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International Centre for Theoretical Physics

United Nations
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IAEA
International Atomic Energy Agency

2016-14

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

30 November - 4 December, 2009

Pre-Earthquake Planning and Post-Earthquake Actions for Nuclear Power Plants: Status Report Report

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ICTP/IAEA Advanced Workshop on Earthquake Engineering for Nuclear Facilities
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Pre-Earthquake Planning and Post-Earthquake Actions for Nuclear Power Plants: Status Report

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Agenda

- Background
- Regulatory and Industry Needs
- Intent of Safety Report
- Assumptions for Program Development
- Development and Review Process
- Pre-Earthquake Planning
- Post-Earthquake Actions
- Next steps

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Pre-Earthquake Planning and Post-Earthquake Actions for Nuclear Power Plants

- Developed as part of IAEA Extrabudgetary Project on Seismic Safety of Existing NPPs
- Drafts by IAEA personnel, TEPCO, and consultants
- Reviewed by 44 institutions, 16 Steering Committee Members, IAEA staff
- To be published as IAEA Safety Report (1st Q – 2010)

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Background

- **Efforts of IAEA for Seismic Safety of NPP**
  - Development of safety standards - seismic design, seismic evaluation of existing NPP, seismic hazard evaluation,....
  - Safety review services to MS (e.g., Japan, Armenia)
- **Recent Earthquake Experience**
  - Strong earthquake experiences in Japan (Onagawa, Shika, Kashiwazaki-Kariwa, Hamaoka)
  - No significant damage to SSCs related to safety
  - Extensive time spent performing evaluations prior to restart after an earthquake – may not have been necessary or desirable (State, Public, Licensee)

⇩

Needs for Standardization of Pre-Planning and Post-Earthquake Actions

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Regulatory and Industry Needs

- Standardized approach to address earthquake effects on nuclear power plants
- Nuclear safety is primary objective
- Address issues related to earthquake ground motions greater than the SL-2 (S2, SSE,)
  - Japan – Onagawa, Shika, Kashiwazaki-Kariwa
  - US - Perry, V. C. Summer
  - Slovenia – Krsko
- Perform realistic evaluations to determine actions to be taken
- Decision criteria for restart to be based on reasonable criteria – restart to be permitted as evaluations are complete and safety is assured

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Earthquake Experience at NPPs

Nuclear Power Plant	Earthquake	Average Time to Restart
Kashiwazaki-Kariwa	NCOE (2007)	Units 6 (25 mos.) Unit 7 (22 mos.)
Shika	Noto Hantou (2007)	Unit 2 (1 yr.) Unit 1 (1 yr. + due to other than earthquake factors)
Onagawa	Miyagi Offshore (2005)	Unit 1 (11 mos.) Unit 2 (5 mos.) Unit 3 (7 mos.)
Medsamor	Spitak (1988)	*
Perry	Leroy (1986)	Pre-operational stage
V.C. Summer	Reservoir Induced Seismicity (1977-1979)	Not shutdown

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Intent of Safety Report

- Given an Earthquake Occurs and Ground Motion is Felt at NPP - Assure Safe Operations of Nuclear Power Plants
  - ✓ Nuclear Safety is top priority
- Provide Detailed Guidance for MS Consideration
  - ✓ Rational, experience-based approach for determining real damage potential of EQ
  - ✓ Systematic methodology for assessing plant readiness for restart
  - ✓ Realistic criteria for assuring long term integrity of plant

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Basic Strategy of the SR

Combined Existing Standards and Recent Experience

New SR

Existing Standards

- ✓IAEA Safety Series
- ✓USA EPRI NP-6695

etc.

Earthquake Experience

- ✓Earthquake Level
- ✓Actual results of Post-Earthquake Actions

etc.

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Basic Concept of new SR

Important considerations to do the Post-Earthquake Actions smoothly are …

Means to grasp the SSCs conditions

- ✓**Methods to detect the change of SSCs conditions**
- ✓**Acceptance criteria**

Means to grasp the seismic motion size

- ✓**Seismic instrumentation**

Decision making for plant restart

- ✓**Actions for restart**

Post- Earthquake Action Programme

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Assumptions for Programme Development

- Programme will be documented as a IAEA Safety Series Report
- Adopt the substance of EPRI NP-6695 (Dec 1989) for earthquake ground motions less than the SL-2 – internationalize the approach
- Apply existing standards and approaches
  - IAEA Safety Guides
  - US NRC
    - Regulatory Guides 1.12, 1.166, 1.167
    - Standard Review Plan
    - Interim Staff Guidance
  - EPRI NP-6695

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Assumptions for Programme Development

- Apply experience gained by regulators and licensees addressing issues of earthquake ground motion at NPP sites due to earthquakes of all sizes
- Safety Report Appendix II summarizes in detail - Individual tables of actions from earthquake – shutdown, evaluation, inspection results, restart conditions, etc. – including time required,....)
  - Onagawa (2005)
  - Shika (2007)
  - Kashiwazaki-Kariwa (2007)
  - Medsamor (1988)
  - Other NPP experience by reference
    - Perry (1986)
    - Virgil Summer (1978-79)
    - Krsko

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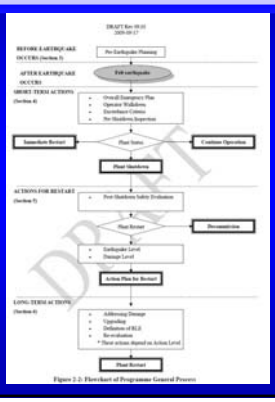
Flowchart of Programme General Process



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Expansion Beyond Existing Guidelines

- Emphasis on Role of Regulatory Body
  - All activities related to safety – approval or concurrence of Regulatory Body
- Methodology Applies to New and Existing NPPs
  - Pre-Planning for New
- Strong Emphasis on Damage Indicating Parameters as Basis for Decision-Making
  - Cumulative Absolute Velocity (CAV), JMA Intensity, others
  - Rather than acceleration parameters (now and in future)

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Expansion Beyond Existing Guidelines

- Example Timing for Immediate Actions after Earthquake
  - Decision-making within 24 hrs
  - All other activities within 8 hrs
- Felt vs. Significant Earthquake
  - Regulatory Body determines Felt vs. Significant and Actions Required
  - Principle – no actions required for earthquakes denoted non-significant

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Expansion Beyond Existing Guidelines

- Action Levels defined as a Function of Damage Level observed and Earthquake Level
- Action Levels updated as a function of results
- Earthquake Level 1: EQ < SL-1
- Earthquake Level 2: SL-1 < or = EQ < or = SL-2
- Earthquake Level 3: EQ > SL-2
  - 3a – High frequency (> 10 Hz)
  - 3b - Mid-amplified (2 – 10 Hz)
  - 3c – Low frequency (< 2 Hz)
- Earthquake Levels 3a – 3c determine different action levels

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Expansion Beyond Existing Guidelines

- Damage Level 1 – No damage to ITS and NITS SSCs
- Damage Level 2 – No damage to ITS SSCs. Damage to NITS SSCs not required for power generation (NRPG).
- Damage Level 3 – No damage to ITS SSCs. Damage to NITS SSCs required for power generation (RPG).
- Damage Level 4 – Damage to ITS and NITS SSCs.
- Damage = Significant Damage per definitions

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Pre-Earthquake Planning – Action Levels

Define the *"Action Level"* which defines actions to be taken after an earthquake

- Defined according to combinations of Earthquake Level and Damage Level
- Classified to 8 levels (Action Level 1 to 8) with sub-categories for Earthquake Levels 3a, 3b, 3c
- Discriminate the actions which should be done before or after restart

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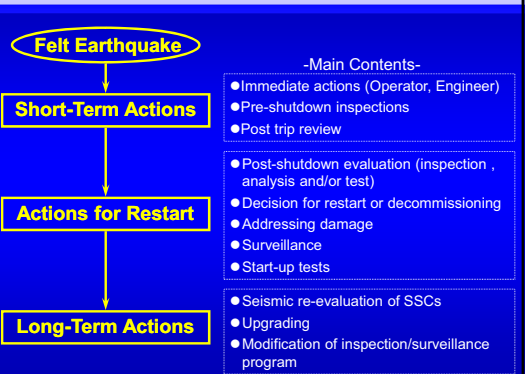
Basic Concept of New SR



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Pre-Earthquake Planning and Post-Earthquake Actions for Nuclear Power Plants

- Pre-Earthquake Planning
- Post – Earthquake Actions
  - Immediate (e.g., within 8 or 24 hrs)
- Post – Earthquake Actions – Short Term
- Post – Earthquake Actions – Long Term

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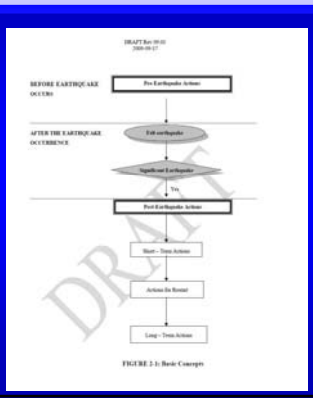
Overall Flow Chart



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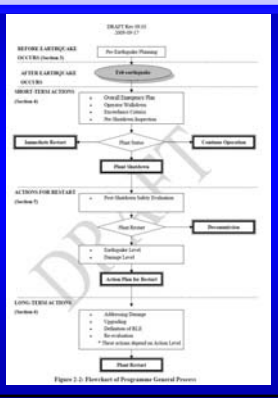
Flowchart of Programme General Process



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Pre-Earthquake Planning

- Overall Emergency Plan
- Seismic instrumentation
- DBE Exceedance
- Malfunction, damage, and significant damage
- Plant shutdown criteria
- Pre-selection of SSCs for post-earthquake inspections
- Procedures and training

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Pre-Earthquake Planning – Overall Emergency Plan

- Scope and purpose – earthquake occurrence to completion of all actions
- Team composition – HQ and on-site plant management and operators
- Roles and responsibilities
- Pre-EQ and post-EQ actions
- Communication plan – Local and Federal Government, media, public, other stakeholders
- Decision-making – Action levels (shutdown, repairs, upgrades, restart, etc.)
- Documentation of all actions
- Training and exercises

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Pre-Earthquake Planning – Seismic Instrumentation

- Automatic or manual shutdown?
- Installation, maintenance, and operability guidelines to be established and followed
- Generally, tri-axial time history accelerographs
- Free-field, foundations, in-structure
- Other instrumentation, e.g. CAV, JMA Intensity, etc.
- Uses (compare recorded data with design parameters)
  - Free-field – SL-1/SL-2, CAV/JMA Intensity
  - Calculation of seismic response/demand on SSCs
- Essential information annunciated in control room

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Pre-Earthquake Planning – SSCs for Inspections

- Pre-selection of SSCs for post-earthquake inspections
  - Representative of important to safety and not important to safety SSCs – risk importance could be considered (US NRC RG 1.201)
  - Example categorization – 40 classes
    - Static (vessels, structures, tanks, ...)
    - Dynamic (pumps, valves, fans, ...)
    - Electrical (transformers, switchgear, ...)
- Base line inspections of SSCs
  - Identify and document pre-existing conditions
  - Visual inspections – documented activity
  - Maintenance
  - Updated periodically

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Pre-Earthquake Planning – Action Levels

- Tiered approach defining actions to be performed prior to and after restart
- Function of Earthquake Level and Damage Level
- May change due to inspection results

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Basic Concept of Safety Report

Define two indicators to decide the evaluation processes after an earthquake

✓Size of earthquake motion

→ *"Earthquake Level"*

- Based on comparison of recorded ground motion and Design Basis earthquakes (SL-1, SL-2)
- Classified to 3 levels (earthquake Level 1 to 3)

✓Significance of damage

→ *"Damage Level"*

- Relation with the seismic safety and/or operability
- Classified to 4 levels (Damage Level 1 to 4)

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Pre-Earthquake Planning – Earthquake Level

- Earthquake Level 1: EQ < SL-1
- Earthquake Level 2: SL-1 < or = EQ < or = SL-2
- Earthquake Level 3: EQ > SL-2
  - 3a – High frequency (> 10 Hz)
  - 3b - Mid-amplified (2 – 10 Hz)
  - 3c – Low frequency (< 2 Hz)
- Earthquake Levels 3a – 3c determine different action levels

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Pre-Earthquake Planning – Definitions

- Damage - Damage is defined as the change in state from the original configuration of an SSC to an altered degraded state due to the earthquake. The broad category of damage is comprised of minor damage and significant damage. Minor damage (e.g., slight impact deformations, insulation deformation, hairline cracks, etc.), even if caused by the earthquake, is not considered significant and does not initiate actions to be taken.
- Significant damage (physical or functional) is considered to be damage which has the potential to adversely affect the operability, functionality, or reliability of SSCs. The term significant damage may refer to: significant damage to SSCs important to safety (ITS); significant damage to SSCs not important to safety (NITS); not important to safety (NITS) – required for power generation(RPG); not important to safety (NITS) – not required for power generation (NRPG).

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Pre-Earthquake Planning – Damage Levels

- Damage Level 1 – No damage to ITS and NITS SSCs
- Damage Level 2 – No damage to ITS SSCs. Damage to NITS SSCs not required for power generation (NRPG).
- Damage Level 3 – No damage to ITS SSCs. Damage to NITS SSCs required for power generation (RPG).
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Pre-Earthquake Planning – Action Levels

Define the *"Action Level"* which defines actions to be taken after an earthquake

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- Classified to 8 levels (Action Level 1 to 8) with sub-categories for Earthquake Levels 3a, 3b, 3c
- Discriminate the actions which should be done before or after restart

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Action Levels

Action Levels

Size of Earthquake motion

Significance of Damage

	Earthquake Level 1	Earthquake Level 2	Earthquake Level 3		
			3a	3b	3c
Damage Level 1	--	Action Level 1	Action Level 5		
Damage Level 2	--	Action Level 2	Action Level 6a,6b,6c		
Damage Level 3	Action Level 3		Action Level 7a,7b,7c		
Damage Level 4	Action Level 4		Action Level 8		

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Pre-Earthquake Planning and Post-Earthquake Actions for Nuclear Power Plants

- Pre-Earthquake Planning
- Post – Earthquake Actions
  - Immediate (e.g., within 8 or 24 hrs)
- Post – Earthquake Actions – Short Term
- Post – Earthquake Actions – Long Term

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Post-Earthquake Actions – Immediate

- Implement Overall Response Plan
- Operator actions
- Engineer actions
- Pre-shutdown inspections (if necessary)
- Decision on next steps (post-trip review, shutdown, restart, additional evaluations)
- Time frame – within about 8 hrs or other as specified by MS

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Post-Earthquake Actions – Immediate

- Assumptions
  - Seismic scram or other conditions led to hot or cold shutdown
  - Plant trip but reactor trip has not occurred
  - Plant continues operation

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Post-Earthquake Actions – Immediate Operator Actions

- Confirmation of EQ
- Stabilize plant by normal and/or emergency OPs
- Activate on-site response plan
- If no seismic scram, determine whether plant should be shutdown
  - Perform pre-shutdown inspections
  - Restart, continue operation, or shutdown
  - IAEA Safety Standards Series No. NS-G-2.2, "Operational Limits and Operating Procedures for Nuclear Power Plant"
- Walkdown inspections
  - Familiar with SSCs (physical and operational characteristics)
  - Accessible areas
- Define initial Damage Level

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Post-Earthquake Actions – Immediate Engineer Actions

- Process recorded motions and compare with SL-1 and SL-2 specifications (generally design ground response spectra)
- Determine Earthquake Level
- Calculate or determine other damage indicating parameters (CAV, JMA Intensity, etc.)
- Compare foundation or in-structure recordings, if necessary
- If no operating instrumentation on-site, apply MS specific criteria to decide if shutdown is required
- Collaborate on decision-making

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Post-Earthquake Actions – Immediate

- Decision on next steps (post-trip review, shutdown, restart, additional evaluations)
- Pre-shutdown inspections (if necessary)
- Assign initial Earthquake Level and Damage Level

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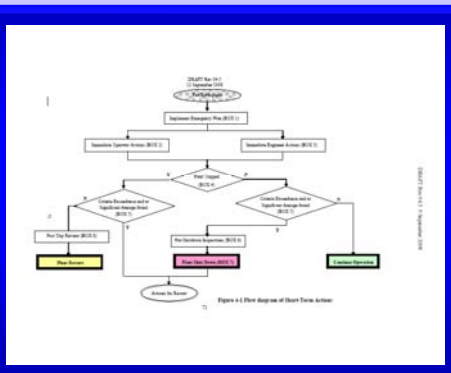
Immediate Actions



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Pre-Earthquake Planning and Post-Earthquake Actions for Nuclear Power Plants

- Pre-Earthquake Planning
- Post – Earthquake Actions
  - Immediate (e.g., within 8 or 24 hrs)
- Post – Earthquake Actions – Short Term
- Post – Earthquake Actions – Long Term

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Post-Earthquake Actions – Short Term

- Assumptions
  - Plant is shutdown
  - Operators – performed walkdowns, initial damage level
  - Engineering – processed records, earthquake level
  - Restart strategy dependent on earthquake level, damage indicating parameters, and initial damage estimates
  - Actions - tiered approach based on results of inspections/tests/evaluations
  - Action levels can change based on results of inspections/tests/evaluations

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Post-Earthquake Actions – Short Term

- Strategy for restart
  - Tiered approach dependent on Action Level and results of inspections/tests/evaluations
  - Initial focused inspections and tests
  - Expanded inspections and tests (ITS and NITS SSCs)
  - Non-destructive examinations
  - Comparative analyses of soil/rock/structure response
  - Comparative analyses of sample subsystems response
  - Surveillance tests
  - Start-up tests
  - Evaluations of SSCs

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Post-Earthquake Actions – Initial focused inspections and tests

- Scope
  - Pre-selected SSCs representative number of samples of "all" passive and active safety related SSCs
  - Non-safety related damage indicators
- Visual inspections
  - Table 5-2 (based on EPRI NP6695)
  - Anchorage, attached piping, conduit, etc., etc.
  - Appendix I provides guidance in the form of guidelines by equipment category with sample data documentation sheets
  - Other evidence of physical or functional damage
- Surveillance tests (limiting conditions, Technical Specifications) recommended/not required

Integrated containment leak test not required

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Post-Earthquake Actions – Expanded inspections and tests

- Scope
  - Subsumes Initial focused inspections and tests
  - All safety related equipment and structures unless a smaller sample is justified
  - Non-safety related SSCs required for normal plant operation
- Visual inspections
- Surveillance tests (limiting conditions, Technical Specifications) required
- Integrated containment leak test recommended/not required

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Action Levels

Action Levels

Size of Earthquake motion

Significance of Damage

	Earthquake Level 1	Earthquake Level 2	Earthquake Level 3		
			3a	3b	3c
Damage Level 1	–	Action Level 1	Action Level 5		
Damage Level 2	–	Action Level 2	Action Level 6a,6b,6c		
Damage Level 3	Action Level 3		Action Level 7a,7b,7c		
Damage Level 4	Action Level 4		Action Level 8		

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Post-Earthquake Actions – Action Levels 1, 2, 3, and 5

- Damage Levels 1, 2, or 3
- Earthquake Levels 2 and 3 (Action Level 5)
- All
  - Initial focused inspections performed
  - Surveillance tests performed
- Action Level 3 (Repair NITS RPG SSCs)
- Action Level 5 (Re-evaluate SH after restart)
- Successful results – plant restart with normal start-up procedures
- Anomalies found – redefine Damage Level and Action Level

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Post-Earthquake Actions – Action Level 4

- Damage Level 4 (Damage to ITS and NITS SSCs)
- Earthquake Levels 1, 2
- Expanded inspections and tests required – subsumes initial focused inspections
- Root cause analysis
- Corrective action based on root cause analysis results – redefine input; repair, upgrade, replace, re-qualify ITS SSCs; verify SSC capacity

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Post-Earthquake Actions – Action Level 4 (cont)

- Repair or replace NITS RPG SSCs performed
- Surveillance tests performed
- Successful results – plant restart with normal start-up procedures
- Restart
- Repair or replace NITS NRPG SSCs performed
- Possibly redefine RLE

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Post-Earthquake Actions – Action Level 8

- Damage Level 4 (Damage to ITS and NITS SSCs)
- Earthquake Level 3
- Steps same as Action Level 4:
  - Expanded inspections and tests required – subsumes initial focused inspections
  - Root cause analysis
  - Corrective action based on root cause analysis results – redefine input; repair, upgrade, replace, re-qualify ITS SSCs; verify SSC capacity

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Post-Earthquake Actions – Action Level 8 (cont)

- Re-evaluate SH before restart, if deemed necessary
- Define SH for SPSA or SMA
- Evaluate capacity of SSCs and plant to new SH
- Repair or replace NITS RPG SSCs performed
- Surveillance tests performed
- Successful results – plant restart with normal start-up procedures
- Repair or replace NITS NRPG SSCs performed

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Action Levels

Action Levels

Size of Earthquake motion

Significance of Damage

	Earthquake Level 1	Earthquake Level 2	Earthquake Level 3		
			3a	3b	3c
Damage Level 1	--	Action Level 1	Action Level 5		
Damage Level 2	--	Action Level 2	Action Level 6a,6b,6c		
Damage Level 3	Action Level 3		Action Level 7a,7b,7c		
Damage Level 4	Action Level 4		Action Level 8		

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Post-Earthquake Actions – Action Levels 6 and 7

- Damage Levels 2 and 3 (no ITS SSCs damaged)
- Actions dependent on Earthquake Level 3a, 3b, 3c
- Earthquake Level 3: EQ > SL-2
  - 3a – High frequency (> 10 Hz) – Action Level 6a/7a
  - 3b - Mid-amplified (2 – 10 Hz) – Action Level 6b/7b
  - 3c – Low frequency (< 2 Hz) – Action Level 6c/7c

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Post-Earthquake Actions – Action Levels 6a and 7a

- Initial focused inspections and tests successful
- Action Level 7a – repair NITS RPG SSCs
- Restart
- After restart
  - Repair or replace NITS NRPG SSCs after restart
  - Re-evaluate seismic hazard after restart, if deemed necessary
  - Re-evaluate ITS SSCs for re-defined SH if deemed necessary (intelligent sample – tiered approach)
  - Upgrade ITS SSCs, if appropriate

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Post-Earthquake Actions – Action Levels 6b and 7b

- Initial focused inspections and tests successful , if not perform expanded
- Comparative analyses – EQ induced response vs. SL-2
- Re-evaluate seismic hazard before or after as deemed necessary
- Re-evaluate ITS SSCs for re-defined SH if deemed necessary (intelligent sample – tiered approach)

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Post-Earthquake Actions – Action Levels 6b and 7b (cont)

- Repair, replace, upgrade ITS and NITS RPG SSCs before restart
- Restart
- After restart
  - Repair or replace NITS NRPG SSCs

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Post-Earthquake Actions – Action Levels 6c and 7c

- Initial focused inspections and tests successful , if not perform expanded
- Comparative analyses – EQ induced response vs. SL-2 – evaluate potential consequences of low frequency ground motion exceedances on SSCs
- Focus on specific SSCs for which low frequency motions are potential issue

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Post-Earthquake Actions – Action Levels 6c and 7c

- Re-evaluate seismic hazard before or after restart as deemed necessary
- Re-evaluate ITS SSCs for re-defined SH if deemed necessary (intelligent sample – tiered approach)
- Upgrade ITS SSCs, if appropriate

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Post-Earthquake Actions – Long Term

- Re-evaluations follow procedures of IAEA Safety Guide No. NS-G-2.13, " Seismic Safety Evaluation of Existing Nuclear Installations," 2009
  - Seismic margin assessment
  - Seismic PSA
  - Seismic design criteria updated
- Definition of seismic input – seismic hazard
- Selection of target SSCs and acceptance criteria
- Calculation of seismic demand for SSCs
- Evaluation of SSCs
- Compliance with acceptance criteria
- Foundation stability assessment

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Earthquake Experience at NPPs

Nuclear Power Plant	Earthquake	Action Level	Average Time to Restart	Reference
Kashiwazaki-Kariwa	NCOE (2007)	7b	Units 6 (25 mos.) Unit 7 (22 mos.)	Appendix II
Shika	Noto Hantou (2007)	6c	Unit 2 (1 yr.) Unit 1 (1 yr. + due to other than earthquake factors)	Appendix II
Onagawa	Miyagi Offshore (2005)	6a	Unit 1 (11 mos.) Unit 2 (5 mos.) Unit 3 (7 mos.)	Appendix II
Medsamor	Spitak (1988)	1	*	Appendix II
Perry	Leroy (1986)	6a	Pre-operational stage	Ref. 29
V.C. Summer	Reservoir Induced Seismicity (1977-1979)	1 or 5	Not shutdown	Ref. 30

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Next Steps

- Draft Rev. 9 distributed 17 September 2009
- Final comments by StC and ScC
  - 1 November 2009
- IAEA editing and formatting
  - 1 December 2009
- Overall review by Dr. Robert P. Kennedy
  - 31 December 2009
- IAEA Publication Committee
  - January 2010
- Publication 1st quarter 2010

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