The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
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International Atomic Energy Agency

2016-17

Joint ICTP/IAEA Advanced Workshop on Earthquake Engineering for Nuclear Facilities

30 November - 4 December, 2009

Evaluation of Seismic Safety of Existing NPP
Part-I Requirements & components capacity

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Evaluation of Seismic Safety of Existing NPP

Part-I *Requirements & components capacity*

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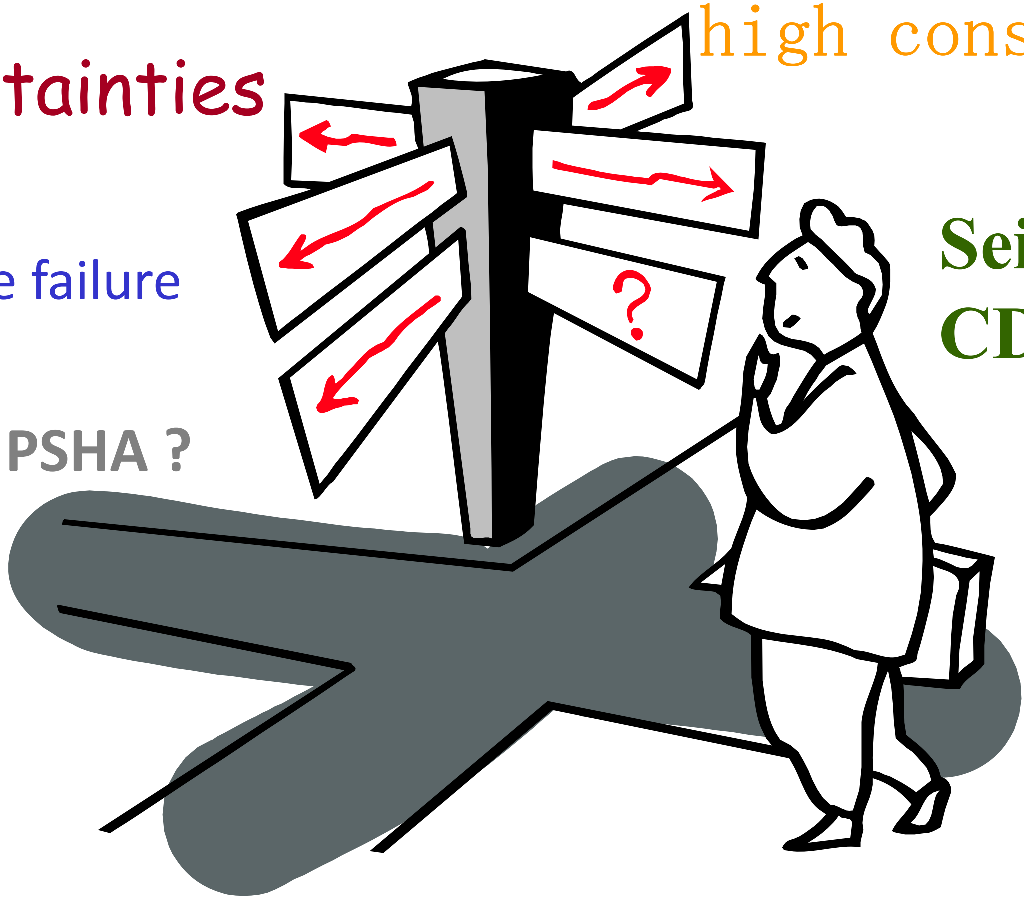
large uncertainties

high consequences

common cause failure



Seismic – CDF !

DSHA or PSHA ?

Content

- Introduction
- Safety requirements
- Tasks for seismic re-evaluation
- Review basis ground motion
- Seismic structure system & components lists
- Components fragilities
- Summary

Introduction

- Objective

  Seismic re-evaluation aims at determining the seismic risk of a plant with respect to current aseismic design specifications and undertake up-gradation of plant, if found necessary, to enhance its safety against seismic hazard to an acceptable level.
- Seismic risk assessment aims at estimating the frequencies of occurrence of earthquake induced accidents that may lead to different level of damage and to identify the key risk contributors so that necessary risk reduction is accomplished.

Introduction

- The assessment of seismic capacity of an existing facility is prompted by the following reasons:
  - Evidence of a greater seismic hazard than expected before due to new data or new methods
  - Regulatory requirements meant to ensure that plant has adequate safety margins against loading effects due to seismic excitation.
  - Lack of aseismic design in the plant design
  - New technical finding such as vulnerability of some structures or equipment or feedback from real earthquakes.
- Two approaches for seismic re-evaluation
  - Deterministic: **Seismic margin assessment (SMA)**
  - Probabilistic: **Seismic core damage frequency (SCDF)**

Introduction

Scope

- To determine the earthquake level that can be withstood without compromising plant safety.
  - assessment of the seismic hazard
  - safety analysis of the NPP
    - *identification of the SSSCs necessary to deal with the seismic event in performing designated safety function.*
  - evaluation of component seismic capacity
  - evaluation of the plant specific seismic capacity .
- Carry out enhancement of seismic capacity of safety related structure, system and component (SSC), if found necessary.

Safety requirements

- Evaluation of the earthquake level that the plant can withstand without compromising following safety functions.
  - ***Group A safety function***
    - ***achieve a safe shutdown,***
    - ***maintain the plant in a safe condition,***
    - ***achieve decay heat removal and***
  - ***Group B safety function***
    - ***confine radioactive materials.***
- SSCs required to perform Group A & Group B function and including those necessary to guarantee defense in depth in an earthquake event are evaluated.

Safety requirements
Limiting conditions

- The plant must be capable of being brought immediately to and maintained in a safe shutdown condition during the first 72 hours following the occurrence of the RBGM level earthquake, initial plant status before the RBGM being normal power operation

- Simultaneous off-site and plant generated power (other than the seismically qualified emergency power) loss up to 72 hours

  (For FBTR, since there is a risk of sodium freezing in some parts of the sodium circuits, there is a need to seismically qualify the emergency power supply systems);

Safety requirements
Limiting conditions

- The required safe shutdown systems would include one main path and one redundant path, to the extent practical;

- There is no external supply of make-up water and other media for safety system operation, e.g. diesel oil, for 72 hours following the event;

- Earthquake induced fires and floods and other seismic interactions affecting the safety functions shall be avoided;

Safety requirements
Limiting conditions

- Rupture and leaking of pipes and inventories as a consequence of the earthquake shall be taken into consideration, unless they are upgraded;

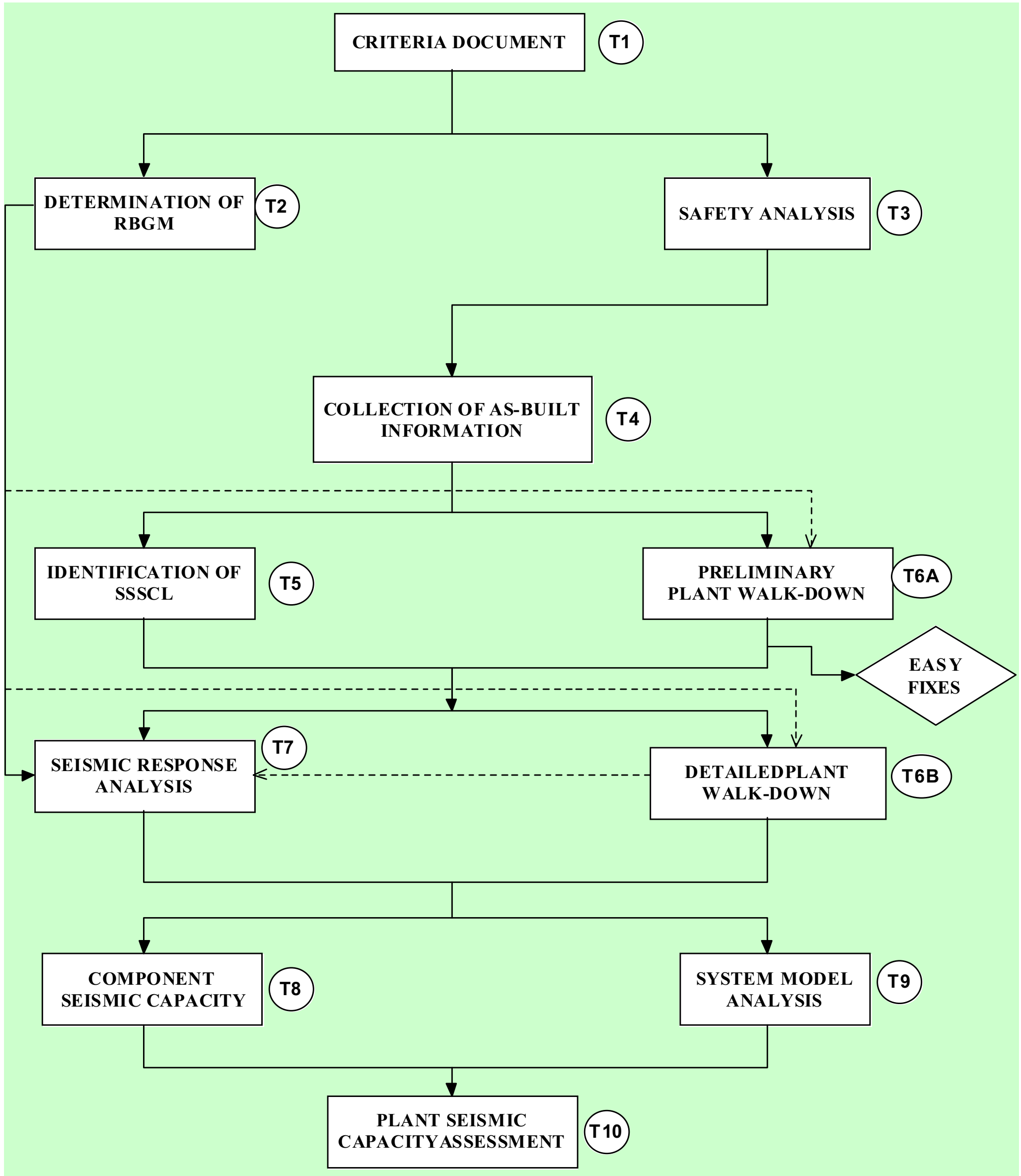
- Other external events such as external fire, flooding, tornadoes, sabotage, etc. are not postulated to occur simultaneously;

- Design basis accident is not postulated concurrent with the earthquake of RBGM level.

Tasks for seismic re-evaluation (FBTR)

T 1	Preparation of criteria document
T 2	Determination of RBGM
T 3	Safety analysis
T 4	Collection of as built data
T 5	Preparation of SSSCL
T 6	Plant walk-down
T 7	Determination of seismic response of SSC
T 8	Capacity assessment of components
T 9	System model analysis
T 10	Capacity assessment of plant

Tasks for seismic re-evaluation (FBTR)



Tasks for seismic re-evaluation (FBTR)

T1 Preparation of criteria document

- **Objective**
  - Compilation of the criteria, requirements and methodology for seismic re-evaluation of FBTR in a manner consistent with current seismic safety criteria and internationally accepted practices.
- **Outcome**
  - Complete methodology, procedures and guidelines for conducting the seismic re-evaluation of FBTR.
- **Deliverables**
  - Document describing the criteria & methodology for seismic re-evaluation of the FBTR

Tasks for seismic re-evaluation (FBTR)

T2 Determination of RBGM Parameters

- **Objective**
  – Derivation of review basis ground motion (RBGM) parameters.
- **Outcome**
  – The RBGM parameters,
    - *peak ground acceleration (PGA),*
    - *response spectrum and*
    - *spectrum compatible time history.*
- **Deliverables**
  – Report on derivation of RBGM parameters.

Tasks for seismic re-evaluation (FBTR)

T3 safety analysis

- **Objective**
  - Postulation of seismically induced initiating events (IE).
  - Identification of frontline and related support systems that perform *Group-A & Group–B safety functions*.
- **Outcome**
  - IE and event tree
  - Frontline & support systems for performing Group-A & Group–B functions, and their fault trees.
- **Deliverables**
  - Initiating events, event tress and fault trees
  - Input for seismic structure, system and component list

Tasks for seismic re-evaluation (FBTR)

T4 Collection of 'as is' data

- **Objective**
  - Compilation of 'as is' information of the plant, its SSCs associated with Group-A & Group-B functions.
- **Outcome**
  - Engineering history of the plant
    - *This will help in identifying the safety chains and associated SSCs required for the safety evaluation.*
  - Target areas and strategy for the plant walk down
  - Screen out broad classes or group of components
- **Deliverables**
  - 'As-is' engineering information relevant to seismic re-evaluation of the plant.

Tasks for seismic re-evaluation (FBTR)

T5 Preparation of SSCL

- **Objective**
  - Identification of the SSC, associated with the frontline systems and support systems performing Group-A & Group-B safety functions. The list is also known as seismic structure, system and components list (SSSCL)
- **Outcome**
  - SSCL & its grouping
- **Deliverables**
  - Report on SSSCL

Tasks for seismic re-evaluation (FBTR)

T6 Plant walk down

- **Objective**
  - Capacity assessment of SSC based on experience based method (EBM) utilizing plant walk down.
- **Outcome**
  - Screen out components which satisfy the criteria of EBM
  - Input for determination of HCLPF capacity of screened out SSC
  - Failure modes of screened in components for further investigation
  - SSC and spatial interaction items needing further evaluation.
- **Deliverables**
  - Screening Evaluation Work Sheets (SEWS)
  - Outlier Seismic Evaluation Sheets (OSES)
  - Screening Verification Data Sheets (SVDS)
  - Equipment Seismic Evaluation Report (ESER)
  - Easy fixes

Tasks for seismic re-evaluation (FBTR)

T7 Seismic response of SSC

- **Objective**
  - Seismic response analysis of SSC against RBGM.
- **Outcome**
  - Seismic response of buildings, pipelines, cable trays, control panels and other mechanical & electrical equipment and components.
  - Input for seismic capacity assessment.
  - Floor response spectra for evaluation of SSCs either by analysis, or testing, or EBM.
- **Deliverables**
  - Report on determination of seismic response of the SSSCs

Tasks for seismic re-evaluation (FBTR)

T8 Capacity assessment of components

- **Objective**
  - Derivation of fragility curve of component and HCLPF capacity assessment
- **Outcome**
  - Seismic capacity of components.
    - *HCLPF capacity for SMA of plant.*
    - *Fragility curves for evaluation of plant S-CDF*
- **Deliverables**
  - Consolidated list of SSSCs and corresponding capacity assessment methodology,
  - HCLPF capacity of components, and
  - Component fragility curves.

Tasks for seismic re-evaluation (FBTR)

T9 System model analysis

- **Objective**
  - Finalization of event trees and fault trees based on outcome of plant walk down, component capacity and incorporating human error appropriately.
- **Outcome**
  - Boolean expressions of front-line system failures
  - Boolean expressions of seismic induced core-melt accident sequences
- **Deliverables**
  - Final fault trees for frontline systems (incorporating support systems) and Boolean expression.
  - Event trees and accident sequences of seismically induced core-melt of each IE & Boolean expression.

Tasks for seismic re-evaluation (FBTR)

T10 Capacity assessment of plant

- **Objective**
  - Determination of overall seismic capacity of the plant in terms of HCLPF capacity and plant fragility for evaluation of SM and SCDF respectively.
- **Outcome**
  - Plant HCLPF capacity plant from SMA
  - Plant fragility curve and SCDF from SPSA.
- **Deliverables**
  - Plant HCLPF capacity, plant fragility and SCDF
  - Major seismic risk contributors to the plant

Review basis ground motion parameter

- Objective of seismic re-evaluation of existing NPP is to review the seismic capability of the plant to perform **Group A** functions (*safe shutdown, maintaining at safe shutdown condition and decay heat removal*) as well as **Group B** function (*containment/confinement of radio activity*).
- This review exercise is accomplished with respect to the ground motion level, termed as review basis ground motion (RBGM) or review level earthquake (REL)

Review basis ground motion parameter

- RBGM or RLE are defined by following parameters
  - Response spectra

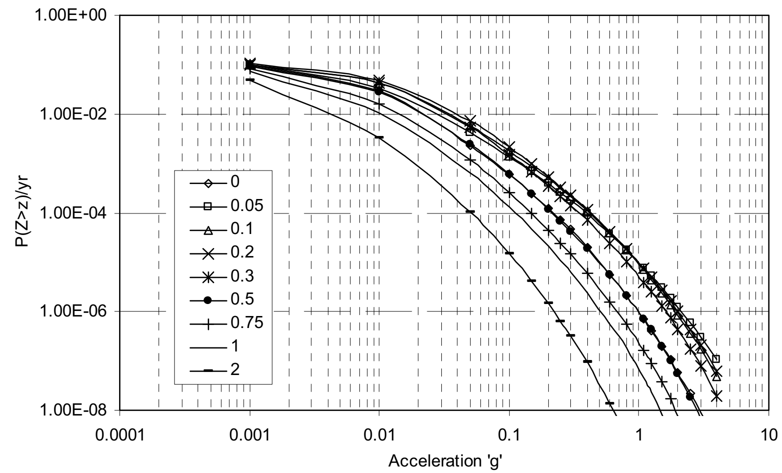
    Peak ground acceleration (PGA)

    Spectral shape
  - Spectrum compatible time history
- RBGM parameters are derived by seismic hazard analysis of site either by
  - deterministic approach

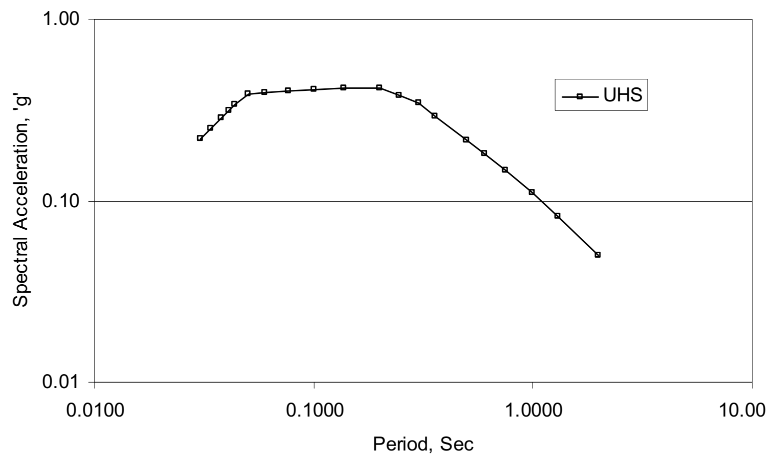
    or
  - probabilistic approach

Review basis ground motion parameter (Kalpakkam site)

– Seismic hazard curve of the site was evaluated by probabilistic seismic hazard analysis (PSHA).
– RBGM parameters were defined by
  * *PGA,*
  * *response spectral shape*
  * *spectrum compatible time history.*
– Response spectra were derived for uniform hazard.

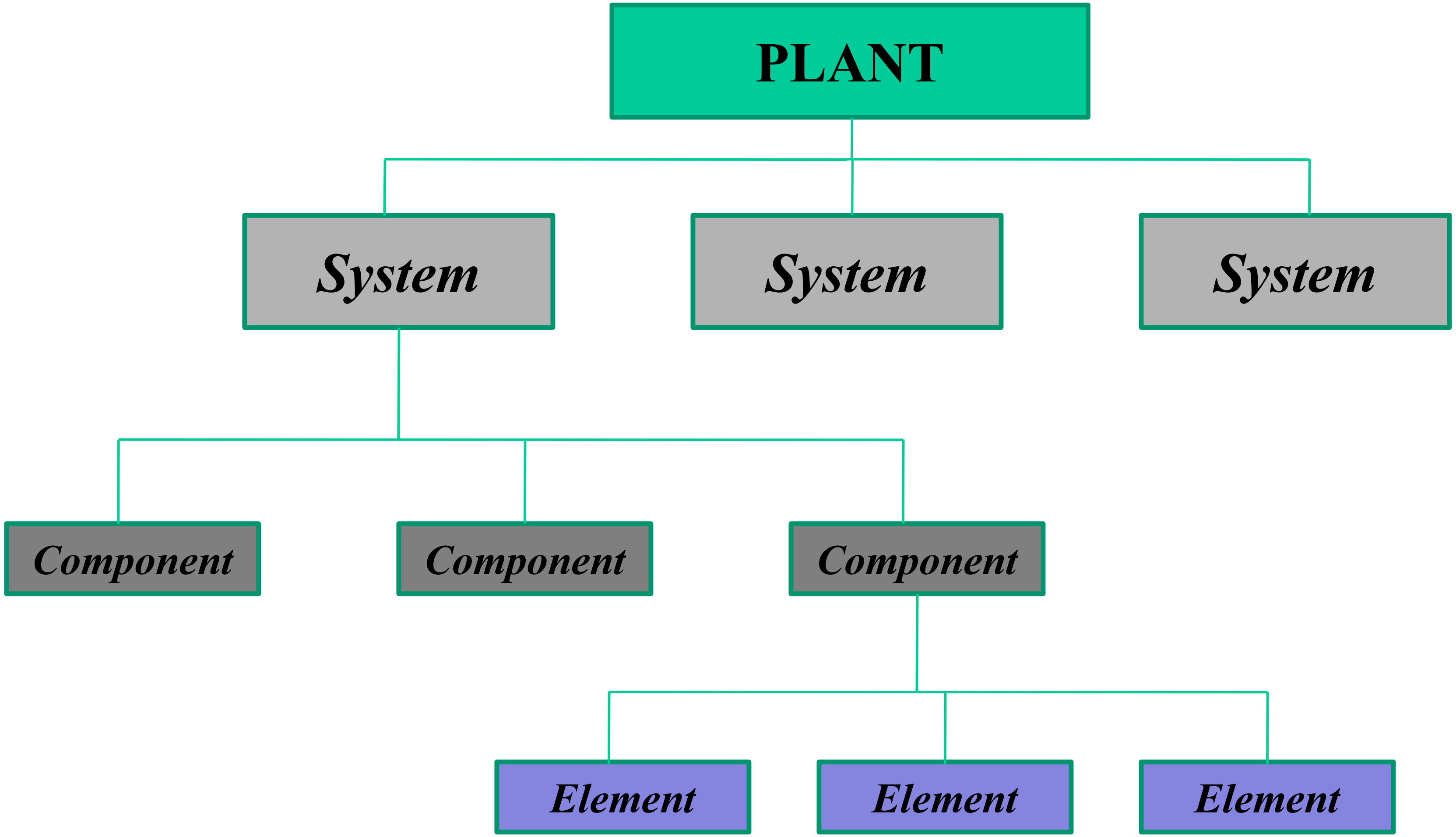


Hazard curves corresponding to different spectral periods.



Uniform hazard spectra generated for Kalpakkam site, (Damping = 5%).

Seismic structure system component list (SSSCL)



Not all SSC(s) are examined for seismic re-evaluation of NPP

Seismic structure system component list

Steps to prepare SSCL

- Postulation of initiating events triggered by earthquake
- Establishment of accident sequence originated by each initiating event by fault tree analysis: ***identification of frontline system along with support system***
- Fault tree analysis for *Top Event (*failure*) of* frontline as well as suppport systems: ***identification of components***

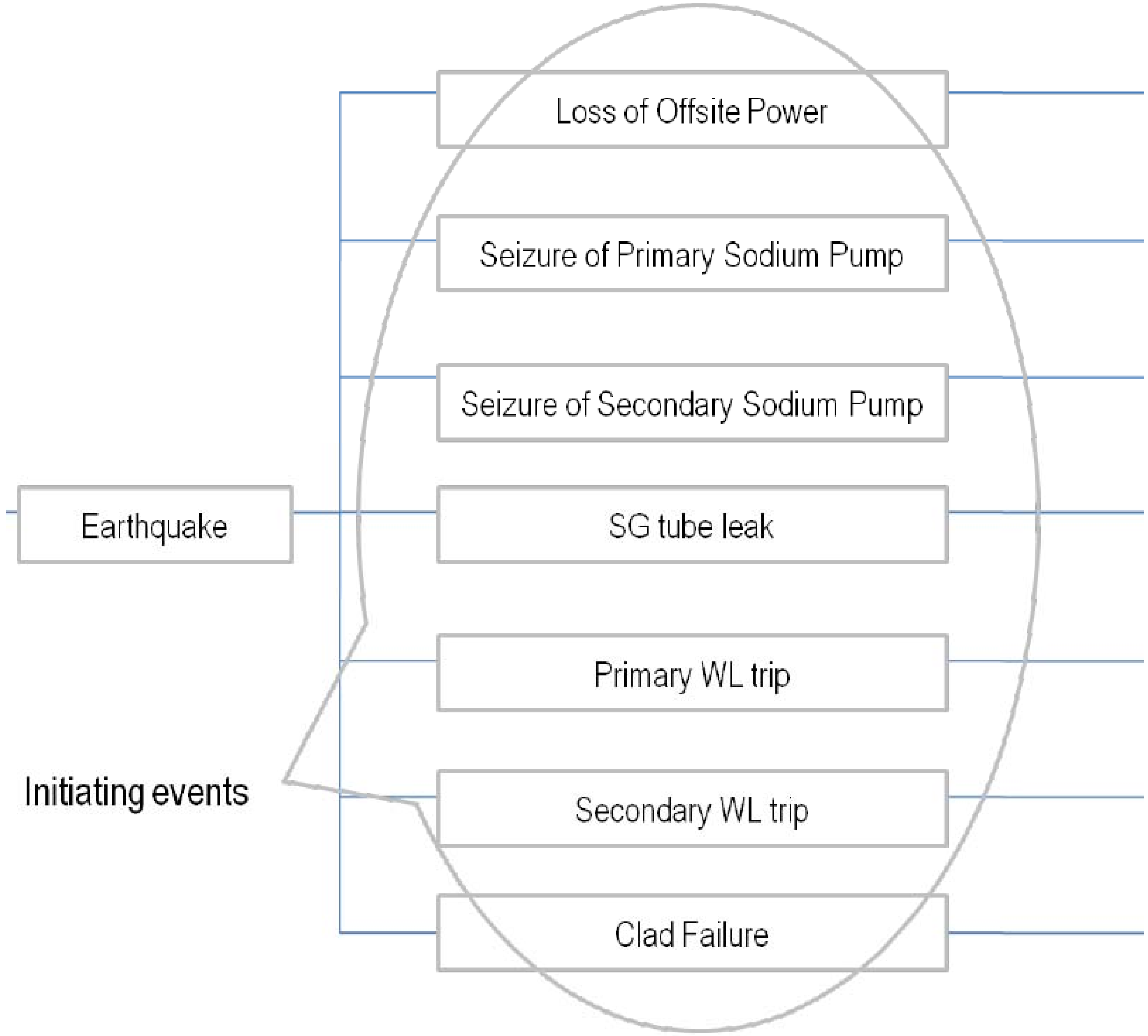
Seismic structure system component list

Initiating Events

- Two approaches for postulating initiating events (IE) for seismic PSA
  - Earthquake itself is the initiating event
  - Earthquake induced ***failure of a basic component or system*** that originates plant transients resulting to propagation of accident scenario and leading to core damage, or breach of containment/confinement function
- Second approach was adopted for postulating initiating events for FBTR seismic re-evaluation. The IE is characterized by either **HCLPF value** (for SMA) or by **fragility parameters** (for SPSA).

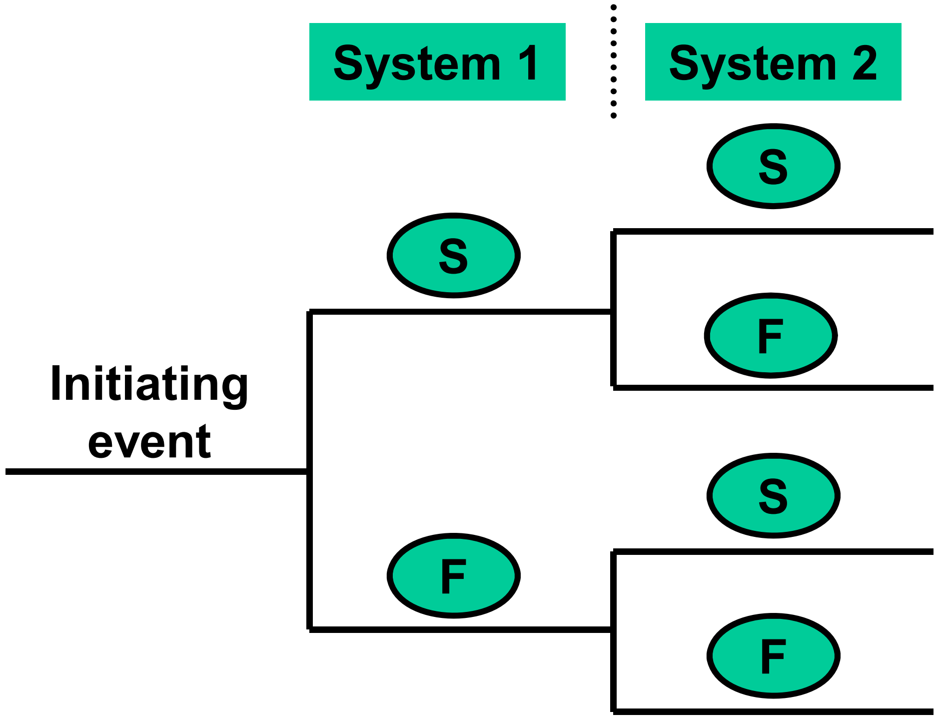
Seismic structure system component list

Initiating events (FBTR)



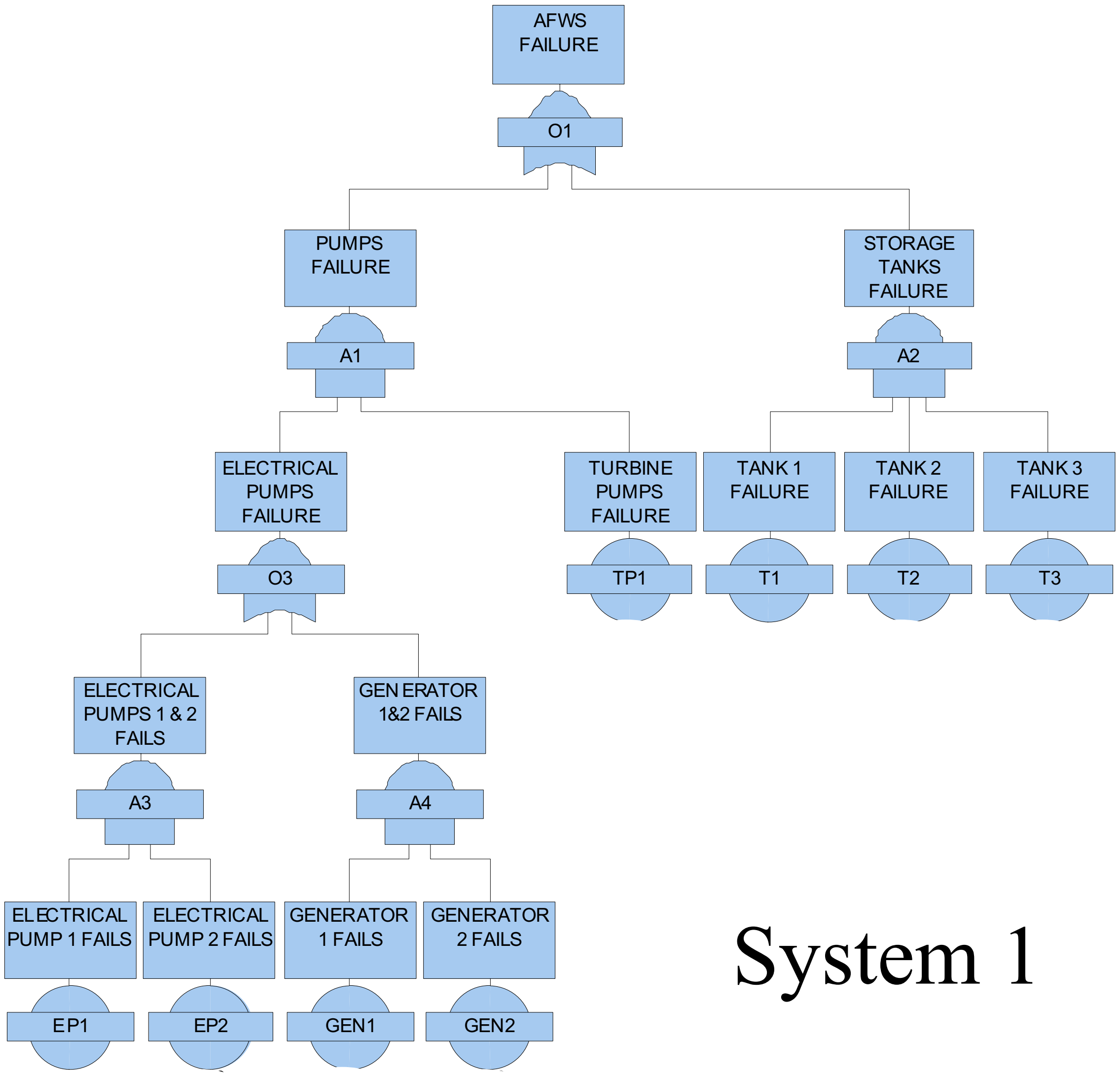
Seismic structure system component list

Event tree



Seismic structure system component list

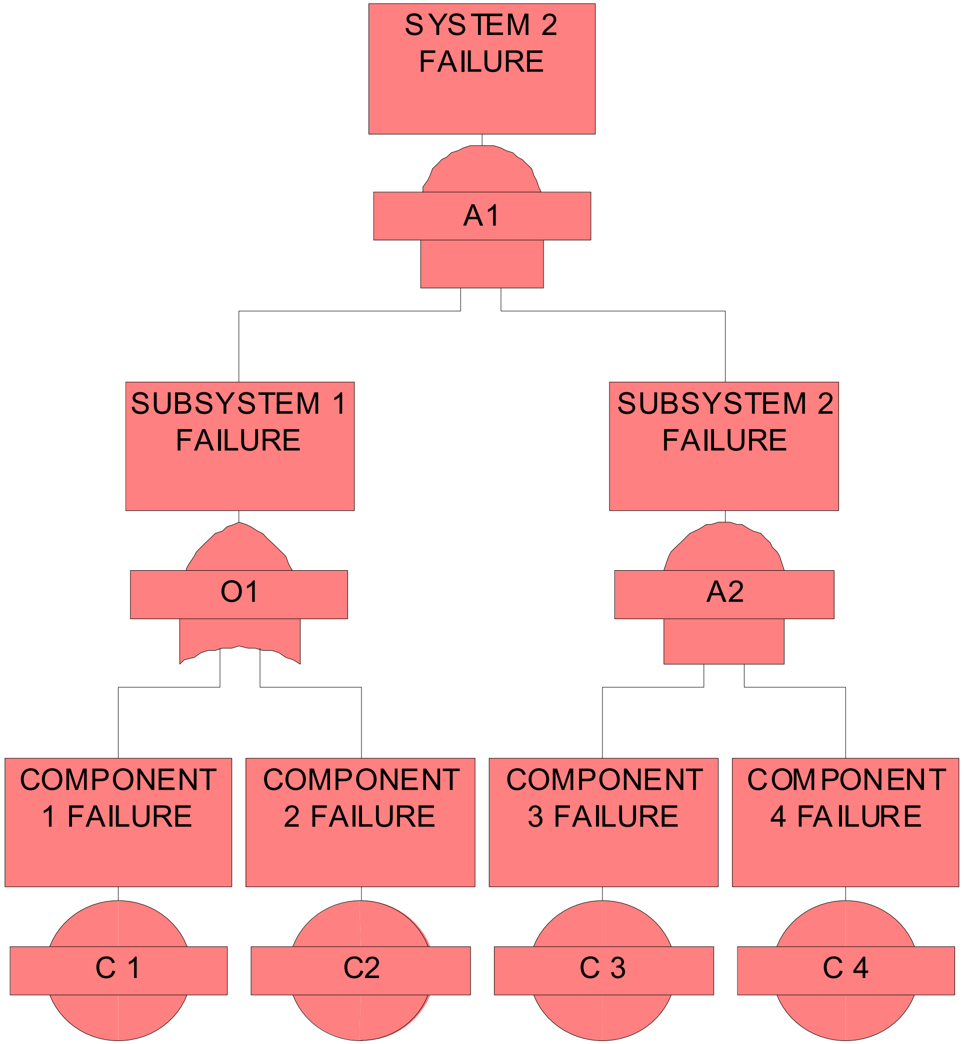
Fault tree of system



System 1

Seismic structure system component list

Fault tree of system



Seismic structure system component list (FBTR)

- **Systems to be qualified**
  - Primary sodium system
  - Secondary sodium system
  - Pre-heating and emergency cooling system
  - Service Water system
  - Diesel generator system
  - RCB AC&V system

- **Buildings to be qualified**
  - Reactor containment building
  - Steam generator building
  - Service building
  - Control building
  - Cooling tower

Component capacity

- Seismic capacity of component corresponds to the earthquake level at which it is extremely unlikely that failure of the component will occur.
- Expressed in terms of the earthquake level that compromises safety of component. The measure of capacity is the so-called **"High Confidence, Low Probability of Failure"** capacity, or "HCLPF capacity".
- Mathematically, the "HCLPF capacity" values are approximately equal to a 95% confidence (probability) of not exceeding about a 5% probability of failure.

Component capacity

- Seismic capacity of components is determined by
  - Direct approach
    - Analysis
    - Testing
  - Indirect approach
    - Experience based approach (plant walk down)
- Two methods to determine seismic capacity of components
  - Deterministic method
    - Conservative deterministic failure margin **(CDFM)** method (***direct***)
  - Probabilistic method
    - Fragility analysis **(FA)** method ***(direct & indirect)***

Component capacity

CDFM method

- CDFM method
  - A set of deterministic rules
  - Obtain a conservative yet realistic assessment of capacity
  - Capacity derived based on these guidelines is an estimate of HCLPF capacity,

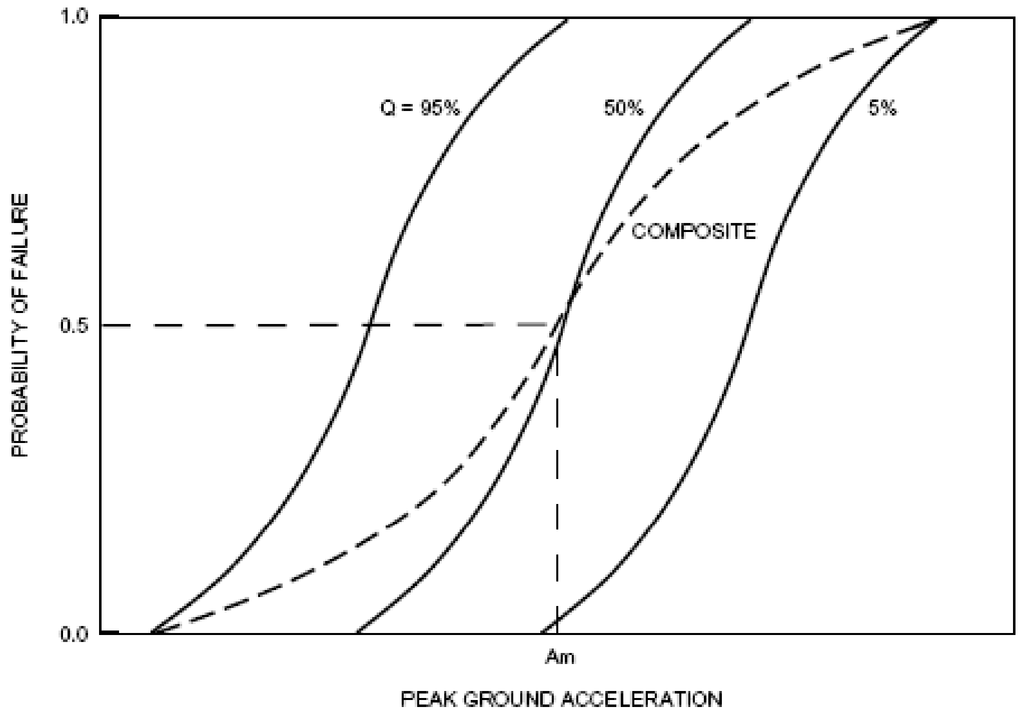
$$A_{c\text{-}HCLPF} = F_S \, x \, A_{RBGM}$$

$$F_S = \frac{S - R_N}{R_T - R_N}$$

S = Seismic capacity; R_T = Total demand;
R_N = Concurrent non-seismic demand

Component capacity
FA method

Seismic fragility is the conditional probability of failure for a given value of seismic input parameter e.g.. peak ground acceleration (PGA).



$$P_f = \Phi\left(\frac{\ln\left(\frac{a}{A_m}\right) + \beta_U \Phi^{-1}(Q)}{\beta_R}\right)$$

Composite fragility

$$P_f = \varphi\,[\ln(a/A_m)/\beta_c]$$

$$\beta_c = (\beta_R^{\,2} + \beta_u^{\,2})^{0.5}$$

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Component capacity

FA method

- Demand: PGA '*a*'
- Capacity: ground acceleration capacity, A:

$$A = A_m .\ \varepsilon_R .\ \varepsilon_U$$

- Three parameters
  - –Median ground acceleration capacity, $\mathbf{A_m}$, and
  - –Two random variables ε_R and ε_U .

    ε_R and ε_U are log-normally distributed random variables, with a unit median and logarithmic standard deviation $\boldsymbol{\beta_R}$ (epistemic or inherent randomness about the median), $\boldsymbol{\beta_U}$ (aleatory uncertainty in estimating the A_m)
  - - $\boldsymbol{\beta_C}$**:** Composite logarithmic standard deviation.

Component capacity

FA method

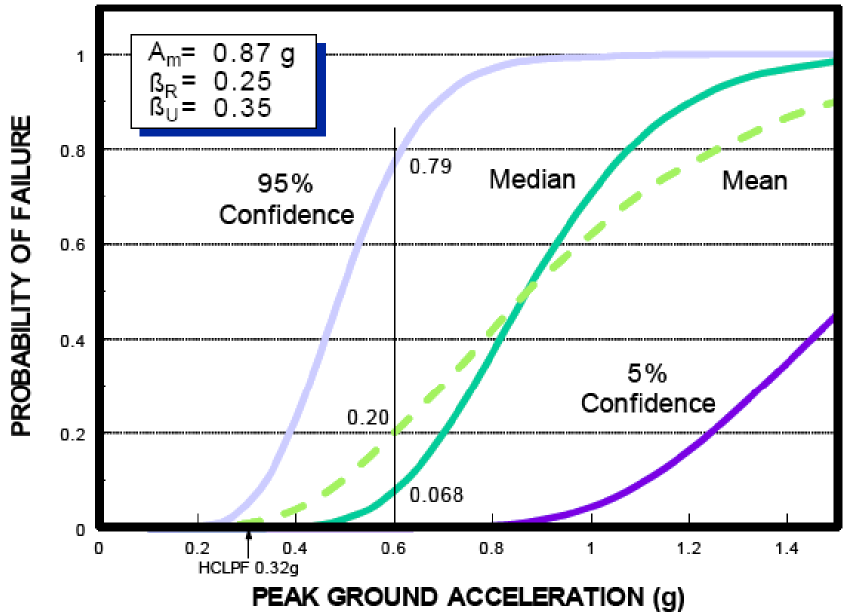
$$A_m = A_{RBGM} * F', \quad F' = F_1' * F_2' * F_3'$$

- F_1: factor representing ratio of capacity and demand
- F_2: factor representing conservatism in assessing capacity
- F3: factor representing conservatism in assessing demand (structural response factor)

Component capacity

FA method

- High confidence low probability failure (HCLPF) capacity is the PGA corresponding to
  - 5% P_f with 95% confidence level.
  - 1% P_f from composite fragility curve



- Fragility from HCLPF value:

Component capacity

FA method

- Relation between A_m and A_{HCLPF}

$$A_m = A_{HCLPF} * e^{-1.645[\beta_R + \beta_u]} ;$$

$$A_m = A_{HCLPF} * e^{-2.33\beta_c}$$

- Relation between $A_{c\text{-}HCLPF}$ and A_{HCLPF}

$$A_{c\text{-}HCLPF} = A_{HCLPF} * e^{-\beta_{rs}}$$

Where, β_{rs} is the combined logarithmic standard deviation for horizontal component response spectrum variable; it's typical value is about 0.3

Component capacity

***FA method*: by analysis**

$$F_1 = F_S = \frac{S - R_N}{R_T - R_N}$$

S = Seismic capacity; R_T = Total demand;
R_N = Concurrent non-seismic demand

$$F_2 = F_\mu$$

$$F_3 = F_R$$

Component capacity

***FA method*: by analysis**

$$F_\mu = \left(\sqrt{2\mu - 1}\right) \in$$

Amplified region of response spectrum (2 to 8 Hz)

$$F_\mu = \mu^{0.13} \in$$

Rigid equipment

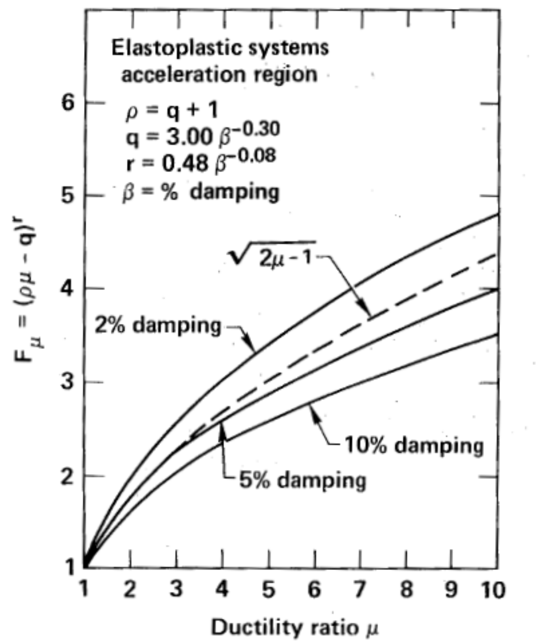
$$F_\mu = (\rho\mu - q)^r$$

Where

$\rho = q + 1$; $q = 3.00\ \delta^{-0.30}$

$r = 0.48\ \delta^{-0.08}$

and δ is the % of damping



Component capacity
FA method: by analysis

$$\overline{F}_R = \overline{F}_{RS} = \overline{F}_{SA} * \overline{F}_{SS} * \overline{F}_{\delta} * \overline{F}_M * \overline{F}_{MC} * \overline{F}_{EC} * \overline{F}_{SD}$$

Civil

F_{SA}: **Factor for ground motion and associated response spectra for a given PGA.**

F_{SS}: **Soil structure interaction factor.**

F_{δ}: **Factor energy dissipation i.e. damping.**

F_M: **Structural modeling factor.**

F_{MC}: **Factor for combination of modes and earthquake analysis results.**

F_{EC}: **Factor for combination of earthquake components**

F_{SD}: **Factor to reflect the reduction of seismic input with depth**

Component capacity

***FA method*: by analysis**

$$\overline{F}_R = \overline{F}_{RE} * \overline{F}_{RS}$$

Mechanical

$$\overline{F}_{RE} = \overline{F}_{QM} * \overline{F}_{SA} * \overline{F}_{M} * \overline{F}_{\delta} * \overline{F}_{MC} * \overline{F}_{EC}$$

$$\overline{F}_{RS} = \overline{F}_{SA} * \overline{F}_{\delta} * \overline{F}_{M} * \overline{F}_{SS}$$

F_{SA} : *Factor associated with the floor spectra used for analysis*

F_{QM} : *Factor used with qualification method*

Component capacity

***FA method*: by analysis**

- Values of median response factors $\bar{F}_{(.)}$ and logarithmic standard deviations are available in literature.

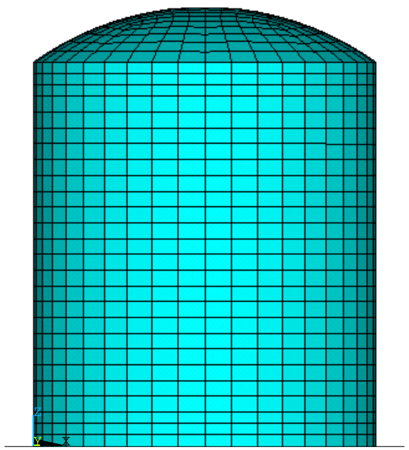
$$\bar{F}_{(RS)} = \prod F_{(.)}$$

$$\beta_{u,R} = \left[\sum \beta_{u(.)}{}^{2}\right]^{1/2}$$

Component capacity

FA method: by analysis

Loc. No	Description	*Induced moment (kN.m)*	*Mom. capacity (kN.m)*	$F_S = F_1$
1	*Raft wall junction*	8.71×10^6	16.90×10^6	1.94
2	*Top of thickened portion*	7.81×10^6	16.10×10^6	2.06
3	*Containment wall EL 100m*	6.13×10^6	12.29×10^6	2.01



$A_{RBGM} = 0.2g$

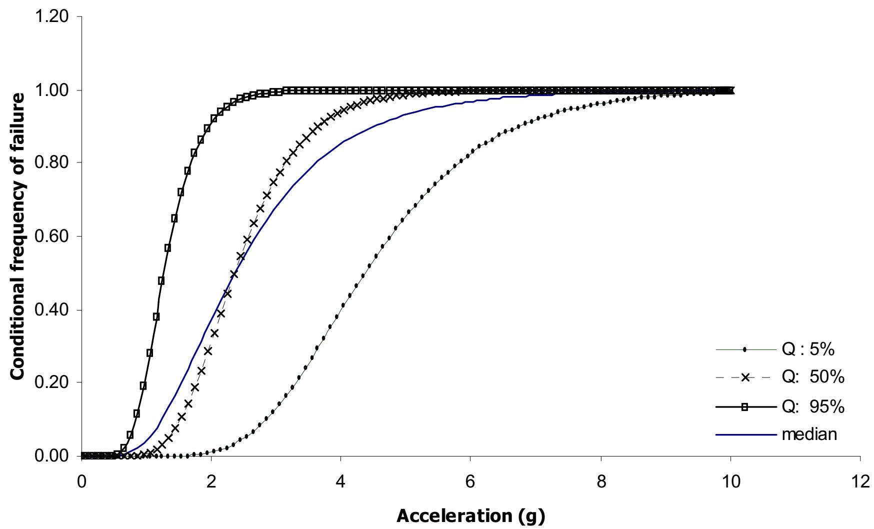
Factors	*Median value*
F_{SA}	1.25
F_{δ}	1.25
F_M	1.0
F_{MC}	1.0
F_E	1.0
F_{SD}	1.0
F_{SS}	1.3
$\boldsymbol{F_3 = F_{RS}}$	***2.03***

Component capacity

***FA method*: by analysis**

Loc. No.	$F_1 = F_s$	$F_2 = F_\mu$	$F_3 = F_{RS}$	F	A_m
1	1.94	3.0	2.03	11.82	2.36g
2	2.06	3.0	2.03	12.55	2.51g
3	2.01	3.0	2.03	12.21	2.44g

Factors	$\beta_{(.)U}$	$\beta_{(.)R}$
F_S	0.15	0.10
F_μ	0.20	0.08
F_{SA}	0.10	0.20
F_δ	0.075	0.075
F_M	0.15	0.00
F_{MC}	0.00	0.075
F_{EC}	0.00	0.075
F_{SS}	0.20	0.20
Combined value	*0.375*	*0.337*

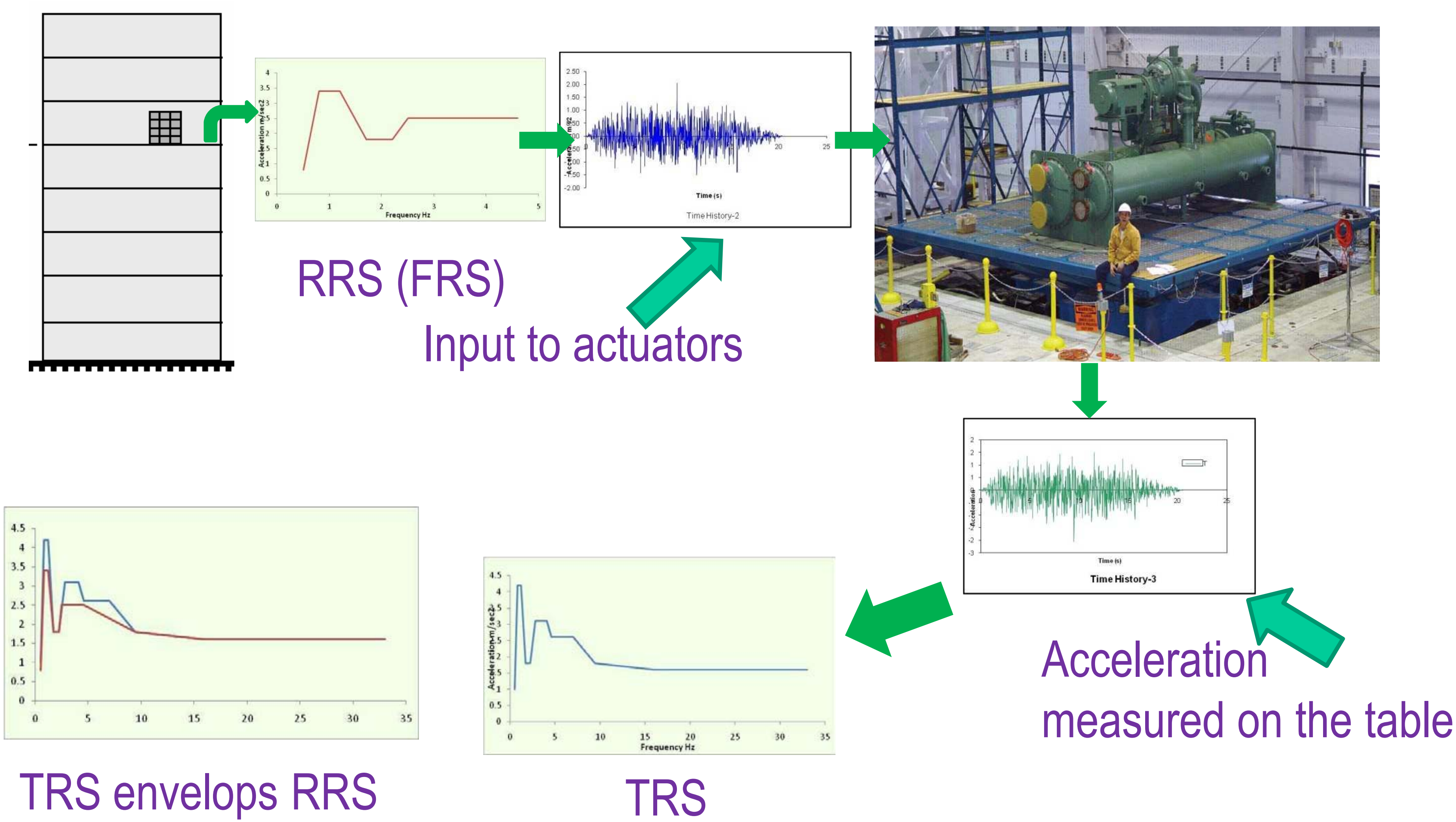


Component capacity
***FA method*: by test**

- Test Response Spectrum
  - Is the motion experienced by the component being tested.
  - It is measured using the instrumentation available in the shake table
  - The response spectrum corresponding to this motion is called the Test response spectrum (TRS).
- Required Response Spectrum
  - Specifies requirements to be met.
  - RRS could be specified by the FRS at the location where the component, when a site specific test is being carried out or a general spectrum like the performance level spectrum provided in IEEE 693 for a generic test.

Component capacity

***FA method*: by test**



Component capacity

***FA method*: by test**

$$F' = F_1' * F_2' * F_3'$$

F_1 *is the factor representing ratio of capacity and demand*

$$F_1 = \alpha . \tau$$

F_2 *is the factor representing the conservatism that is judged to exist in the TRS based on the testing methods used*

F_3 represents the structure response factor

Component capacity

***FA method*: by test**

$$\tau = \frac{TRS}{RRS}$$

$$\alpha = \frac{C_T C_I}{C_C D_R}$$

Cabinet based test

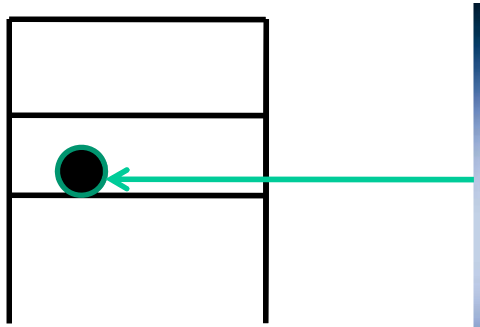
$$\alpha = \frac{C_T C_I}{C_C \dfrac{AF_C}{F_{MS}} D_R}$$

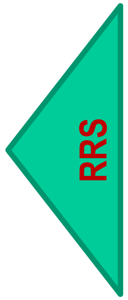
Device based test

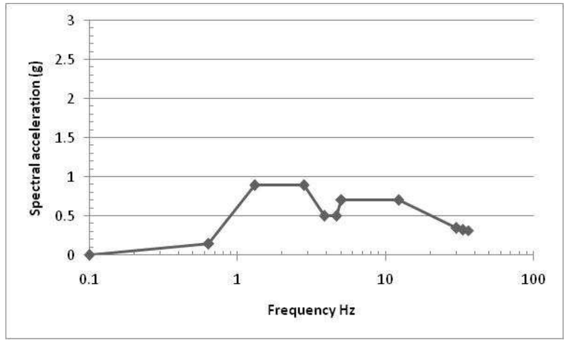
C_C	Clipping factor for narrow banded demand
C_T	Clipping factor for narrow banded TRS
C_I	Capacity increase factor
D_R	Demand reduction factor
AF_C	Cabinet amplification factor
F_{MS}	Multi axis to Single axis conversion factor

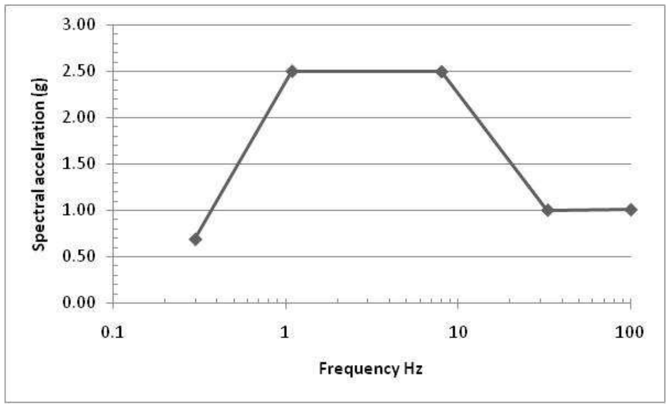
Component capacity

***FA method*: by test**









- MCC located in first floor, demand given by FRS derived from 3 time histories. PGA of site = 0.2g
- Natural frequency of MCC is approximately 10 Hz.
- Similar MCC qualified by shake table testing for IEEE 693 performance level high spectrum anchored to a PGA of 1.0g .

Component capacity

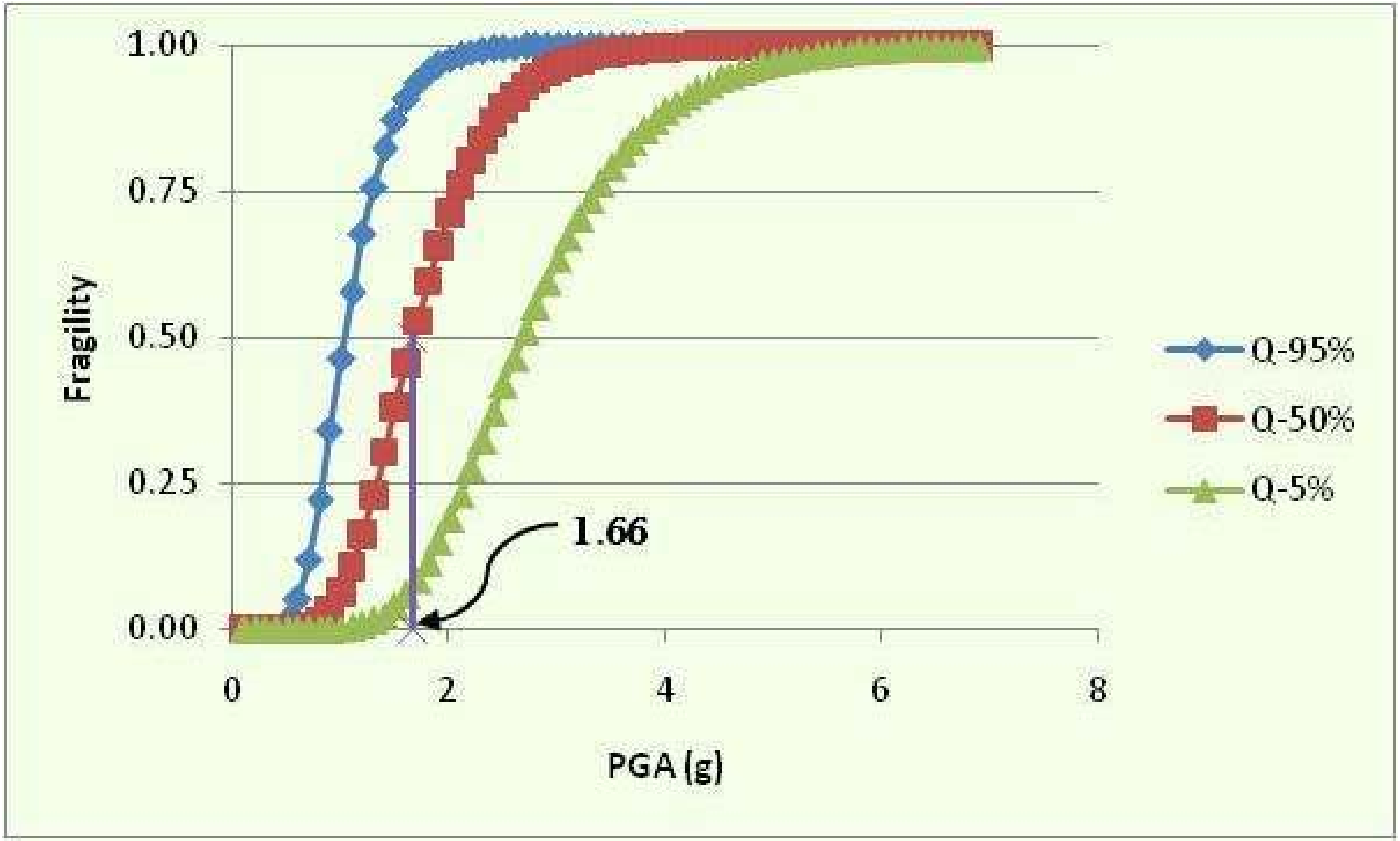
FA method: by test

Factor	*Peak Value*
TRS	2.5g
RRS	0.705g
α	**3.55**
C_I	1.1
C_C	1.0
C_T	1.0
D_R	1.0
τ	**1.1**

Factor	*Median*	β_R	β_U
$F_1 = \alpha . \tau$	**3.905**	**0**	**0**
F_2	**1.40**	**0.22**	**0.09**
$F_3 = F_{RS}$	**1.67**	**0.24**	**0.27**
F	**9.13**	**0.33**	**0.29**
A_m	***1.66g***	***0.33***	***0.29***

Component capacity

***FA method*: by test**



Component capacity

***FA method*: by EBM**

$$F' = F_1' * F_2' * F_3'$$

F_1 is the factor representing ratio of capacity and demand

$$F_1 = \alpha . \tau$$

α is generally taken as unity

τ is the ratio of the ground motion level at which the component ceases to perform its intended function to the experience data capacity spectrum (Reference spectrum or GERS)

$\mathbf{F_2}$ is factor representing conservatism in capacity specrum

$\mathbf{F_3}$ represents the structure response factor

Component capacity

***FA method*: by EBM**

$$\tau = \frac{SCS}{SDS}$$

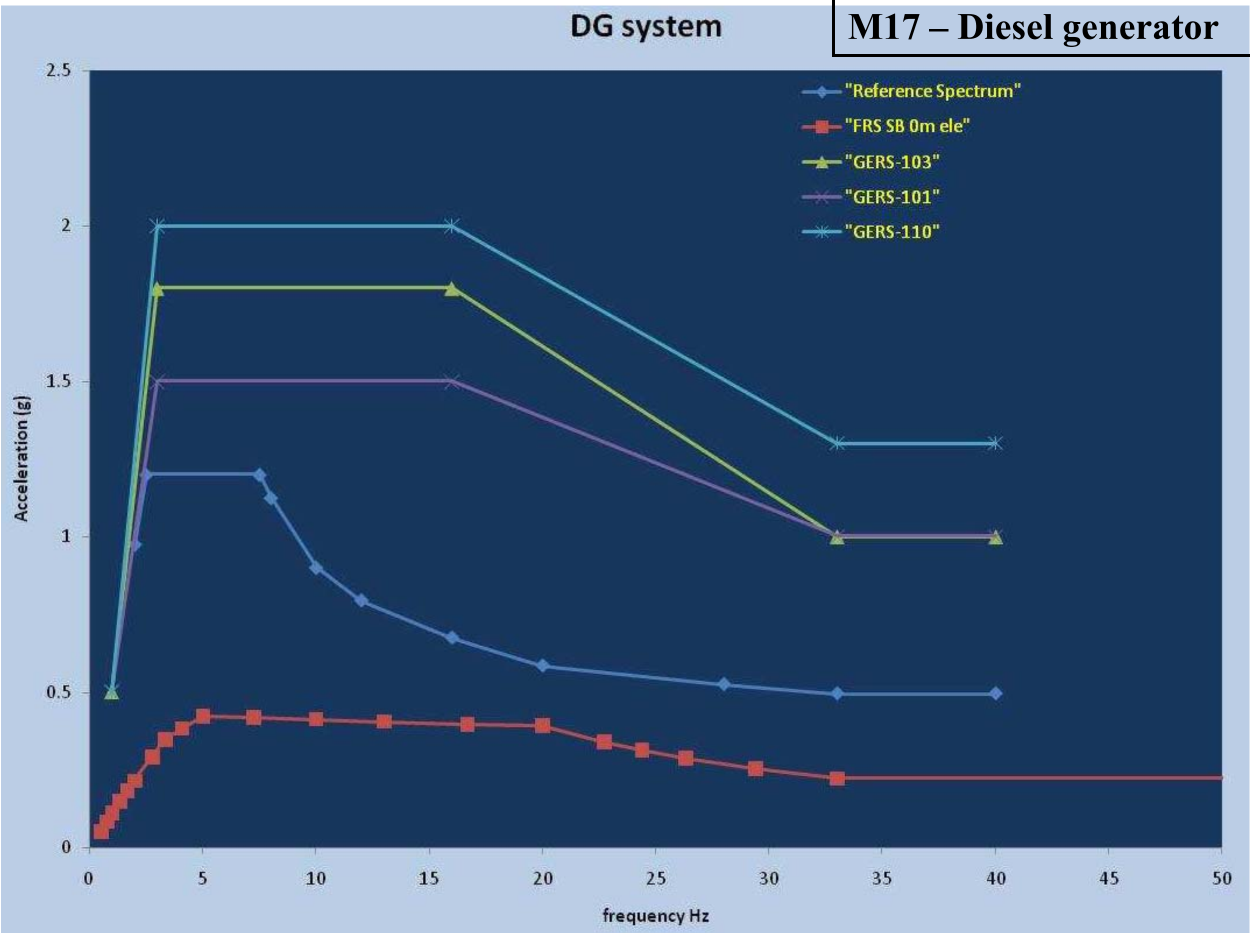
- SCS: Seismic capacity spectrum,
  - Reference spectrum or GERS
- SDS: Seismic demand spectrum
  - Floor response spectrum

Spectrum used to define capacity	F_2	β_C
Reference spectrum	2.35	0.30-0.60
GERS (Non-relay)	1.49	0.25
GERS (relay)	1.07	0.20

Component capacity

***FA method*: by EBM**

Equip class & description	Demand	Capacity
E8 – I &C panels	FRS – SB 0m el.	RS
E3 – LVSG	FRS – SB 0m el.	GERS 103
E2 – MCC	FRS – SB, TB 0m el	GERS 101
E7 – Battery chargers	FRS – SB 0m el	GERS 110
M13 – Diesel transfer pump	FRS – SB 0m el	RS
M17 – Diesel generator	FRS – SB 0m el	RS

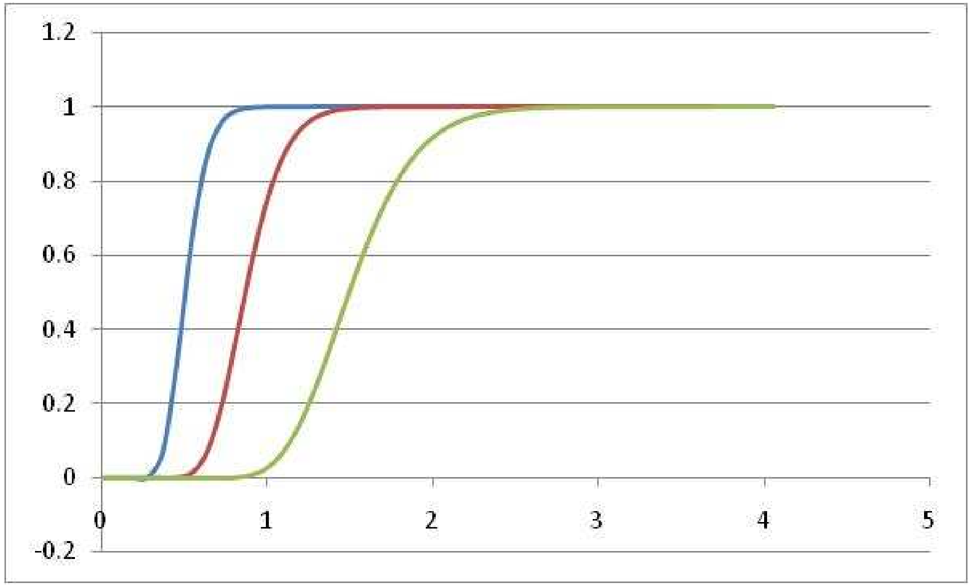


Component capacity

***FA method*: by EBM**

Component	**SCS**	**SDS**	$\mathbf{F_1}$	$\mathbf{F_2}$	F_3	F	$\boldsymbol{\beta_R}$	$\boldsymbol{\beta_{\underline{U}}}$
Diesel Generator	0.5g	0.21g	2.38	2.35	1.28	7.16	0.41	0.46

Am	1.5g
βr	0.41
βu	0.46



Thanks

Question please