The Abdus Salam
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International Atomic
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"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

14 - 25 February 2005

Lesson learnt from the IAEA reviews

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2nd Workshop on
"Earthquake engineering for nuclear facilities. Uncertainties in seismic hazard assessment"
ICTP - IAEA

ICTP, Trieste, February 14-25, 2005

Lesson learnt from the IAEA reviews

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Content

1. The IAEA services

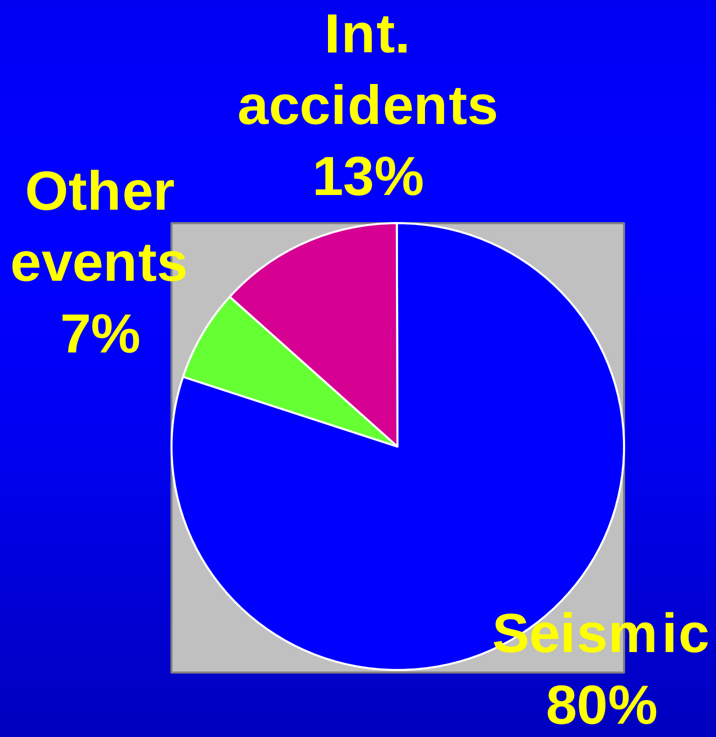
2. Generic issues from the IAEA reviews
    1. Site requirements
    2. Site specific data
    3. Site specific monitoring
    4. Diffuse seismicity areas
    5. Maximum potential earthquake
    6. Attenuation curves
    7. Capable faults
    8. Spectrum shape

3. The IAEA docs

ESRS review missions (1990 – 2004)

- The ESRS review missions

Total N. of tasks



Issue n.1

Lack of appropriate site safety requirements

- Min Max vs probabilistic (or mixed)
- Probabilistic targets. Typically in MS they are **lower than internal PIEs**:
  - 10-7/y for single event
  - 10-6/y for combined events
- Risk approach and probability of failure
  - P(rad.acc.) = P(event) * P(overstress) * P(release) (if independent!)
  - 10-7/y = X * 10-2/y * 10-1/y (**for earthquake**)
  - 10-7/y = X * target exposure * target capacity (for ACC)
  - 10-7/y = X * NPP exposure * target features (for expl.)

  P(event) could be reduced around 10-5/y and could be coupled with analysis of engineering provisions!
- Load combinations (LOCA + Earthquake), relationship with **internal** events (external events should have a lower probability, in general!!)

Facility dependent!!

Requirement > P (rad. Consequences) =

P Event * P Cond.Failure * P Release

Component dependent!!

- Probability of the event (SPL, 10E-7?), probability of the interaction to the site , probability to have an initiating accident (CPV, 0.1?), probability of a sequence of events leading to an accident (DBPV, 10E-6), probability to have serious consequences

Grading the facility hazard

Proposed classes

1) NPPs (and LNG large storage)

2) High level waste and spent fuel facilities (toxic, explosive, chemical biological storage facilities) near public

3) Same as before but far from public

4) Low level waste (Dams, government facilities, hospitals, bridges)

5) Industrial and conventional facilities **> Conventional standards**

Criteria

- Installed thermal power
- Needs for active safety systems
- Potential for quick dispersion (e.g.: explosions, wind)
- Long term effects (persistent)
- Number of involved people

The performance goals

Hazard Category of the facility		Power rating	Inventory TBq (10^{12} Bq) (I)	
			B - γ[1]	**α[2]**
HC-1	**High**	10 ? P < 100 MW	I> 2E6	I> 10
HC-2	**Medium**	2 ? P < 10 MW	4E5<I<2E6	2<I<10
HC-3	**Low**	0.1 ? P < 2 MW	4E4<I<4E5	0.2<I<2
HC-4 (SR)	**Very low**	P ? 0.1 MW	I<4E4	I< 0.2

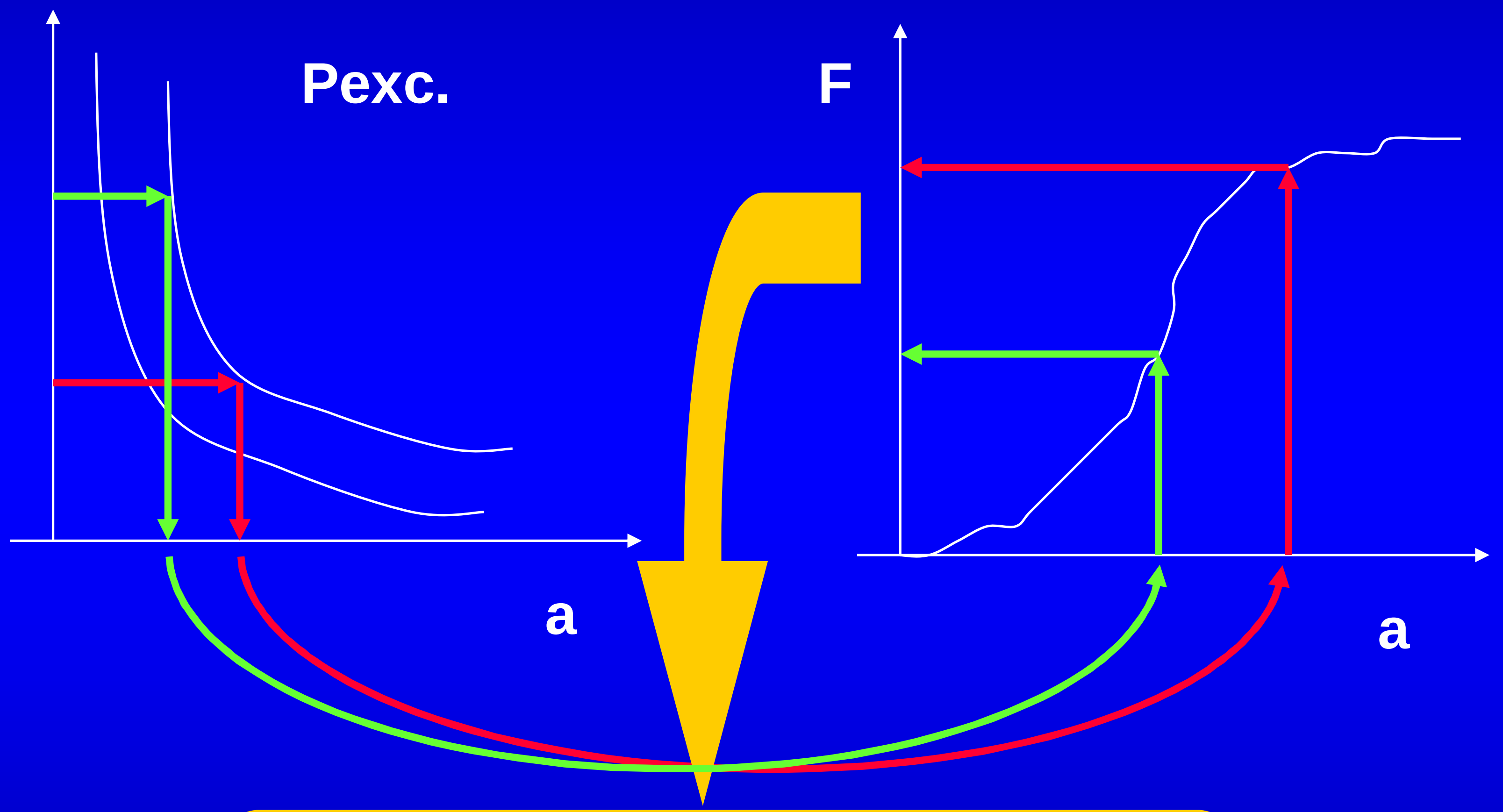
Hazard Category of the Facility	EEC1	EEC2	EEC3
HC-1	10^{-5}/a	10^{-4}/a	10^{-3}/a
HC-2	10^{-5}/a (only for the barriers, if needed)	10^{-4}/a	10^{-3}/a
HC-3	(*)	10^{-4}/a (only for the barriers, if needed)	10^{-3}/a (industrial installations)
HC-4 (SR)	(*)	(*)	(*)

(*) These facilities cannot host components in this EEC. See section 2.5

Mean probability of exceedance limits typically used for nuclear design (in case of NPPS one order lower than the probability associated to internal events!!)

	EXTERNAL							
Performance Or Design Category[4]	**Earthquake[6]**	**Straight Wind[2]**	**Tornado**	**Precipitation[1]**	**Flood**	**Blast[5]**	**Aircraft Crash[5]**	**High Energy System Rupture**
5	10^{-5}	$1x10^{-6}$	$1x10^{-6}$	10^{-2}	$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$
4	10^{-4}	$2x10^{-4}$	$2x10^{-6}$	10^{-2}	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$
3	$4x10^{-4}$	$2x10^{-3}$	$2x10^{-5}$	10^{-2}	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$
2	$1x10^{-3}$	$1x10^{-2}$	---	$2x10^{-2}$	$1x10^{-2}$	---	---	---
1	$2x10^{-3}$	$2x10^{-2}$	---	$2x10^{-2}$	$2x10^{-2}$	---	---	---
0	---	---	---	---	---	---	---	---

Hazard and fragilities



Pfailure = Pexceedance * Fragility

Decision

In order to guarantee the target "performance goal" (probability of failure-probability of release) a decision should be taken:

	"Red" strategy	"Green" strategy
Hazard	Low probability (standard)	High probability
Design	Low safety margin (Conventional standard)	High safety margin (Nuclear standard)

Issue n.2

Lack of site specific data

- Very rarely the database for the site is presented as suggested in the SG. Usually, for the regional, near regional and site vicinity, the database consists only of existing information coming from official authorities and from published papers.

- Inevitably, the existing regional data reflect the scientific state of the art in the countries as well as the status of the official authorities dealing with geological and seismological problems (for example, the status of the official geological cartography, seismic catalogues, seismic monitoring systems, etc.). Therefore data vary significantly from country to country, not only in quantity but also in quality. For example, mapping scales (i.e. the available detail) can significantly differ from country to country. Specific studies are available in some areas but not in others, or the time intervals of seismic catalogues are different, and so on.

- When the site is at or near the border with another country or when the regional area comprises several countries the lack of homogeneity of the database can be especially pronounced. For example, maps, reports or catalogues show dramatic differences in the perceived ground motions of same seismic events across country boundaries.

- Lack of homogeneity of the database also commonly arises when the site is located on a coastline. More emphasis is usually given to the onshore rather than offshore area, although the offshore data are often critical for the site evaluation and they can be of much better quality.

Issue n.3

Lack of site specific monitoring

- Experience shows that seismic or microseismic networks are often employed, sometimes at considerable cost, without any real appreciation of how the data that are recorded have to be used in the overall hazard assessment.
- Indeed, in some cases, the project schedule is so tight that the monitoring study is not contractually required in relation to the issuing of a site safety report.
- Experience shows that good results, in terms of effectiveness and cost, can be obtained when the local seismological network is constituted as part of a regional or national seismological network under the jurisdiction of the national competent authority.

Issue n.4

Identification of diffuse seismicity areas

- Because of inhomogeneities and incompleteness in the database, the identification of seismogenic sources and zones of diffuse seismicity (seismotectonic provinces) was often carried out on the basis of seismological data derived from the existing catalogues.

- Especially for potential seismogenic structures in the near region of the site not manifesting recent seismicity, problems were often encountered in defining their activity status and/or capability. There were similar problems in defining the boundaries of zones of diffuse seismicity. While the usual explanation was that they are based on seismotectonic considerations, very rarely there was any methodological support for the boundaries that have been employed.

- The data base (pre-instrumental, instrumental, site specific data) has to be homogeneised, as small events are available only in recent years, aftershocks may bias the statistics (they should be included only if the seismotectonic does not use Poisson assumptions for the maxima distribution) and big events occurred in the past have higher uncertainty associated. In this phase, the use of paleoseismology can improve a lot the reliability of the data base through the analysis of geological records of past earthquakes (faulting, liquefaction, coastline uplift) by means of age dating and displacement estimation.

- Dealing with zones of uniform seismicity, the boundaries between such zones should represent different characteristics of seismicity such as activity rate, depth distribution, focal mechanism, etc. To recognize such differences it may be necessary to apply statistical tests and it should certainly be necessary to check any proposed boundaries against the distribution of those earthquakes which are candidate for a "complete" dataset. A complete data set is composed of those earthquakes whose magnitudes are above the contemporary magnitude threshold for catalogue completeness for the whole area (which, preferably is derived on independent historical or instrumental considerations).

Issue n.5

The maximum potential earthquake

- It is usually defined on the basis of seismicity data (e.g. maximum historical observed earthquake plus one degree in intensity or 1/2 degree in magnitude, frequency/recurrence relationships, etc.). Very rarely these values are compared with the data coming from the characteristics of the geological structure and tectonics (e.g. slip-rate-magnitude; rupture length-magnitude, displacement-magnitude, paleoseismic data, etc.).
-
- This is due to the fact that data on current tectonics are often lacking and also that the mathematical formulas used to estimate the max. magnitude are coming from the "earthquake-geology" and sometimes they are not well known and understood (for example, the rupture length is often confused with the fault length). Sometimes reviewers have found that earthquake magnitude values derived from the treatment of seismological data were in total disagreement with the characteristics of geological structures in the region: in some cases, maximum magnitude values implying significant surface faulting were used without any evidence for such phenomena, and in other cases low values of maximum magnitude were used in spite of strong evidence of large surface faulting.

- A problem that might be encountered in this context, is the issue of the fault which is “active but not capable”, implying that the size of the maximum potential earthquake is limited. There are, of course, many faults of this type around the world but too often such an attribution is claimed for faults (in all sorts of seismotectonic environments) where the evidence is inadequate. It is recommended, therefore, that faults are put into this category only when the available data cannot support any other classification.

- The definition of the maximum potential earthquakes in zones of diffuse seismicity is more problematic: that is why the guidance given in the SG is more prudent. There are also strong national positions on this issue. For example, in Japanese practice, a floating earthquake of magnitude 6.5 is recommended; however, it would be difficult to argue that earthquakes of this size could not occur in many other parts of the world. Given the relative infrequency of earthquakes of this size, particularly in regions of low seismicity, and the fact that they do not inevitably leave near-surface evidence of their occurrence, this magnitude provides a standard against which other figures can be judged.

Issue n.6

Attenuation curves

- It may be noted that both attenuation and spectral shape can be different for near-field and far-field sources.

- It is common practice to have more than one design basis earthquake associated with each hazard level (SL-1 and SL-2 according to the SG), each one representative of a potential seismogenic area. All of these should be considered in the design and appropriate enveloping should be carried out on the results. However, in many cases unphysical enveloping of ground motions or spectra associated to different seismogenic sources were recorded. A reliable seismogenic model usually implies different sets of potential earthquakes coming at the site: they should all be included in the design basis as far as possible, without loosing their physical nature by averaging and enveloping.

- Attenuation relations describe the decay of the severity of earthquake ground motion with distance from the earthquake`s focus. They can be framed in terms of macroseismic intensity or in terms of one or more of the measured parameters of ground motion (most commonly, to-date, peak horizontal ground acceleration or, in Japan, peak velocity). With the increase in the use of uniform risk spectra (see below), there may be a number of frequency-specific attenuation relations.

- While, for a long time, piecewise-linear spectra, originally derived in the United States, were used in many other countries, with the improvements in recording equipment, there is increasing recognition that the use of such broadband spectra can be both over-conservative and unconservative at the same time. The so-called uniform risk (or hazard) spectrum is now in quite common usage for assessing the seismic safety of existing plants although, to-date, they do not appear to have been used for design.

- It is considered that the guidance provided in the SG remains sound but that the emphasis should now be put on using attenuation relations and spectral shapes that are locally valid. Preferably, they should be derived using local data but, where this is impossible, every effort should be made to confirm the suitability of imported formulations or, where new relations are being determined, the appropriateness of imported data.

Issue n.7

Capable faults

- There shall be an effort to collect and evaluate the best available tectonic interpretations, geological maps, geological cross-sections, microseismic and sub-regional network data, and geophysical data in the region to aid in the identification and quantification of potentially active and capable faults. Integration of different techniques is the best tool to decide for the capability!

- Formal criteria, such as IAEA Safety Guide NS-G-3.3 shall be used to develop the geological and seismological databases as well as determine whether any of the identified faults in the immediate vicinity of the site are capable. This will likely require a field investigation by a qualified geologist.

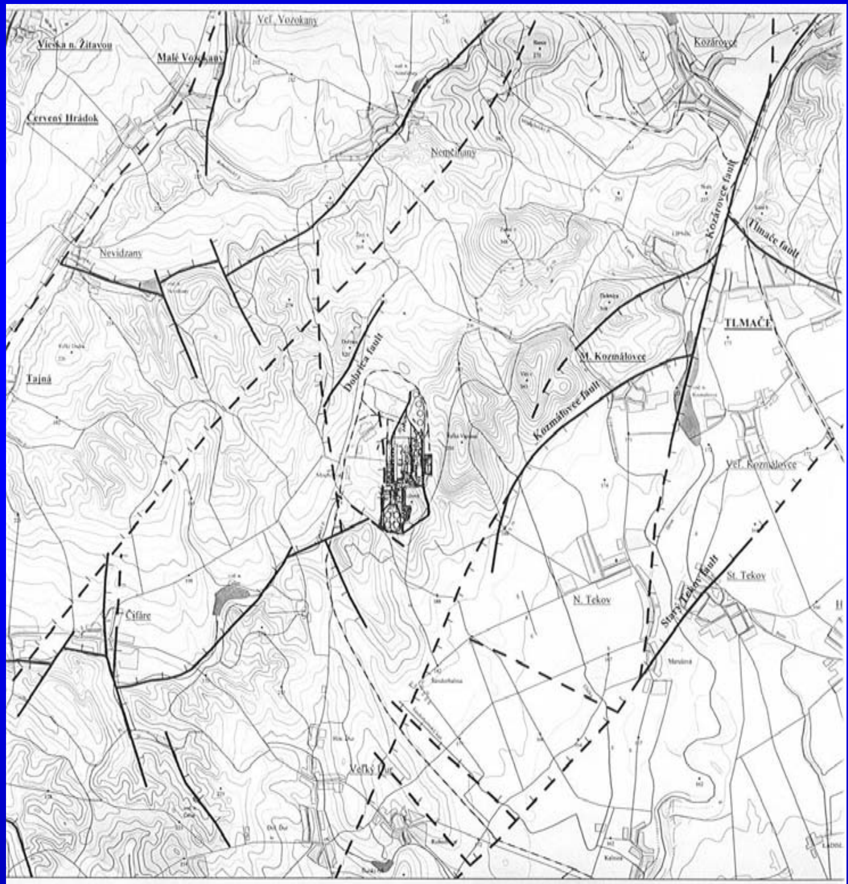
- There shall be a clear and sufficiently conservative rationale for determining the fault lengths, widths, and depths. This shall be done by properly taking into account the uncertainty in these estimates. The entire fault zone, not just the individual segments, shall be considered when estimating fault lengths and maximum magnitudes.

- Temporary microseismic arrays should be used to determine whether there are alignments of small earthquakes along the more significant identified faults in the geological database to determine whether they can be considered potentially active.

- There should be an effort to eliminate as many steps as possible when converting magnitudes in order to avoid the compounding of uncertainty.

- The seismological database shall be enhanced with microseismic and sub-regional earthquake catalogues as appropriate and significant historical events should be studied carefully to ensure their reliability and accuracy. A separate catalogue of volcanic events shall be developed for the explicit purpose of developing a volcanic seismicity source zone, when necessary.

- The seismological database should be extended to include focal mechanisms and stress drop and uncertainties in all of the parameters.


Vieska n. Žitavou
Malé Vozokany
Veľ. Vozokany
Kozárovce
Červený Hrádok
Nemčňany
Kozárovce fault
Tlmače fault
Nevidzany
TLMAČE
Tajná
Dobrica fault
M. Kozmálovce
Kozmálovce fault
Veľ. Kozmálovce
Čifáre
N. Tekov
St. Tekov
Starý Tekov fault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Issue n.7

Spectrum shape

- The RLE ground motion shall be defined in terms of a response spectrum and representative time histories, such as found in the SG.

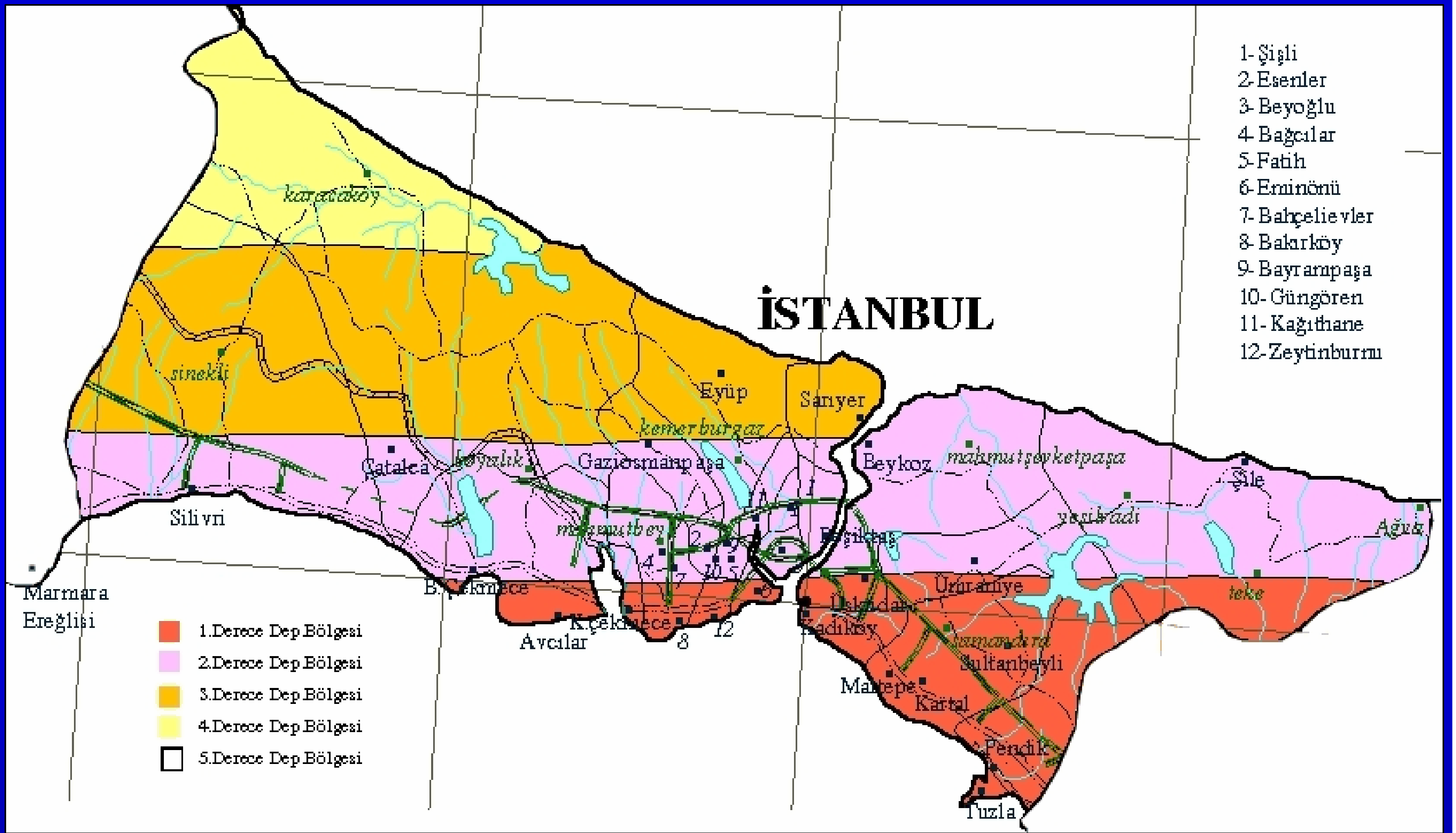
- The same attenuation relations used to estimate PGA shall also be used to estimate response spectral ordinates in order to better quantify the appropriate spectral shape of the controlling events contributing to the RLE response spectrum. This should be done whether a PSHA or a DSHA is used to develop the RLE ground motion.

- The response spectral shapes derived from the DSHA and PSHA should be compared with standardized spectral shapes commonly used in practice (e.g., NEHRP and NUREG 0098), as well as to that derived from procedures currently accepted by the regulatory body, to ensure that a sufficiently conservative, yet realistic, RLE response spectrum or spectral shape is selected.

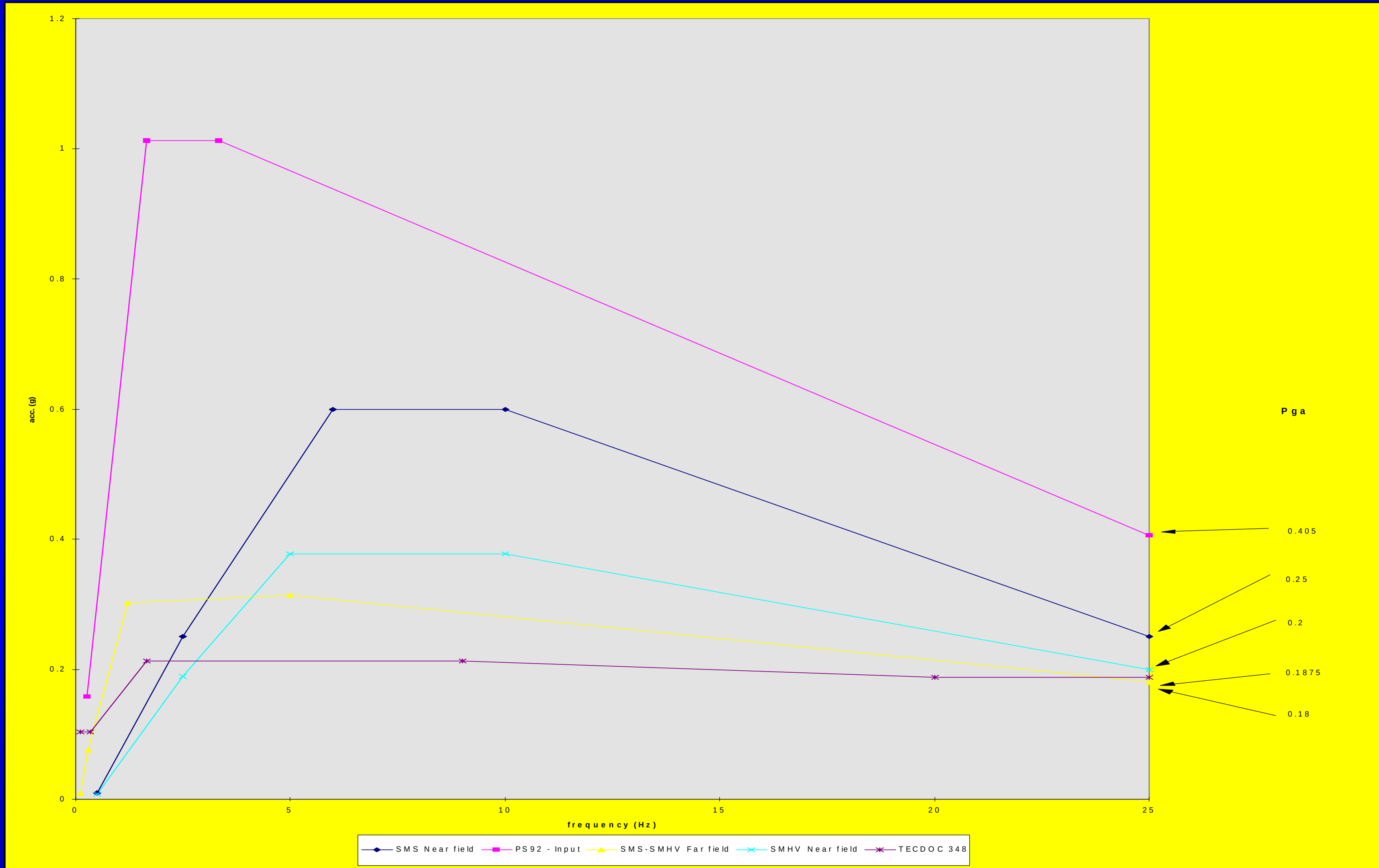
- If a PSHA is used to develop the RLE response spectrum, this spectrum shall be developed using procedures defined in the SG.

- If a DSHA is used to develop the RLE response spectrum, this spectrum should be developed from a site-specific spectrum using spectral attenuation relations (the preferred method). If the preferred method is not used, then the RLE response spectrum should be developed using an estimate of PGA and a sufficiently conservative, yet realistic, spectral shape using one of the methods presented above. The use of a standardised response spectral shape should be avoided because of its very conservative broad-banded shape.

- If vertical RLE response spectra are required, they should be derived from the horizontal RLE response spectra using vertical-to-horizontal spectral ratios corresponding to the size and distance of the controlling events and the site conditions beneath the site.



İSTANBUL
1- Şişli
2- Esenler
3- Beyoğlu
4- Bağcılar
5- Fatih
6- Eminönü
7- Bahçelievler
8- Bakırköy
9- Bayrampaşa
10- Güngören
11- Kağıthane
12- Zeytinburnu
1.Derece Dep.Bölgesi
2.Derece Dep.Bölgesi
3.Derece Dep.Bölgesi
4.Derece Dep.Bölgesi
5.Derece Dep.Bölgesi
Eyüp
Sarıyer
Beykoz
Şile
Ağva
Silivri
Marmara Ereğlisi
Çatalca
Gaziosmanpaşa
Avcılar
Üsküdar
Kadıköy
Ümraniye
Sultanbeyli
Maltepe
Kartal
Pendik
Tuzla



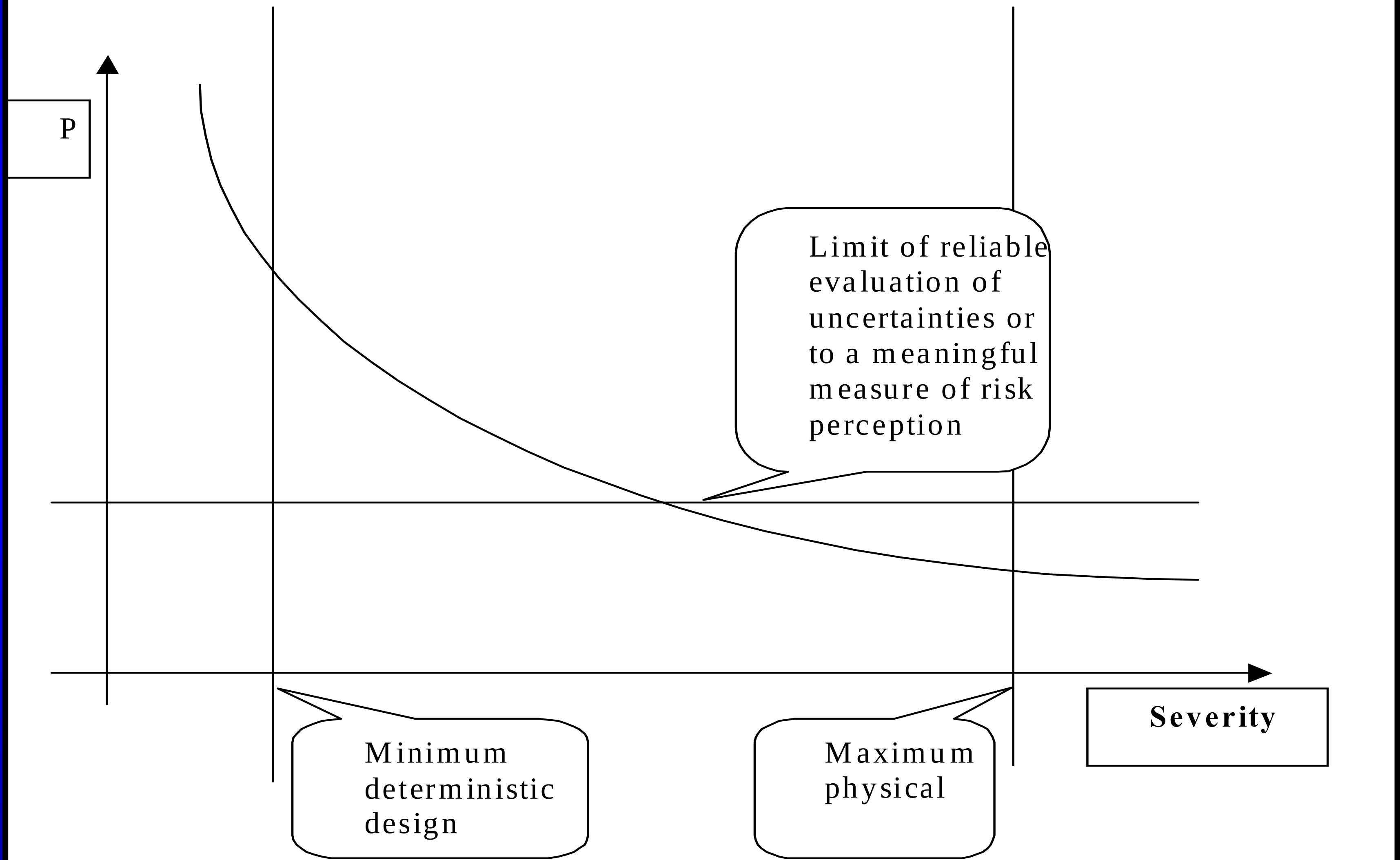
acc. (g)
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
frequency (Hz)
Pga
0.405
0.25
0.2
0.1875
0.18
SMS Near field
PS92 - Input
SMS-SMHV Far field
SMHV Near field
TECDOC 348

Conclusions

- Studies have shown that the SSE developed according to the DSHA ground motions correspond to a *median* reference probability of around 10^{-5} /y, or a *mean* reference probability of around 10^{-4} /y.
- Therefore, the DSHA can be a valid approach for evaluating seismic hazards, especially when seismic hazard curves are not well constrained or are generally unreliable, as long as it can be shown that the deterministic design event is sufficiently conservative by nuclear design standards.
- However, demonstrating such conservatism is a task that is often difficult to achieve without a thorough geological, seismological, and geophysical investigation of the site region and showing that the selected event represents nearly a “worst-case” scenario.

(K.Cambpell)

If the geological, seismological, and geophysical data are of sufficient reliability to perform a PSHA, the PSHA approach might be considered a potentially more reliable method for developing the RLE ground motion and results are expected to be less conervative.



P
Limit of reliable evaluation of uncertainties or to a meaningful measure of risk perception
Minimum deterministic design
Maximum physical
Severity