The Adequacy of DOE Natural Phenomena Hazards Performance Goals from an Accident Analysis Perspective

Jeff Kimball
Defense Nuclear Facilities Safety Board Staff

Department of Energy NPH Conference
October 26, 2011

OBJECTIVE: Assess whether the DOE NPH performance goal concept as used in the Documented Safety Analysis process is adequate or needs additional guidance

Background

- ANS Standard 2.26 and the concept of Seismic Design Categories (SDC) and Limit States (LS)
- ASCE Standard 43-05 and the concept of Design Categories and Associated Performance Goals
- DOE Standards 3009 and 1189 and the concept of unmitigated consequences from accident analysis to designate Safety-Class structures, systems, and components (SC-SSC) and SDC

Presentation Focus: Seismic Risk Insights as Impacted by SDC and LS Selection

Understanding NPH Terminology

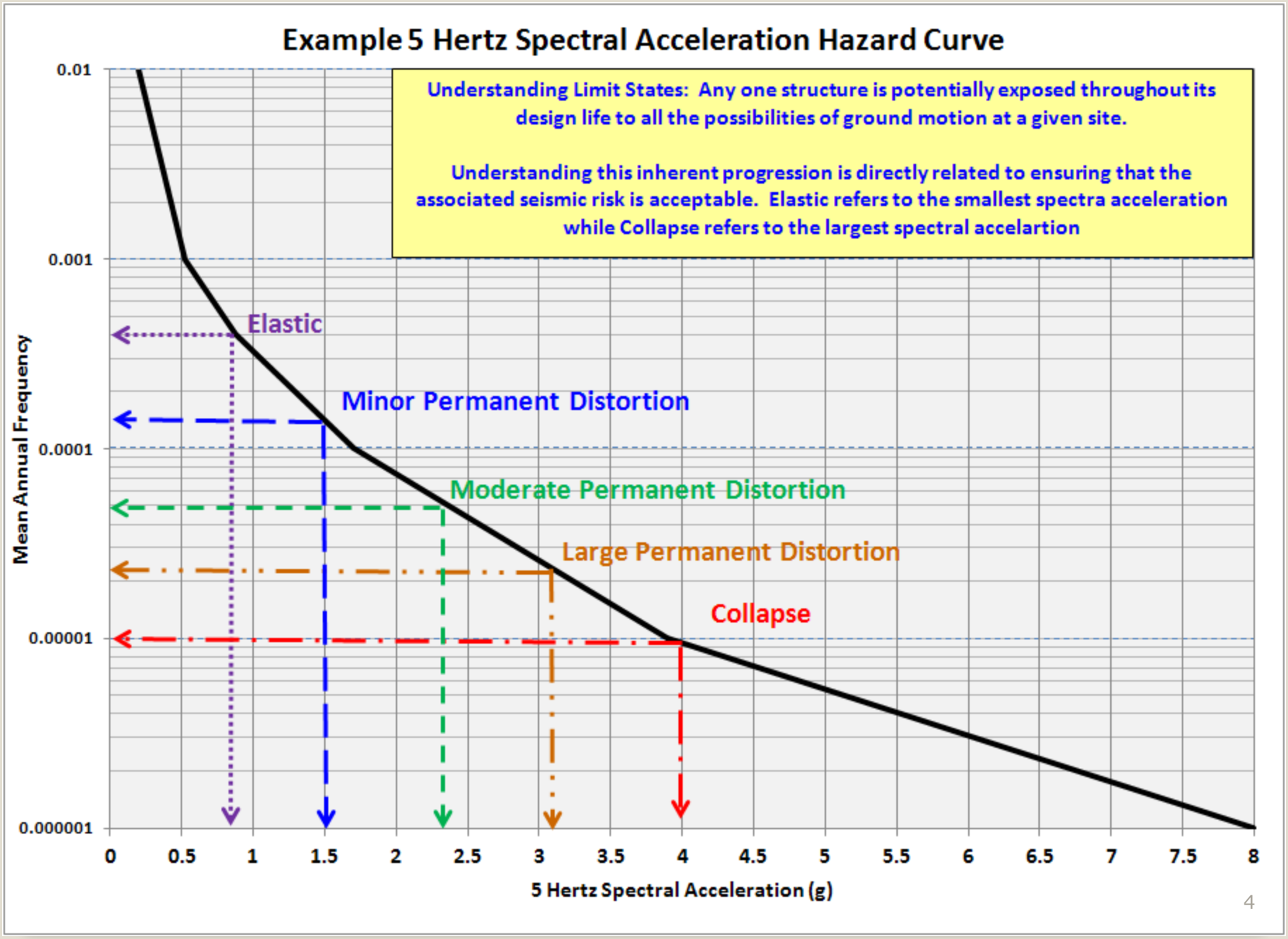
Seismic Design Category: One of five categories that are used to establish seismic hazards evaluation and SSC seismic design requirements

Limit State: The limiting acceptable deformation, displacement, or stress that an SSC may experience during or following an earthquake and still perform its safety function. Four Limit States are used.

ANS Standard 2.26 assigns probabilistic performance goals to each of the Seismic Design Categories

From an accident analysis perspective (severe seismic accident) is the DOE NPH performance goal approach adequate?

Adequate from a seismic risk context


Example 5 Hertz Spectral Acceleration Hazard Curve
Understanding Limit States: Any one structure is potentially exposed throughout its design life to all the possibilities of ground motion at a given site.
Understanding this inherent progression is directly related to ensuring that the associated seismic risk is acceptable. Elastic refers to the smallest spectra acceleration while Collapse refers to the largest spectral accelartion
Elastic
Minor Permanent Distortion
Moderate Permanent Distortion
Large Permanent Distortion
Collapse
Mean Annual Frequency
0.01
0.001
0.0001
0.00001
0.000001
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
5 Hertz Spectral Acceleration (g)

Steps to Assessing the Adequacy of NPH Performance Goal Concepts

1. Establish seismic risk assessment approach
2. Assess collapse frequency for each SDC/LS category
3. Assess seismic risk implications and the use of unmitigated consequences to select SDC
4. Conclusions

SEISMIC RISK ASSESSMENT

While seismic risk could consider a range of seismic accident scenarios, seismic risk is likely to be dominated by seismic collapse. We will use seismic collapse to compare each SDC/LS combination on an equal footing.

Risk = Accident Frequency * Accident Consequence

Accident Frequency is frequency of collapse

Accident consequence could be measured in a variety of ways such as offsite dose or population exposure

Assessing Seismic Collapse Frequency for Each SDC/LS Combination

The analytical approach is based on the alternative methods to meet the intent of seismic design performance goals.

ASCE 43-05 Commentary Section C
Basis for seismic provisions of DOE Standard 1020 (UCRL-CR-111478

$$P_f = \{H_D * e^{(1/2*(KH*\beta)^2)}\} / (C_{50} / DBE)^{KH}$$

P_f = probability of failure
H_D = mean annual frequency of the DBE
KH = slope of the ground motion hazard curve
C_{50} = 50% capacity spectral acceleration value
DBE = design basis earthquake spectral acceleration value
β = composite structural uncertainty value

Sufficient to get risk insights or first order insights

Assessing Seismic Collapse Frequency for Each SDC/LS Combination

To implement the analytical approach we need to estimate the C_{50} values for each of the SDC/LS combinations.

For this exercise we will assume a RC shear wall structure.

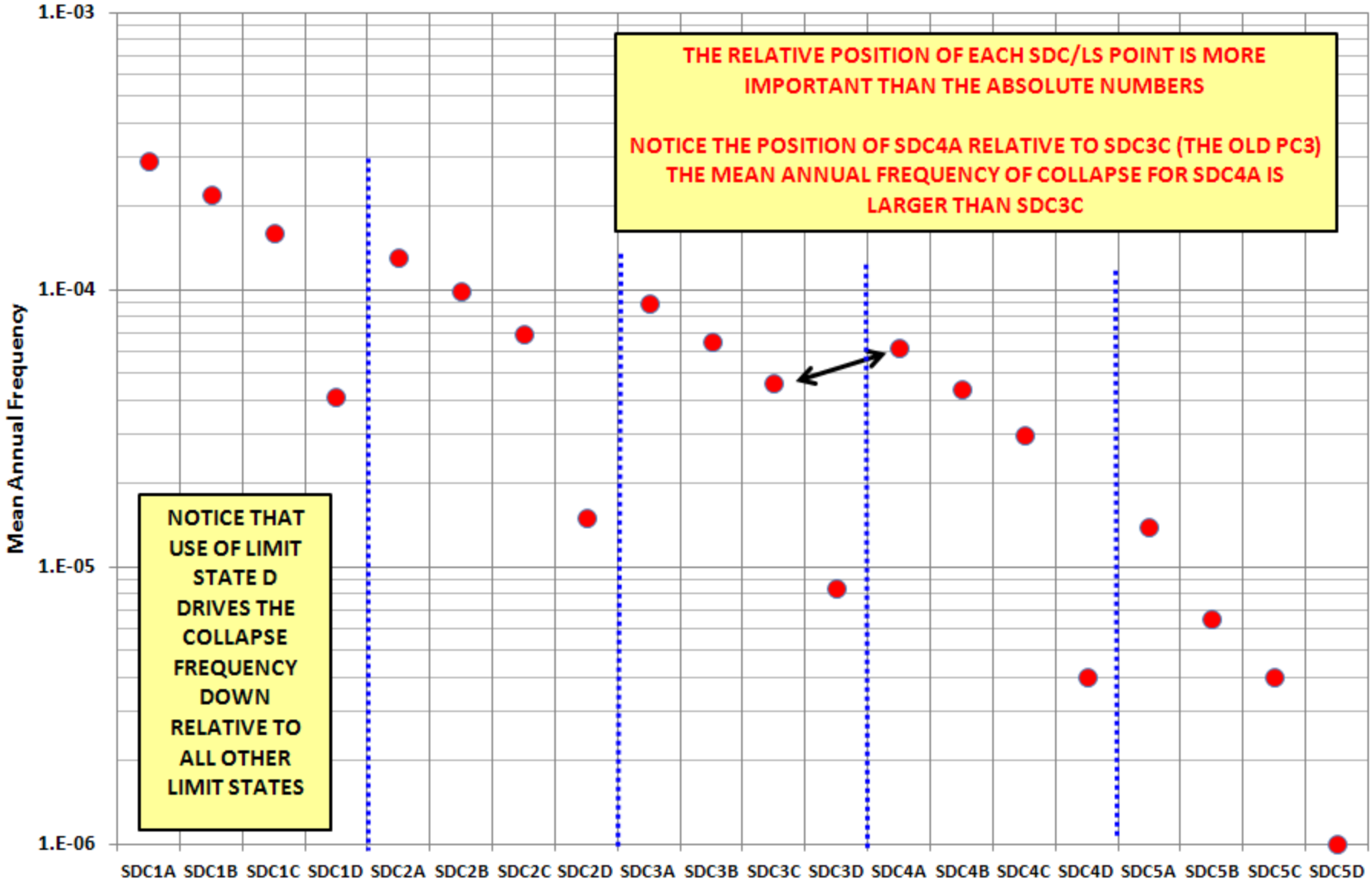
To go between LS we will use the ASCE 43-05 ductility factors as scale factors – assuming that these are 95% confidence values, best estimate ductility factors are derived.

This also requires an assumption on the uncertainty distribution for seismic capacities – a range will be considered.

A seismic hazard curve (5 Hertz spectral acceleration) from an NNSA site is used.

Again these are intended to be first order collapse insights

ASSESSMENT OF COLLAPSE FREQUENCY VERSUS SDC/LS COMBINATION



ASSESSING SEISMIC COLLAPSE FREQUENCY FOR EACH SDC/LS COMBINATION

To gain confidence in rank order the results of this assessment are compared to an independent assessment performed by another staff member

Current Assessment	Alternative Assessment
SDC1A	SDC1A
SDC1B	SDC1B
SDC1C	SDC2A
SDC2A	SDC3A
SDC2B	SDC1C
SDC3A	SDC2B
SDC2C	SDC3B
SDC3B	SDC1D
SDC3C	SDC2C
SDC1D	SSC5A
SDC2D	SDC3C
SDC5A	SDC5B
SDC5B	SDC2D
SDC3D	SDC3D
SDC5C	SDC5C
SDC5D	SDC5D

While the exact order is not the same the general trends are similar indicating some confidence in using these type of results to get first order insights into seismic risk implications

Unmitigated Consequences and Seismic Design Category DOE Standard 1189 (March 2008)

Table A-1 from DOE-STD-1189 shows that SDC-3 should be used if unmitigated consequences to the public exceed 25 rem (the Evaluation Guideline from Appendix A of DOE-STD-3009)

The text notes that "*If the quantitative public criterion for SDC-3 of Table A-1 is exceeded significantly for any project (between one and two orders of magnitude) then the possibility that SDC-4 should be invoked must be considered on a case-by-case basis".*

Given the appreciation of seismic collapse versus SDC/LS does the selection of SDC-4 versus SDC-3 make sense?

SDC/LS Seismic Risk Implications

Consider 3 Hypothetical New Facilities

Facility 1 has public offsite consequences of 50 rem
Facility 2 has a public offsite consequence of 500 rem
Facility 3 has public offsite consequences of 5000 rem

Facility 1 selects SDC-3
Facility 2 and 3 select SDC-4

To appreciate seismic risk we simply multiply the collapse frequency for each of the SDC/LS combinations with the offsite consequences for the 3 facilities

Facility 1: **SDC-3A {.0045}, SDC-3B {.0033}, SDC-3C {.0023}, SDC-3D {.00042}**
Facility 2: **SDC-4A {.03}, SDC-4B {.02}, SDC-4C {.01}, SDC-4D {.002}**
Facility 3: **SDC-4A {.3}, SDC-4B {.2}, SDC-4C {.1}, SDC-4D {.02}**

From a Seismic Risk Perspective the increase in offsite consequence For Facilities 2 and 3 is not offset by lower collapse frequency for SDC-4
Inconsistent relative risk between SDC-3 and SDC-4

SDC/LS Seismic Risk Implications

Implications

- SDC-3 is very conservative – high implied seismic risk for SDC-4 is ok – WHERE IS THE PROOF?

AND/OR

- SDC-4 is not conservative especially when doses exceed the DOE Offsite Evaluation Guideline by 10 or more

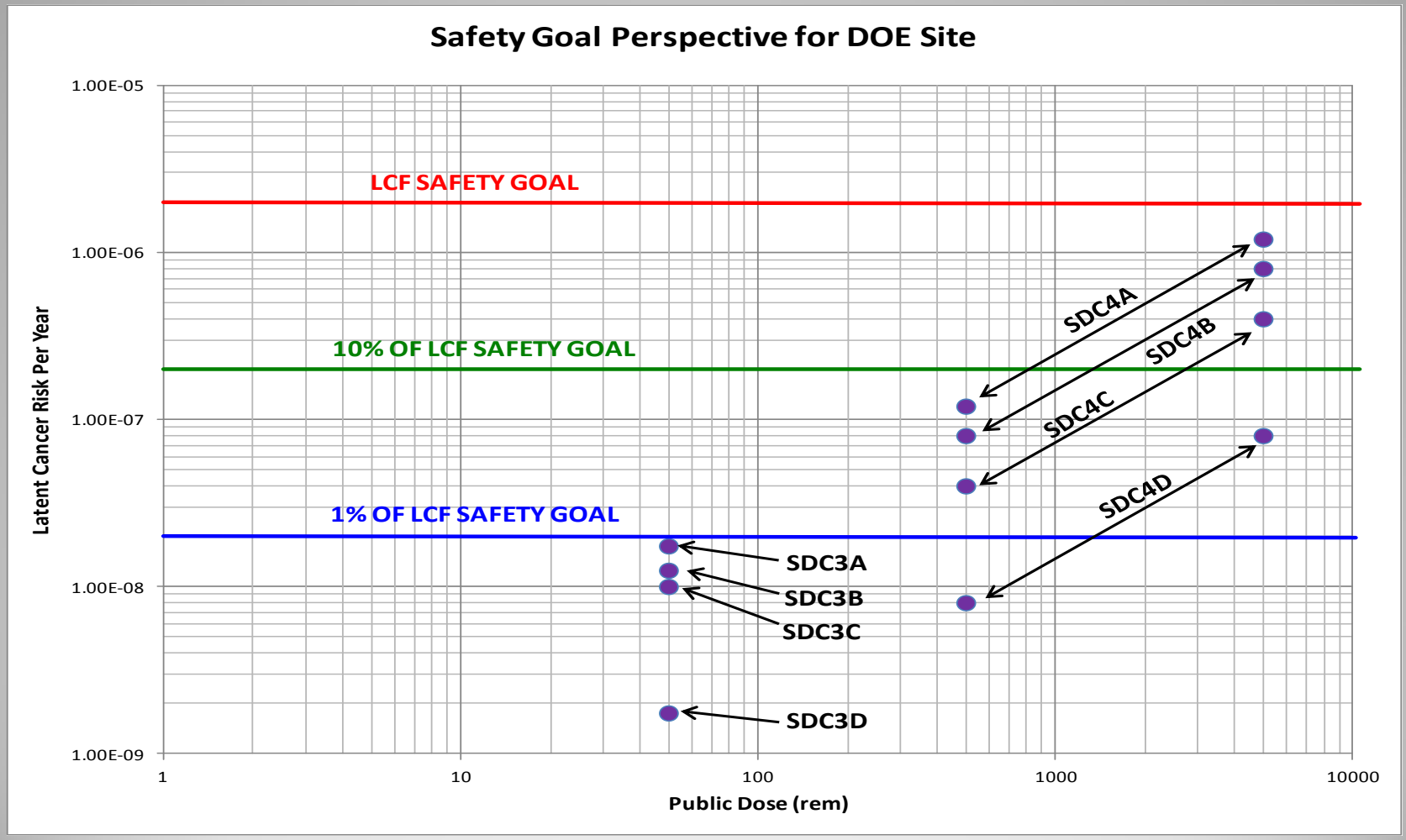
How do we tell?

Need insights from seismic risk assessments to defend the implied link between offsite consequences and SDC

Experience from the DOE/DP Safety Survey
Risk Insights: Accident Analysis and EIS

Next Chart is an Example of such insights

Using DSAs and EIS results one can back out the relationship between offsite consequences and Latent Cancer Fatality Risk (Safety Goal) - Example



Seismic Risk Implications

What percent of the safety goal should a single accident take up for a new facility? A few percent

Given that, the implication is that dose times seismic collapse should be ~ ≤ .01

SDC-3 meets that check and is conservative

SDC-4 does not meet that check when doses exceed the EG by more than about a factor of 10

Conclusions

While the DOE NPH Performance Goal concept has worked well for many nuclear facility applications, this assessment suggests that the use of SDC-3 or SDC-4 (and their associated performance goals) may result in unacceptable seismic risk if used for situations where the offsite public consequences are very large.

DOE needs to perform a technically defensible assessment of the link between unmitigated accident consequences from severe seismic events such as seismic collapse to justify the link between unmitigated consequences and Seismic Design Categories.

The offsite dose values in Appendix A of DOE Standard 1189 should be revisited.

Conclusions

Until that is completed DOE Needs to Limit the Use of SDC-4 to only those cases where unmitigated seismic accident consequences exceed the Evaluation Guideline by about an order of magnitude, otherwise SDC-5 should be used.

For any new facility where the unmitigated seismic accident consequences exceed the Evaluation Guideline by more than an order of magnitude DOE Needs to require that seismic collapse for the structure be quantified to ensure seismic risk (offsite dose * seismic collapse ~ ≤ .01) is acceptable.

DOE Needs to work with ANS to close the gap in linking seismic risk and establishing appropriate Seismic Design Categories based on unmitigated consequences.