Strength versus gamma Dose
S = □1*(1/(1 + A*(R/M)□1))□2
Sommers - Wet
M = 1.3 x 10^11
□1 = 2
□2 = 0.5
X10 - Dry
M = 1.5 x 10^9
□1 = 0.5
□2 = 0.5
Possible Alkali-Silica Reactions above 10^7 rad
Generally recognized danger zone
Data used for safety evaluations
Compressive Strength
130%
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
1.E+09
1.E+10
1.E+11
1.E+12
1.E+13
Cumulative Dose (rads)
Upper Bound
Mid Estimate
Lower Bound
Sommers - Wet
Alexander

Concrete Compressive Strength versus gamma Dose

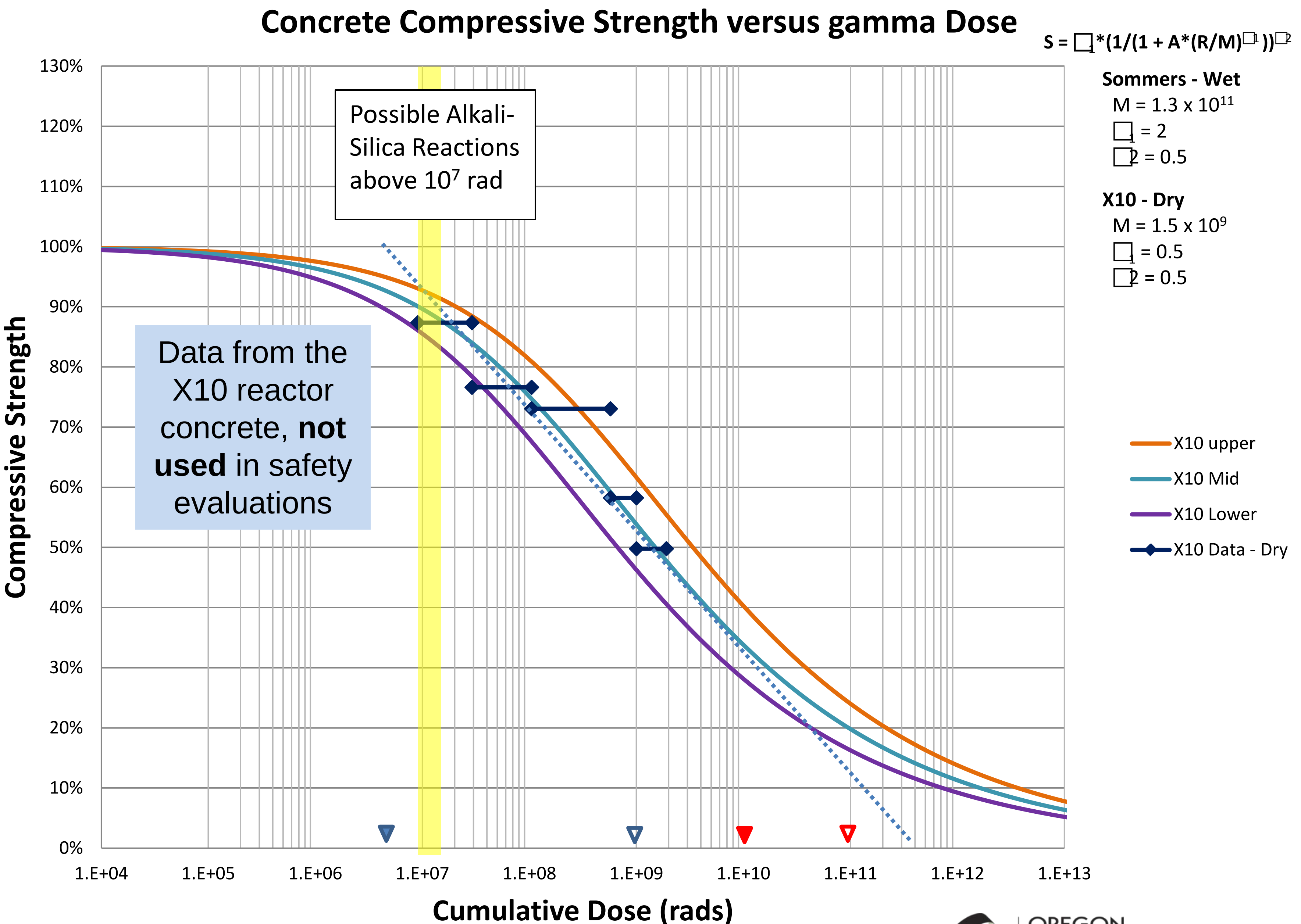


S = □*(1/(1 + A*(R/M)□))□

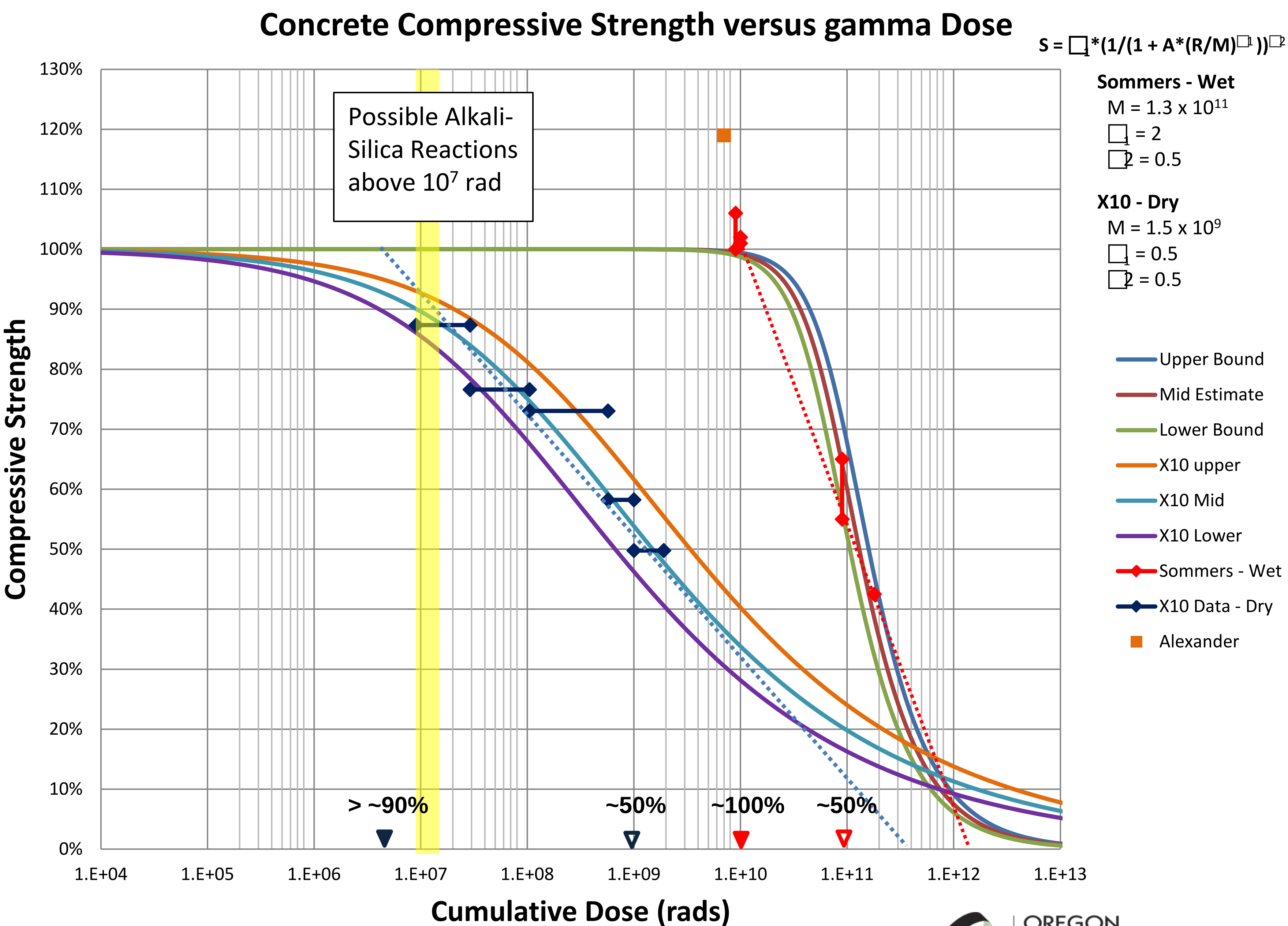
Sommers - Wet
M = 1.3 x 10^{11}
□ = 2
□2 = 0.5

X10 - Dry
M = 1.5 x 10^9
□ = 0.5
□2 = 0.5

OREGON DEPARTMENT OF ENERGY

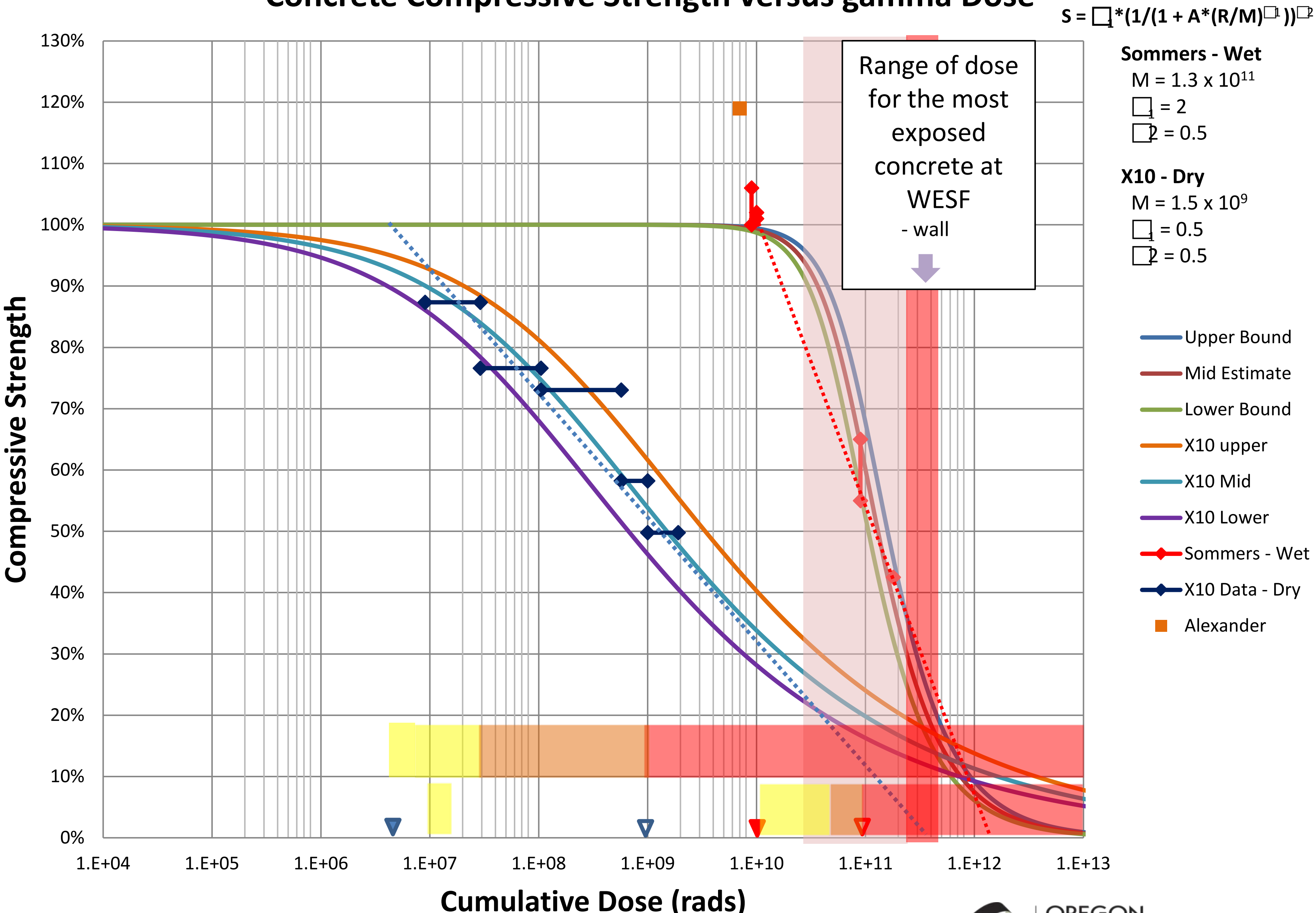


OREGON DEPARTMENT OF ENERGY

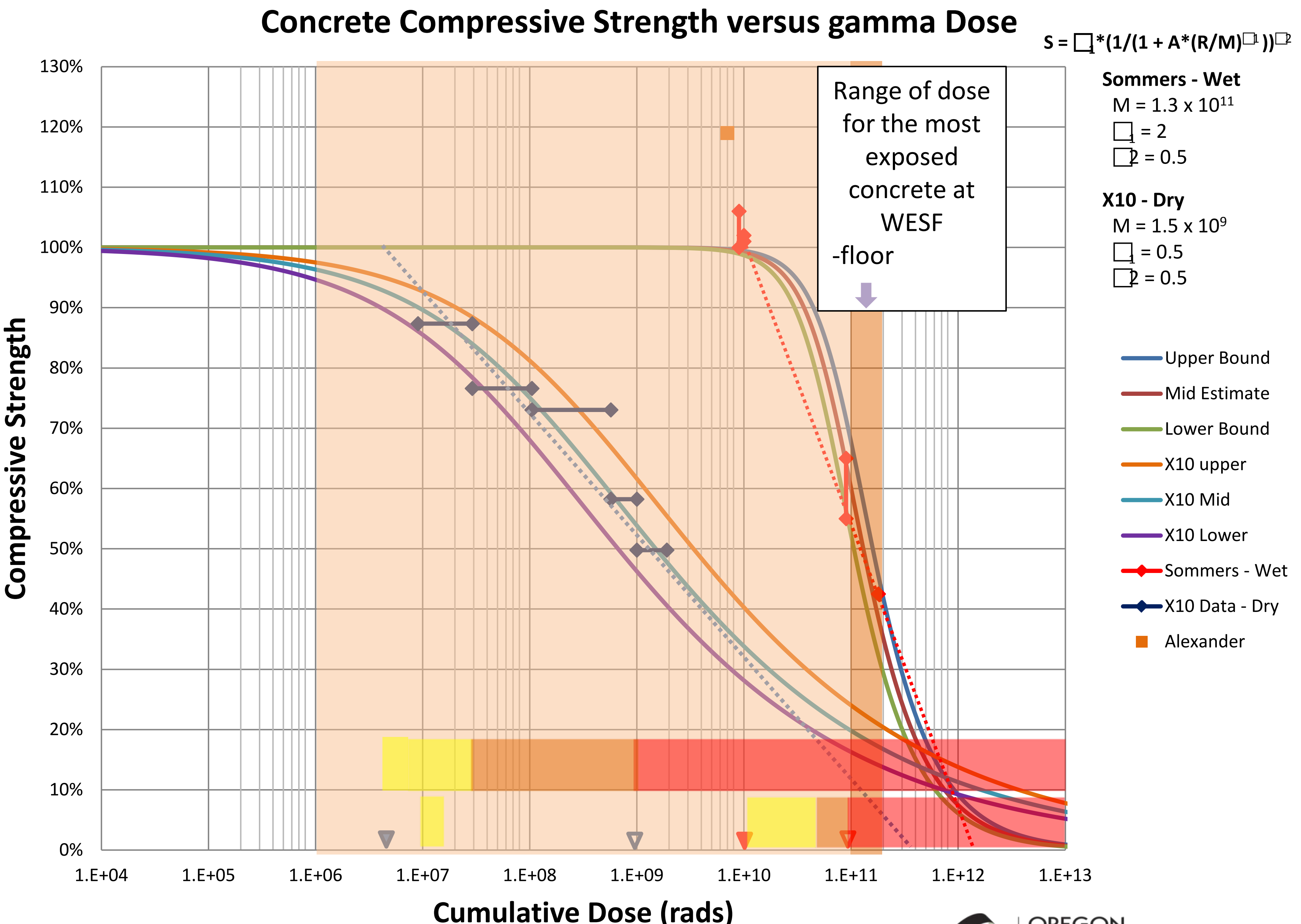


OREGON DEPARTMENT OF ENERGY

Concrete Compressive Strength versus gamma Dose

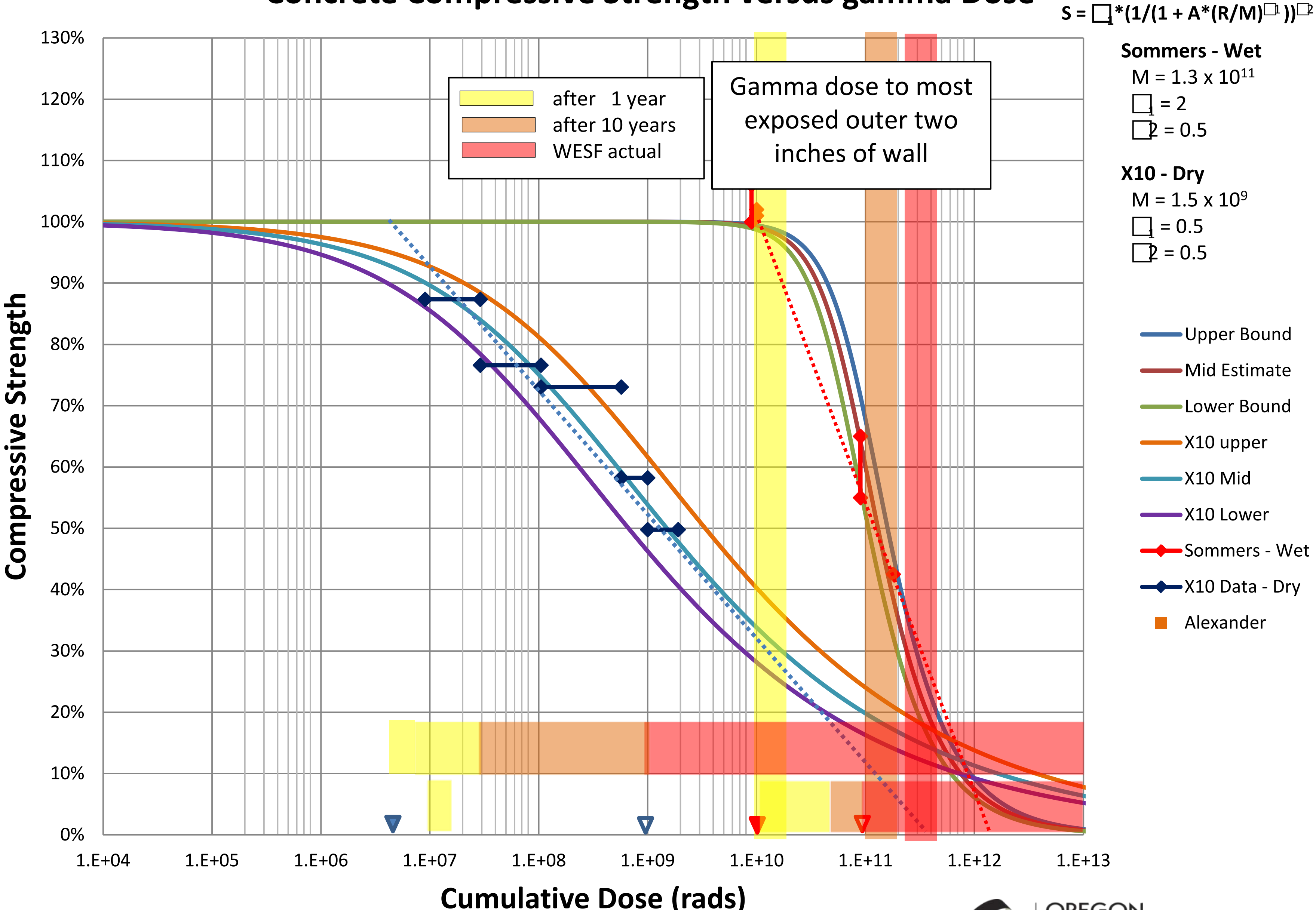


OREGON DEPARTMENT OF ENERGY



OREGON DEPARTMENT OF ENERGY

Concrete Compressive Strength versus gamma Dose



OREGON DEPARTMENT OF ENERGY

Structural Strength

- Project staff assert that the concrete walls were built to be 12 times as strong as needed.

OREGON DEPARTMENT OF ENERGY

Structural Strength

- Project staff assert that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g

Structural Strength

- Project staff assert that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g
  - Importance Factor 1.5 (used in structural calculations)

OREGON DEPARTMENT OF ENERGY

Structural Strength

- Project staff assert that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g
  - Importance Factor 1.5 (used in structural calculations)
  - Derating for known damage 0.75

OREGON DEPARTMENT OF ENERGY

Structural Strength

- Project staff assert that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g
  - Importance Factor 1.5 (used in structural calculations)
  - Derating for known damage 0.75
  - Calculated loss of strength from damage ≥ 2

OREGON DEPARTMENT OF ENERGY

Structural Strength

- Project staff tell us that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g
  - Importance Factor 1.5 (used in structural calculations)
  - Derating for known damage 0.75
  - Calculated loss of strength from damage ≥ 2
  - Strength now 12 x 0.25/0.8 x 0.75 /1.5 /2 => **0.94**
    - Less than required!

OREGON DEPARTMENT OF ENERGY

Structural Strength

- Project staff tell us that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g
  - Importance Factor 1.5 (used in structural calculations)
  - Derating for known damage 0.75
  - Calculated loss of strength from damage ≥ 2
  - Strength now 12 x 0.25/0.8 x 0.75 /1.5 /2 => **0.94**
    - Less than required!

Structural Strength

- Project staff tell us that the concrete walls were built to be 12 times as strong as needed.
- Factors affecting the required strength:
  - Seismic forces now 0.80 g, then 0.25 g
  - Importance Factor 1.5 (used in structural calculations)
  - Derating for known damage 0.75
  - Calculated loss of strength from damage ≥ 2
  - Strength now 12 x 0.25/0.8 x 0.75 /1.5 /2 => **0.94**
    - Less than required!

OREGON DEPARTMENT OF ENERGY

Questions & Concerns

- There is very little good data
  - Can we find/get more?
  - Does the X10 data apply?

OREGON
DEPARTMENT OF
ENERGY

Questions & Concerns

- There is very little good data
  - Can we find/get more? – Does the X10 data apply?
- There is no actual data on the resistance of the concrete used in WESF to gamma dose
  - Does DOE plan to core the concrete? Or… ?

Questions & Concerns

- There is very little good data
  - Can we find/get more? – Does the X10 data apply?
- There is no actual data on the resistance of the concrete used in WESF to gamma dose
  - Does DOE plan to core the concrete? Or… ?
- Assumptions about how to calculate concrete strength with severe damage may not be valid
  - How do we validate these?

OREGON DEPARTMENT OF ENERGY

Questions & Concerns

- There is very little good data
  - Can we find/get more? – Does the X10 data apply?
- There is no actual data on the resistance of the concrete used in WESF to gamma dose
  - Does DOE plan to core the concrete? Or… ?
- Assumptions about how to calculate concrete strength with severe damage may not be valid
  - How do we validate these?
- Where else might this be a problem? SSTs, CSB, WTP, HLW, etc… ?

OREGON DEPARTMENT OF ENERGY

Questions & Concerns

- Is there a credible path or mechanism that could ever lead to drain down of a pool?
  - If so, the consequences appear to be unrecoverable with large consequences.
  - That looks to be a really bad plan.

Questions & Concerns

- Is there a credible path or mechanism that could ever lead to drain down of a pool?
  - If so, the consequences appear to be unrecoverable with large consequences.
  - That looks to be a really bad plan.
- Why didn't the safety basis consider radiation dose to concrete?
  - The initial studies were done at Hanford and known long before.
  - What other big issues are missing from this and other facility safety basis evaluations?

OREGON DEPARTMENT OF ENERGY

Where might there be problems?

- Can exist anywhere total dose exceeds level where damage begins

Where might there be problems?

- Can exist anywhere total dose exceeds level where damage begins
- Depends on concrete type, composition, …
  - Can be as low as 10^6 – 10^7 rad
  - Standard is 1 – 1.3 x 10^{10} rad

OREGON DEPARTMENT OF ENERGY

Where might there be problems?

- Can exist anywhere total dose exceeds level where damage begins
- Depends on concrete type, composition, …
  - Can be as low as $10^6 – 10^7$ rad
  - Standard is $1 – 1.3 \times 10^{10}$ rad
- Depends on exposure time

Where might there be problems?

- Can exist anywhere total dose exceeds level where damage begins
- Depends on concrete type, composition, …
  - Can be as low as $10^6 – 10^7$ rad
  - Standard is $1 – 1.3 \times 10^{10}$ rad
- Depends on exposure time
- Knowing the half-life, and dose rate at the beginning, average or end (termination), we can make a table with levels of concern.

OREGON DEPARTMENT OF ENERGY

Concrete Compressive Strength – Dose rates of concern

Time Exposed	Time exp T	60.00 525,964	years hours
Half Life Cs^{137}	$t_{1/2}$	30.17	years

	Relative Dose Rates
Initial	1.000
Average	0.543
Center	0.626
Terminal	0.252

Dose rates to reach limits at time T

Oak Ridge X-10			Initial	Average	Center	Terminal	
10.0E+06	rad	Initial effect	35	19	22	**9**	rad/hour
1.0E+09	rad	50% reduction	3,500	1,900	2,200	**880**	rad/hour
1.5E+09	rad	Essentially complete	5,300	2,900	3,300	**1,300**	rad/hour

General Rule							
15.0E+09	rad	Initial effect	53,000	29,000	33,000	**13,000**	rad/hour
100.0E+09	rad	50% reduction	350,000	190,000	220,000	**88,000**	rad/hour
1.0E+12	rad	Essentially complete	3,500,000	1,900,000	2,200,000	**880,000**	rad/hour

Potential advice bullets

- 1
- 2
- 3
- 4
- 5
- 6
- 7