Probabilistic Seismic Hazard Analysis: Background Information

Introduction

Nuclear power plants are designed and built to withstand strong earthquakes based on their location and nearby earthquake activity. This seismic design basis is established before a plant is built, using site-specific seismic hazard assessments. First, designers calculate the site's expected earthquake motions. Then, the design accounts for these ground motions so that it will safely withstand the earthquake and protect the public and the environment.

Our methods of assessing seismic hazards have evolved over time as our scientific understanding of earthquake hazards has improved. Each operating U.S. nuclear power plant determined its expected ground motions independently with site-specific information from historical earthquake catalogs and examination of local geology. Plant designers examined earthquake sources near a site. They used the largest quake from that sample to determine the site's expected ground motion. This "deterministic" approach has been replaced with "probabilistic" analysis. This broader approach examines how all seismic sources and earthquake types can affect a site.

Probabilistic Seismic Hazard Analysis Methodology

The NRC's regulations and guidance point U.S. nuclear power plants to Probabilistic Seismic Hazard Analysis (PSHA) as the favored assessment process. PSHA objectively assesses a site's seismic hazard. Seismic hazards are determined by combining knowledge of seismic sources surrounding a site, how often those sources generate earthquakes and how ground motions change based on a quake's magnitude and distance from the site. The PSHA method also meets NRC requirements to account for uncertainties in what we know.

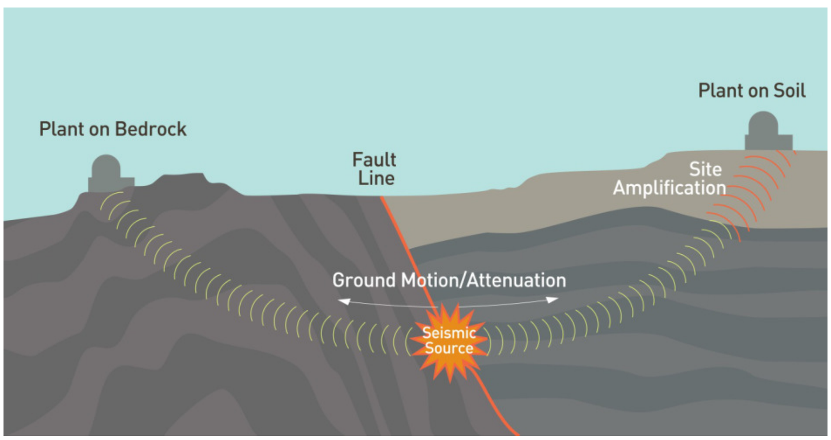
A properly conducted PSHA study will produce an estimate of how likely a given ground motion level is for a certain time period (such as the operating life of a reactor). The studies describe ground motion in units of "g," the acceleration due to Earth's gravity. For example, a PSHA study might conclude a site has a 10 percent chance of exceeding ground motion of 0.3 g (a "strong" quake) within 50 years. The study could also estimate the maximum ground motion expected in the next 10,000 years at the site.

PSHA studies must account for uncertainty in their data. Current PSHA practices deal with uncertainty by incorporating alternative views into a calculation using "logic trees". For example, the three-dimensional relationship of a seismic source to a site in a PSHA study may be incompletely defined. In this situation, the PSHA would develop reasonable alternative site-source relationships. Each alternative model would become a branch in the logic tree. Each branch would be incorporated into the overall seismic hazard from that specific source. As with any sort of analysis, the final PSHA's quality depends on the quality and reliability of data that goes into the work. NRC guidance points to Senior Seismic Hazard Analyses Committee

(SSHAC) guidelines for developing input models for seismic hazard studies at nuclear power plants. The SSHAC guidelines are described in NUREG 6372, available online at http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6372/ . This process relies on extensive input and guidance from the scientific community. This process leads to input models that represent the best knowledge and broad scientific perspectives, while also appropriately considering alternative ideas and views.

As shown in the figure below, a proper PSHA study needs information from three key areas:

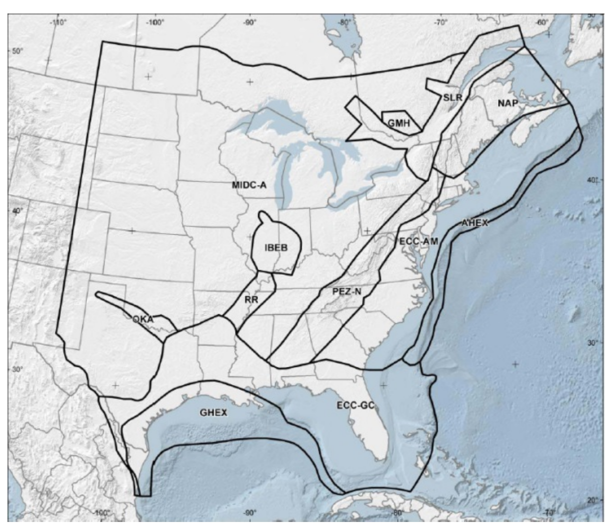
- seismic sources and their relative locations to the site in question;
- how often each of those sources is expected to generate an earthquake of a given strength; and
- how earthquake energy is transmitted between the source and the site.



Here's a brief description of these three essential information sets.

Seismic Sources:

Geologically uniform areas that generate similar types of earthquakes are considered "seismic sources." A PSHA study identifies and characterizes seismic sources by conducting extensive geologic and geophysical investigations. The region's geologic history, previous earthquakes and their characteristics and geophysical properties of rocks are all studied using available information. The study identifies and maps boundaries of

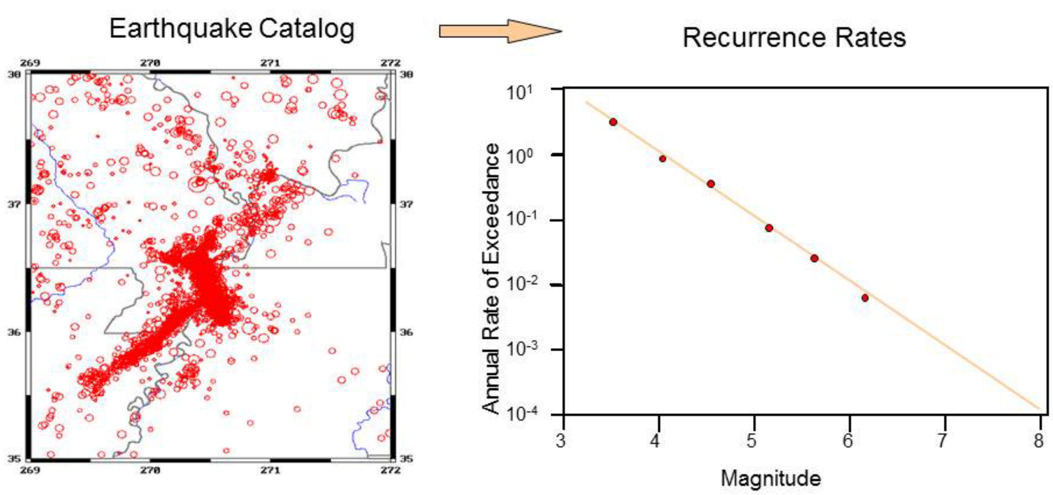


distinct seismic sources. Each identified seismic source's strongest expected earthquake is also assessed using past earthquake data and various geologic factors. NRC regulations call for PSHA studies to incorporate uncertainties regarding these seismic sources' geometries and their maximum earthquakes.

Almost all U.S. nuclear power plants lie east of the Rocky Mountains. While the West Coast is notorious for its earthquakes, the Central and Eastern United States (CEUS) has many seismic sources of its own. Together with the Dept. of Energy and the Electric Power Research Institute, the NRC in 2012 issued an approved CEUS seismic source model. This model used more than 400 years of historical earthquake reports, as well as detailed geologic information. The model, available online at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2115/, supports seismic hazard analysis for any potential or existing CEUS site. The figure above shows some of the model's seismic sources. The NRC requires PSHA studies to consider seismic sources within at least 200 miles of a site.

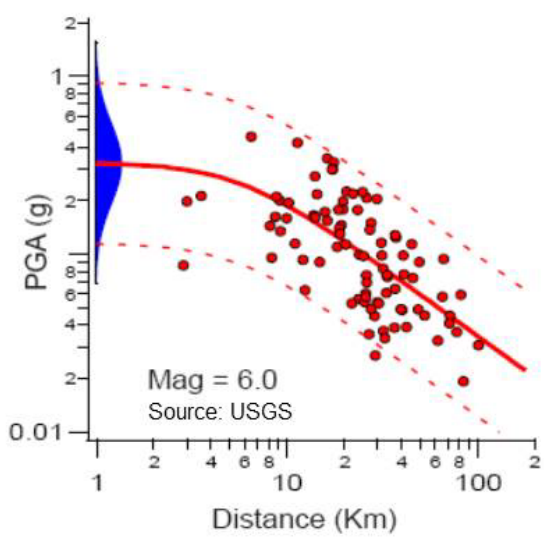
Earthquake Catalogs and Recurrence Rates:

Another essential piece of PSHA information involves where and how often a seismic source will generate earthquakes of different strengths. PSHA studies obtain this information from earthquake catalogs compiled from a variety of sources such as the U.S. Geological Survey. Evidence of earthquakes in geologic formations often supplements the historical data in U.S. earthquake catalogs. Analyzing this information usually shows a simple relationship between an earthquake's strength and its rarity: the larger the quake, the rarer it is. PSHA studies assume the historical rate of earthquakes will accurately represent a region's seismic activity for at least as long as the analyzed nuclear power plant operates.



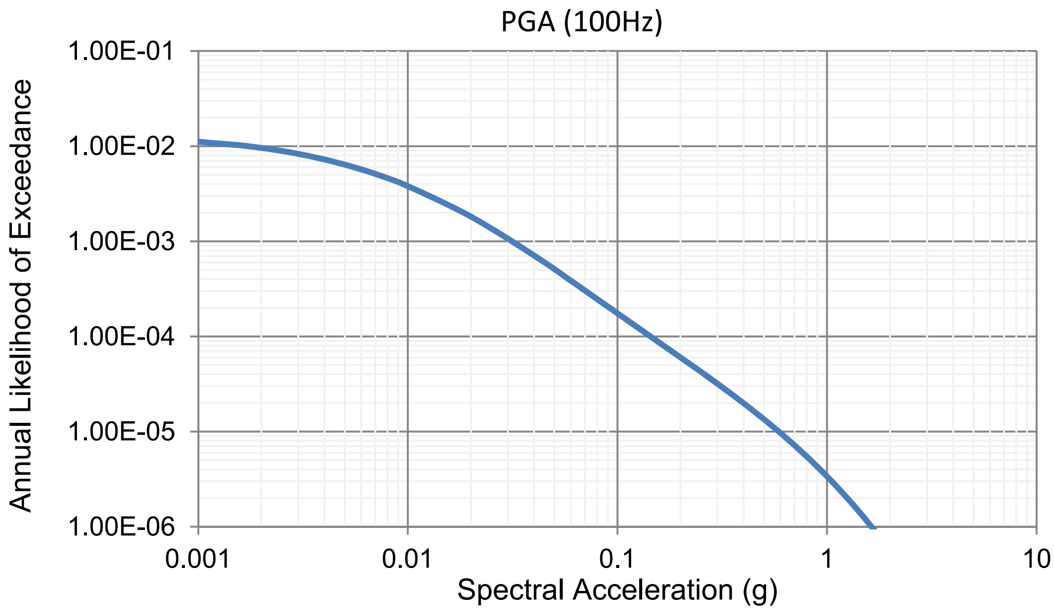
Ground Motion Prediction Models:

The third key area of a PSHA study involves understanding a site's expected ground motions based on a given earthquake's strength and distance. Earthquake energy spreads out from its origin through different geological layers, weakening the further it travels. Ground motions observed at any given point depend on the earthquake's distance to the site. Ground motion prediction models provide information about a site's expected ground motion levels, given an earthquake's distance and magnitude. These models are essential for a PSHA, which must analyze all of a seismic source's possible earthquakes. The red line in the figure below shows how the average ground motions for a magnitude 6 quake vary with distance. The red dots are individual ground motion measurements, plotted by their distance from the earthquake location. The blue curve represents the uncertainty (variability) in ground motion measurements. These models apply to specific regions and work best when based on an extensive set of observed quakes. If a region only has a limited number of observations, those can be supplemented with simulated earthquake ground motions for a variety of situations.



Calculation of Seismic Hazard:

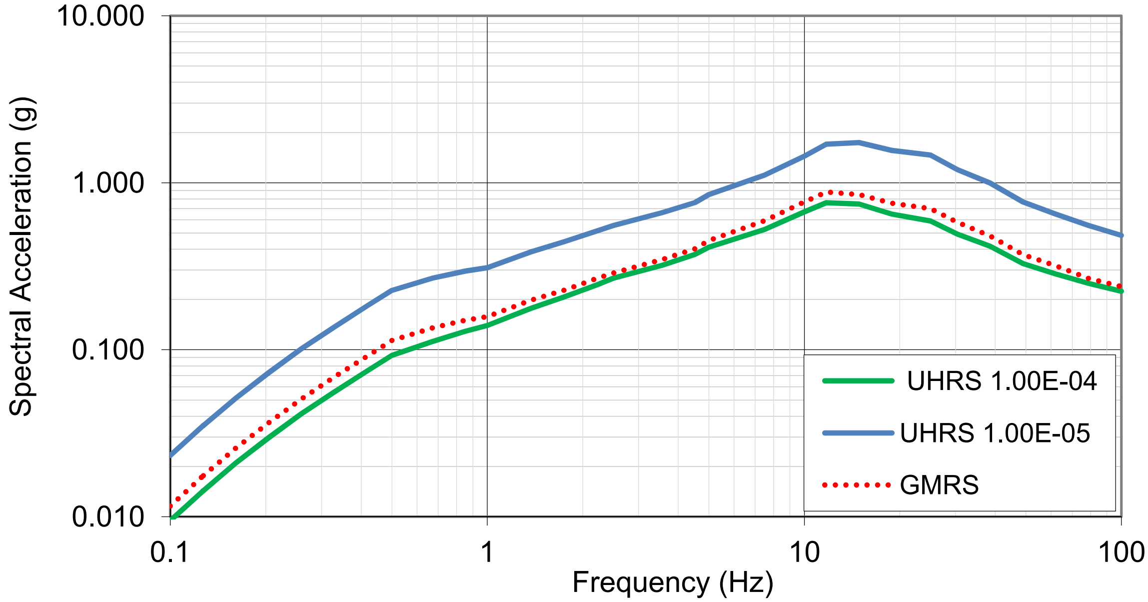
All of this information goes into calculating seismic hazard curves. This process determines how often a site can expect to have ground motions of a given strength. The chart below shows a seismic hazard curve for how strongly the ground would shake at 100 times per second (or hertz, abbreviated Hz). Earthquake researchers consider 100 Hz a good measure of a site's peak ground acceleration (PGA). The chart below shows a quake shaking the site at one-thousandth of a "g" is expected once in a hundred years. A quake shaking the site at 1 g is expected once every 300,000 years or so. PSHA studies calculate similar seismic hazard curves for different ground motion frequencies of interest, usually between 0.5 Hz and 100 Hz.



The next step in a PSHA creates what is called the uniform hazard response spectra to take into account all the seismic hazard curves for the site. The spectra represent the expected ground motions at a range of frequencies for a given period of time. For the seismic hazard at U.S. nuclear power plants we pay particular attention to the 10,000- and 100,000-year periods. In the figure below, the green line shows the spectra curve for quakes in the 10,000-year period. The blue line shows the spectra for quakes in the 100,000-year period.

Many plants calculate uniform hazard response spectra as if the reactor is located on hard rock. Some plants, however, sit on compacted soil or soft rock. These layers of softer materials can amplify ground motion at some frequencies. A “soft rock” plant determines this site amplification by modeling the physical characteristics of the soil and rock under the site, then calculating how the model responds to ground motions from hard rock. The plant then uses the site-amplification model to appropriately increase or decrease the uniform hazard response spectra.

The final step in seismic hazard calculations creates the ground motion response spectra (GMRS), which the nuclear power plant uses to properly design its safety systems. Plants calculate the GMRS based on the uniform hazard response spectra calculated for 10,000- and 100,000-year periods, using specific performance-based criteria. The dotted red curve below represents the GMRS a plant’s design would have to safely deal with for that site.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1.000
0.100
0.010
Spectral Acceleration (g)
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1
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