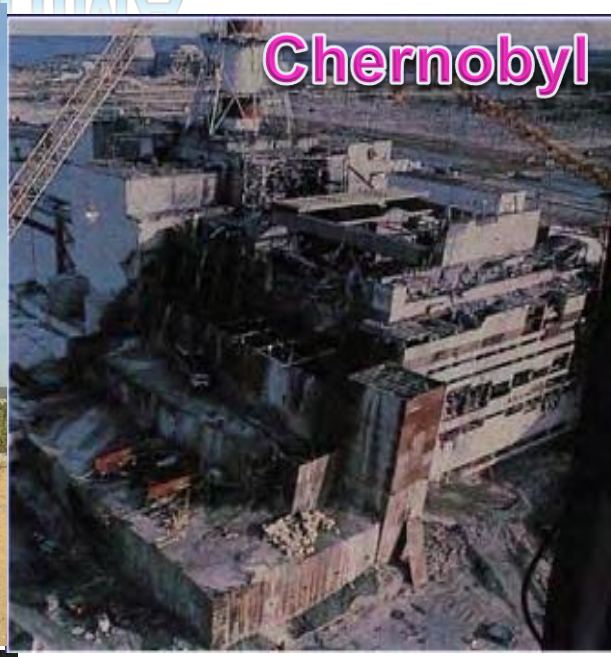
KARACHI NUCLEAR POWER PLANT (KANUPP)

LESSONS FROM FUKUSHIMA



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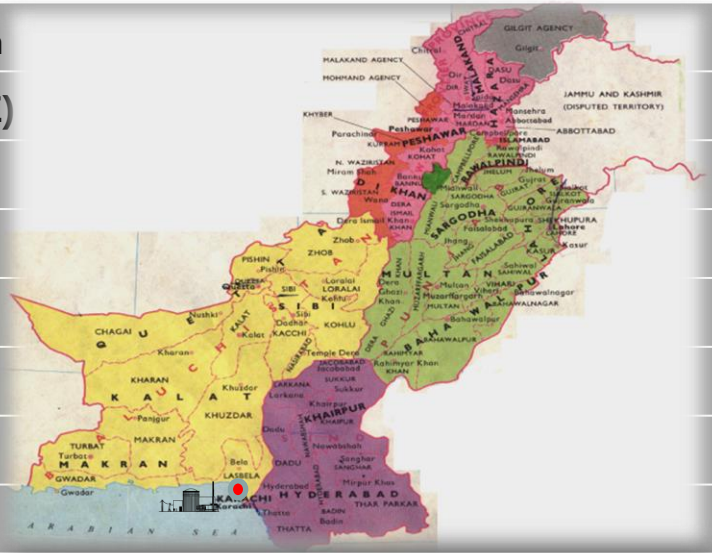
International Experts' Meeting on Severe Accident Management in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant

Organized in connection with the implementation of the IAEA Action Plan on Nuclear Safety

IAEA Headquarters, Vienna, Austria, 17–20 March 2014

KANUPP- Introduction

OWNER:	Pakistan Atomic Energy Commission
DESIGNER	Canadian General Electric (CGE)
LOCATION Arabian Coast:	30 KM West of Karachi
REACTOR TYPE:	PHWR (CANDU)
COMM.OPERATION:	1972
THERMAL POWER:	433 MWth
GROSS ELECTRIC POWER:	137 MW (100 MWe)**
NET ELECTRIC POWER:	125 MW (90 MWe)
LICENSING POWER:	98 MW
MODERATOR:	Heavy Water (D2O)
COOLANT:	Heavy Water (D2O)
CALANDRIA:	Stainless Steel
FUEL CHANNEL:	Zr-2.5wt% Nb
FUEL :	Natural Uranium (UO2)
FUEL SHEATH:	ZircAlloy–4
RE-FUELLING SEQUENCE	ON-Power
TURBINE-GENERATOR	Non Reheat, Tandem Compound



** Plant Gross Capacity degraded since January 2004

KANUPP – Significant Events

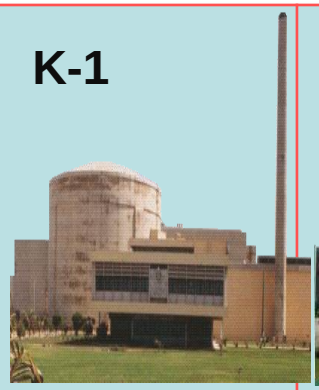
Significant Milestones

1965	Contract Signed with CGE Canada
1966	Construction Started
1971	First Reactor Criticality Achieved
1971	First Synchronization with the Grid
1972	Inauguration and Commercial Operation
1976	Suspension of Vendor Support
1977	Parts Manufacturing set up
1980	First Pakistani Fuel Bundle in Core
1989	WANO and COG Membership
2002	Completion of Design Life
2003	First re-licensing outage
2006	Second re-licensing outage

Reviews & Assessments

1985	1st IAEA OSART Mission
1989	2nd IAEA OSART Mission
1989	IAEA ASSET Mission
1994	1st WANO Peer Review by TC
1996	WANO-TC Peer Review Follow-Up
1999	IAEA AMAT Mission – Ageing Mgt.
2000	2nd WANO Peer Review by AC
2002	Probabilistic Safety Assessment - Level-1
2006	KFSAR Update Revision-2
2009	Fire - PSA
2010	3rd WANO Special Review by TC
2011	1st PAEC Internal Peer Review (IPR)
2012	KANUPP Safety Assessment
2013	WANO TC Peer Review Follow-up
2013	IPR / FRAP Follow-up

Current Status of Nuclear Power

K-1	C-1	C-2	C-3	C-4	K-2/3
					
1972	2000	2011	2016	2016	~ 7 Years
KANUPP-1	CHASNUPP-1	CHASNUPP-2	CHASNUPP-3	CHASNUPP-4	KCPP
137 MW	325 MW	330 MW	340 MW	340 MW	2x1100 MW
PHWR	PWR	PWR	PWR	PWR	APC1000
Canada	China	China	China	China	China

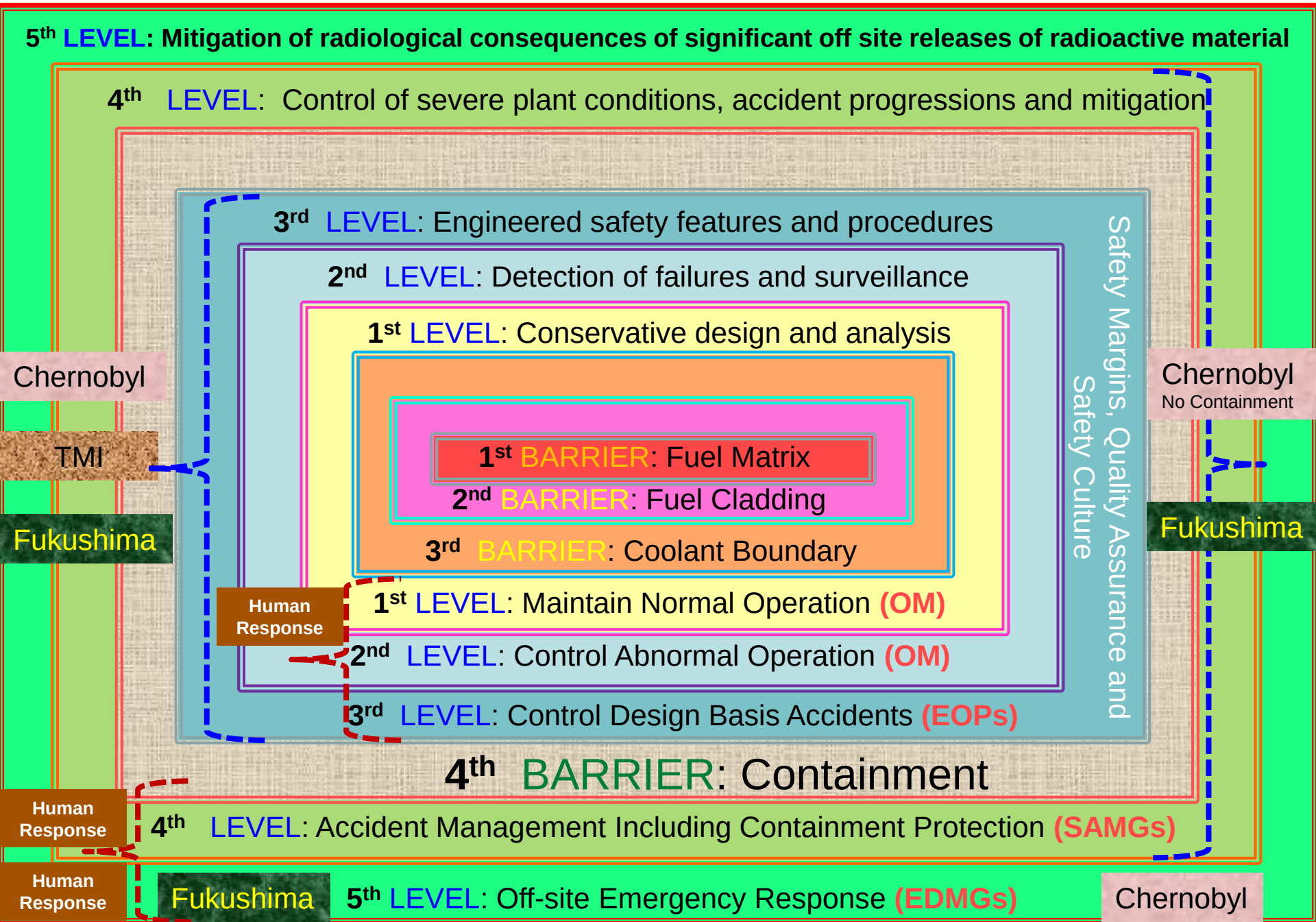
Energy Security Plan 2005 = 8,800 MWe till 2030.
Vision 2050 = 40,000 MWe till 2050.

Fact = 05 Severe Core Damages in last 35 years

Plant / Unit	TMI – 2	Chernobyl - 4	Fukushima-1/2/3/4/5/6
Power (MWe) - Type	960 - PWR	1000 - RBMK	1x460, 4x784, 1x1100 - BWR
Country / Commissioning	USA - December, 1978	USSR - March 1984	JAPAN - March 1971-Oct.1978
INES Rating	5	7	7
Event Date – Time	March 28, 1979, 04:00 hrs	April 26, 1986, 01:23 hrs	March 11, 2011,14:46 hrs
Event	Internal – affecting single unit	Internal – affecting single unit	External– affecting multi units
Cause and nature	Equipment failure and human error causes reactor coolant fluid to leak. Partial core meltdown	Safety bypass. Power surge during a test causes the reactor to catch fire and explode.	Prolonged Station Blackout. Loss of cooling function as a result of damage caused by earthquake and tsunami
Response	Cooling pump restored	Building sealed off by the sarcophagus	Injection of sea / fresh water to core
Containment Integrity	Hydrogen explosion. Containment provision prevented public exposure	No containment provision.	Damage to secondary containment during venting of primary containment.
Radiation Released (peta - becquerels)	0.062	5200 - Belarus, Russia, Ukraine, Franc, Italy affected	770
Death due to nuclear accident	0	30 - 33	0-3
Long term health effects	No Known	Thousands of cancer and radiation death cases	Not yet known
Evacuation zone	8 km (pregnant women, pre-school going children, voluntary)	30 km (116,000 – 230,000)	20 km (80,000 – 141,000)

Ref: Various Sources

Basic Concept of Design-in-Depth and Lessons Ignored (IAEA – INSAG 10)



Philosophy in Defense-in-Depth

- **Follow Safety fundamentals:- Cool, Confine, Control**
- **Provide redundancy, diversity, separation, protection in equipment and systems**
- **Avoid Common cause failure, single failure and ensure fail safe design**
- **Maintain Safety margins to compensate for equipment failures and human errors**
- **Protect safety and critical equipment against internal and external hazards**
- **Develop competency for conservative, safety-oriented decision making**
- **Ensure high levels of equipment reliability and human performance**
- **Establish tested and effective accident management and emergency preparedness**

- **Site Selection**
- **Plant Design and Operational safety**
- **Staff Training and Qualification**
- **International Benchmarking**
- **Radiation Protection and Environment Monitoring**
- **Emergency Preparedness**

Fukushima in Pictures – Ref: TEPCO

11th March 2011, 9.0 Magnitude Earthquake Followed by Tsunami after about one hour

- No to nuclear power
- Alternate to zirconium based or zircaloy cladding
- Site selection should be under global assessment scheme
- Having multiple units at one site needs critical review in terms of post accident response and management
- Long term station blackout is reality
- Measures to restore public confidence
- Key valves must have redundant control system
- Spent fuel storage must be away from the site
- There shall be multiple access roads to the plant and these must be wider and clear.
- Strong Regulatory Role
- Improved decision making and communication during uncertainty
- Place larger structures of hydrodynamic design towards the ocean and smaller installations in the "wake" region behind larger structures
- Maintain containment structural integrity (Chernobyl lesson ignored)
- Organizational structure and staffing with due regard to SA's
- Aged and old generation plants should be replaced
- Training and guidelines to face un-expected situations. Severe Accident Simulators ?
- Effective drills and exercises to manage long term post accident management actions

Ignorance of Warning Signs

S. No.	Lesson from FUKUSHIMA
1	Highly Vulnerable site
2	Location of emergency equipment
3	Prolonged station blackout
4	In-adequate diverse electric supply system
5	Improper communication during emergency
6	Delays in critical actions
7	Lack of training at emergency
8	Delays in outside help or assistance
9	Operator has to take critical decisions
10	Un-expected, complex, stressful conditions
11	In-adequacies in Emergency Preparedness
12	Regulatory, Corporate and Human performance

Corporate Regulator Utility

1. **Protect** safety and critical equipment and systems from internal & external hazards
2. Prepare operator to face challenging **unexpected** situations and for **critical** decision making
3. **Controlled filtered venting** of containment to protect integrity against internal threats
4. Coordinated, **tested** and well prepared emergency preparedness and management program

TARGET

Prevent Accident at all Cost. Prepare for Prolonged Accident Management & Emergency Preparedness

Plant Process People

FUKUSHIMA Response Action Plan (FRAP)

In response to Fukushima NPPs Accident a targeted action plan called Fukushima Response Action Plan (FRAP) issued for KANUPP by Corporate Office on 22 June 2011

Current Status of FRAP

Description	Main Tasks		Studies		Actions	
	#	%	#	%	#	%
Total	78	-	66	-	370	-
Completed	63	80.77	63	95.45	230	62.16
In progress	15	19.23	03	4.55	140	37.84

Plan Prepared	1st Review	2nd Review	3rd Review	4th Review	Future Review
Jun 2011	Oct 2011	Jun 2012	Feb 2013	Sep 2013	May 2014

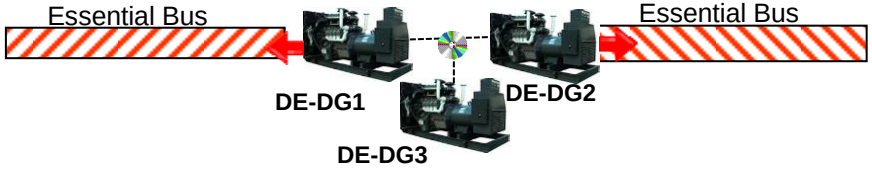
Actions

FUKUSHIMA

1. External Natural Hazards
2. Make-shift AC Power
3. DC Power Capacity
4. Fire Protection and Control
5. Emergency Cooling
6. Hydrogen Hazard
7. Containment Integrity
8. Spent Fuel Cooling
9. EOPs, SAMGs (on-site)
10. Emergency Preparedness
11. Operator Training and Preparedness

Lessons Learned

KANUPP Before FUKUSHIMA Accident



220V AC , 24 V DC Batteries

Building Spray

S-Boilers

Reactor Building

N-Boilers

PHT System

Core

IJW System

Filters

Ground Level = 138 ft elevation

Sump

MH-TK1

EL = 110′

MH System

Spent Fuel Bay

Distribution Room

EFW System

With RFW-TK2 for 36 hrs

2 x EFW-PPs

EFW-TK1

EFO-TK1 3175 USG

For one FIJW-DG for 96 hours

EFO-TK3 240 USG

EFO-TK4 240 USG

EFO-TK2, 750 USG

FIJW-DG1/DG2

400 KW each

EFW-DG1/DG2

150 KW each

Service Building

FIJW System

FIJW-TK1, 180 ton H2O for 100 min or 1.66 hrs

P

EL = 120′

Pump House = 109 ft elevation

Arabian Sea

Mean Sea level = 100 ft elevation

Overall Concept of KANUPP Response Plan to FUKUSHIMA Accident

Lesson

(3):- Continuous charging of batteries

(3):- Station emergency lighting

DE-DG4/DG5

220V AC , 24 V DC Batteries

3

Installed at = ~ 170 ft elevation

EWI-D1/D2

(5) DSW

2

Essential Bus

DE-DG1

DE-DG2

DE-DG3

DE-DG6

Essential Bus

(2):- Mobile DG

(2):- Fuel oil storage = 9 days

(2):- Extended SBO of ~ 11 days can be catered

(2):- FIJW-DGs connection to essential busses

(1):- Proper and effective Drainage System

Building Spray

S-Boilers

Reactor Building

N-Boilers

EWI-D1/D2

(5) VCW

PHT System

IJW System

Long term H2 through MCCI = 430 kg

(6):- Max H2 = 7% by vol

6

:-PARs and H2 Analyzer

MH-TK1

Sump

EL = 110′

MH System

(3):- Power to essential MOVs

8

(8):- Spent Fuel Cooling

Boiling in 19 days

Dry out in 140 days

Spent Fuel Bay

EWI-D1/D2

(5) EFW

EFW System

For one FIJW-DG for 96 hours

EFO-TK1 3175 USG

EFW-TK1

With RFW-TK2 for 36 hrs

2 x EFW-PPs

EFO-TK2, 750 USG

EFO-TK3 240 USG

EFO-TK4 240 USG

2

EFW-DG1/2

FIJW-DG1/2

1) Seismic Strengthening of service and turbine buildings

Service Building

EWI-D1/D2

(5) FIJW

FIJW System

FIJW-TK1, 180 ton H2O for 100 min or 1.66 hrs

P

EL = 120′

(5) BYW

EWI-D1/D2

(7):- Containment Max press = 40 psig.

Filtered Venting System

7

Scrubber Tank

Filters

Ground Level = 138 ft elevation

4

Fire tender

(4):- Strengthening of fire fighting capabilities

5

:-Water injection through portable diesel driven pump

= Injection Points

1

Re-assessment of External Hazards

Distribution Room

(1):- Water tight sluice gates

9

Development of external EOPs and SAMGs

10

Emergency Preparedness

Pump House = 109 ft elevation

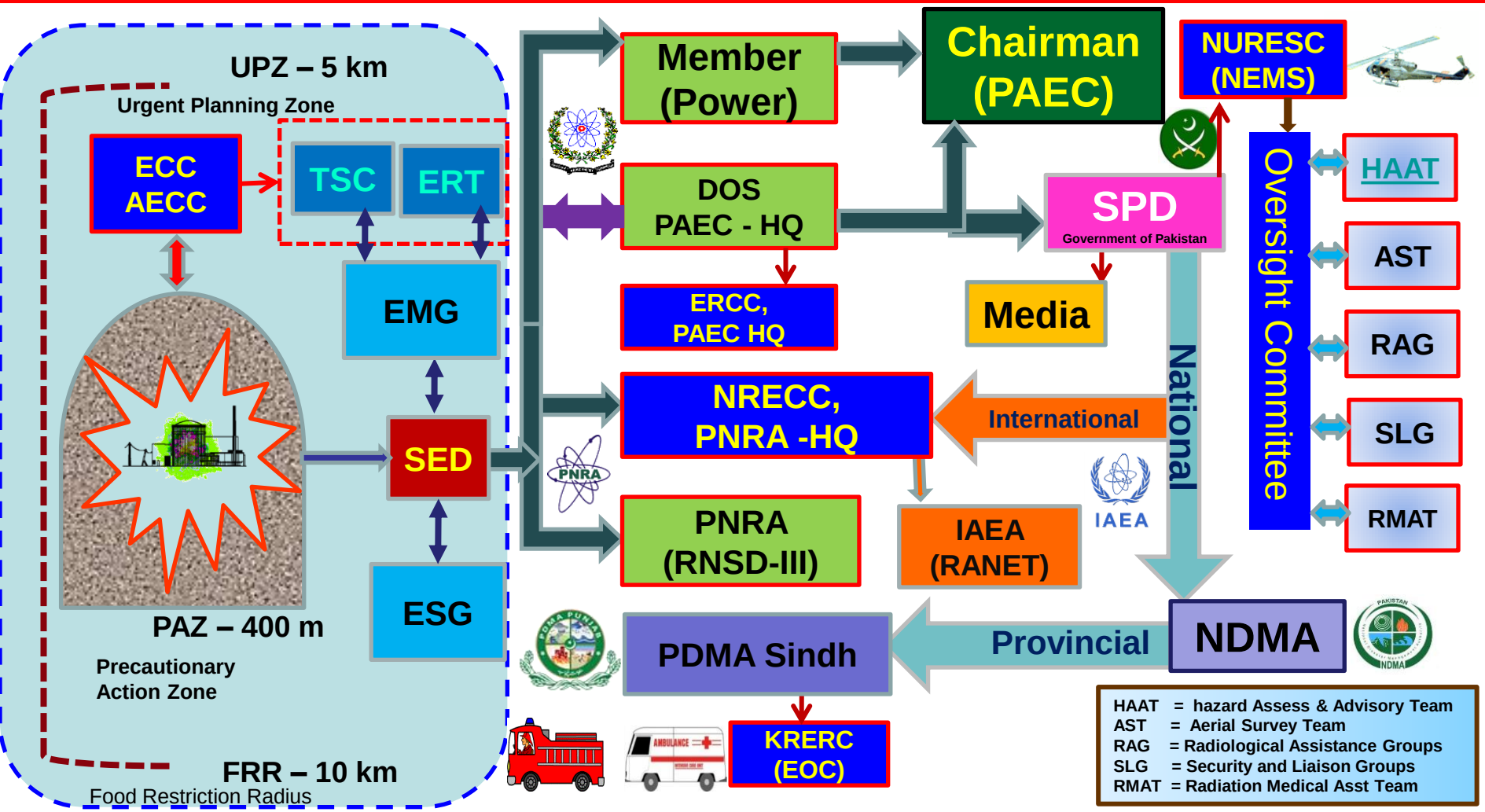
(1):- Early Tsunami Warning System (TEWS) from PMD + Fax Machine in MCR

Arabian Sea

Mean Sea level = 100 ft elevation

Maximum Tsunami Wave = 109.31 ft

KANUPP Severe Accident Emergency Response & Coordination Plan



SS	Shift Supervisor
SED	Site Emergency Director
EMG	Emergency Management Group
ESG	Emergency Support Group
TRC	Technical Support committee
ERT	Emergency Response Team

AECC	Alternate Emergency Control Centre
NURESC	Nuclear & Radiological Emergency Response Centre
ERCC	Emergency Response Coordination Centre
EOC	Emergency Operation Centre
RANET	Response Assistance Network
NRECC	Nuclear & Radiological Response Cord. Centre

DOS	Directorate of Safety
SPD	Strategic plans Division
NEMS	Nuclear Emergency Mgt. System
NDMA	National Disaster Mgt. Authority
PDMA	Provincial Disaster Mgt. Authority
IAEA	International Atomic Energy Agency

ENVIRONMENTAL MONITORING AND EMERGENCY RESPONSE

Air-Borne Activity (KANUPP Colony, Sandpit, KIRAN)

Soil, Water, Milk and Vegetation samples up to 5-10 km on half yearly basis

Gamma monitors (TLDs) in plant area (5) and city (10)

Stack Monitors
SBV1R (Iodine)
SBV2R (Noble Gases)
SBV3R (Particulate)
SBV4R (Gamma)

10 CFR 100 (design)
PAK – 914 / IAEA (Operation)

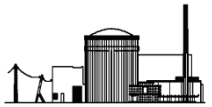
Sheltering = 1 rem (10 mSv) (ADL) for 2 days
Evacuation = 5 rem (50 mSv) (ADL) for 7 days
Iodine Prophylaxis = (100 mGy) CAD

AD1R (Inactive Drainage)
AD2R (Active Drainage)

Fish sample on yearly basis

Pakistan Environmental Protection Council (PEPC) has approved National Environment Quality Standards (NEQS) – Parameters monitored are TSS, TDS, COD, BOD pH, Temp. etc.

Human Error Prevention Tools



Situation Awareness

- Questioning Attitude
- STOP When Unsure
- Task Preview
- Pre-Job Brief
- Job site Review
- Post-Job Review
- Turn over

Procedure

- Procedure use
- Procedure Adherence
- Proc. Deviation Approval
- Place Keeping

Verbal Communication

- Effective Verbal Communication
- Phonetic Alphabets
- 3-Way Communication

Checks

- First Check
- Self Check
- Peer Check

Verification

- Independent Verification
- Concurrent Verification

Operational Barriers

- Flagging
- Blocking

Care

- Care Enough to Act

Fundamental Tool

Conditional Tool

OOPS

Out Of Procedure, Parameter, Process – STOP

Summarize Anticipate Foresee Evaluate Review

STAR

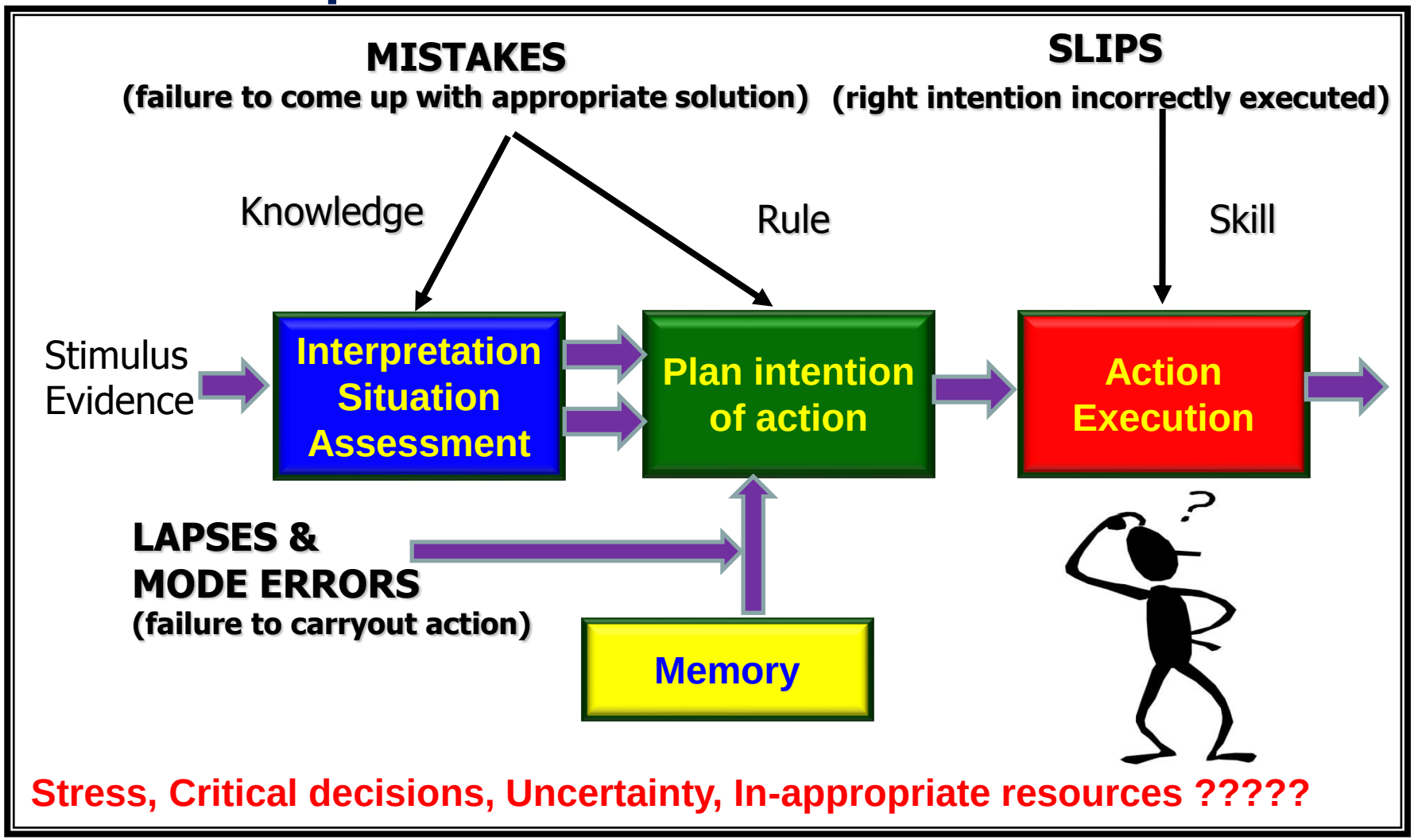
Stop Think Act Review

Questioning Attitude:	To identify gaps between actual and desired situation
Stop When Unsure:	To eliminate doubt, uncertainty and confusion
Task Preview:	To prepare worker to perform a job right first time
Pre-Job Brief:	To understand what to accomplish and what to avoid
Job Site Review:	To improve situation awareness when first arriving at site
Post Job Review:	To perform self assessment after work for feedback
Turn Over:	To orderly transfer work related information to others
Procedure Use:	To aware and link directly to procedure classification
Procedure Adherence:	To ensure that procedure is understood and followed
Procedure Deviation:	To ensure approvals prior to deviating procedure
Place Keeping:	To mark steps to avoid repetition and omission

Verbal Comm.:	To ensure understanding between sender and receiver
Phonetic Alphabets:	To eliminate confusion regarding letter of referred alphabet
3-Way Comm.:	To ensure reliable transfer of information & understanding
First Check:	To ensure proper equipment is to be manipulated
Self Check :	To focus attention on the task, keeping in mind STAR
Peer Check:	To prevent an error by the performer during critical steps
Independent Ver.:	To detect an error by the performer involving equipment
Concurrent Ver.:	To prevent an error by the performer when doing action
Flagging:	To ensure that correct equipment is being manipulated
Blocking:	To ensure that incorrect equipment not being manipulated
Care Enough to Act:	To take action to improve situation or to prevent harm

Ref: TG-001-2009 (HEPTOOLS)
Operation Division

Taxonomy of Human error under unexpected and uncertain situations



Guidelines, Procedures, Policies, Testing and Training

The Key Efforts in KANUPP

- **Walk-Through Exercises:-** Step by step review of SAMGs from effectiveness and practicality
- **Table Top Discussions:-** Agreement of all available experience on critical actions
- **Implementation Drills:-** Field simulation exercises from implementation perspective.

Specific Color Coding of FRAP Related Equipment & Piping

Source	Location	Prolonged Station Blackout (PSBO)	PSBO + LOCA
DE-DG1 1250 kW DE-DG2 1250 kW DE-DG3 1250 kW	Separate Diesel Rooms at about 2 ft higher than Ground elevation. Either of the essential power bus (DE-PL5 or PL6) may be energized through these.	Normal Standby Diesel Generators. Unavailable	Normal Standby Diesel Generators. Unavailable
EFW-DG1 150 kW EFW-DG2 150 kW	Ground elevation protected by flood wall of 3 ft	Supply to Boilers to ensure heat sink availability	Not Required as it will not be effective
FIJW-DG1 400 kW FIJW-DG2 400 kW	Ground elevation protected by flood wall of 3 ft	To start standby core cooling and component cooling by energization of DE-PL5/PL6 if required.	For emergency injection in case LOECI by energizing essential buses.
DE-DG4 100 kVA DE-DG5 100 kVA	Tank Area Higher Elevation for batteries through DE-INV7 and INV8 and DE-REC3 and REC4	To prolong station battery power by continuous charging of 24 V DC and 220 V UPS system	To prolong station battery power by continuous charging of 24 V DC and 220 V UPS system. Power supply to IJW and FIJW MOVs through selector switch.
DE-DG6 300 kW	About 4 ft higher than ground elevation protected by flood wall	Can be used to energize DE-PL5 or DE-PL6 in case of un-availability of FIJW-DGs for core and component cooling	Can be used to energize DE-PL5 or DE-PL6 in case of un-availability of FIJW-DGs for emergency injection
EWI-D1, 100 psi, 100 igpm EWI-D2, 100 psi, 100 igpm	Independent Diesel Driven pumps in Tank area at higher elevation.	For water injection to any of the following systems: EFW, FIJW, BYW, VCW, DSW, FW etc.	For injection to core via FIJW piping.
Mobile DG 300 kW	Can be brought on site from CROF site and connected to any of the essential panels (DE-PL5 or PL6) near ISI shed	Limited power to any load connected to DE-PL5 or DE-PL6 in case of loss of all station DE-DGs for core and component cooling	Limited power to any load connected to DE-PL5 or DE-PL6 in case of loss of all station DE-DGs for emergency injection

Thank you !

LESSONS STILL BEING LEARNT !

Post Accident Complexities

HOPE FOR THE BEST
PREPARE FOR THE WORST

Smart man learn from his own mistakes.
Wise man learn from the mistakes of others.

Prevention is better than cure !

Attempts To Control Contamination By Radioactivity In Fukushima

Reactor 4 plans call for the removal of spent fuel rods from Reactor 4's building.

Source: Tokyo Electric Power Company

Underground Frozen wall

Pipes will carry liquid nitrogen into the ground freezing the soil to create a barrier to prevent ground water from being contaminated

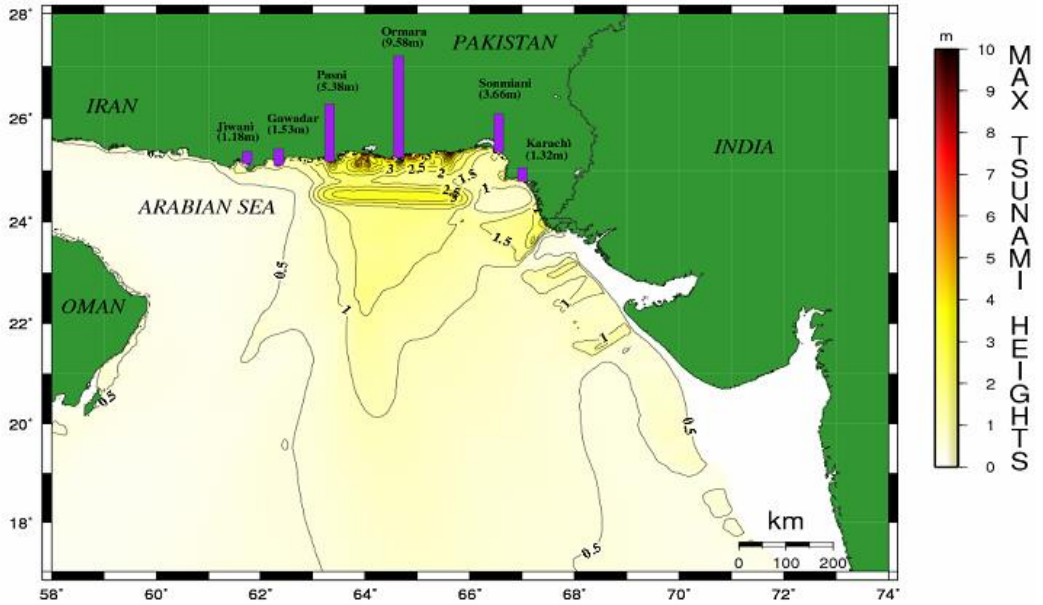
Impermeable Sea wall

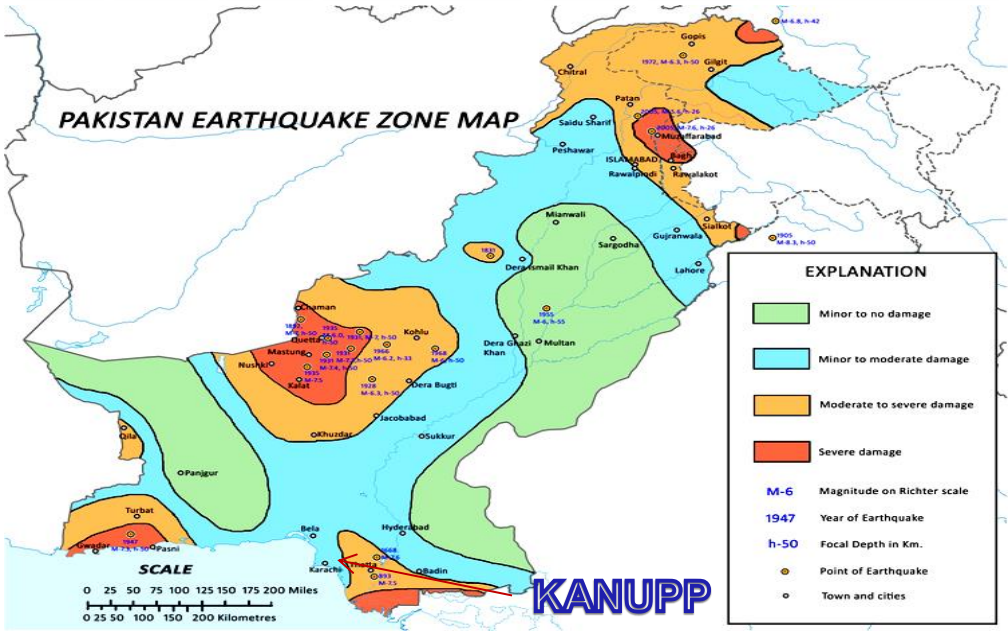
A sea wall scheduled for completion in one year will attempt to prevent contaminated water from flowing into the ocean.

Water Tanks:- Since the disaster in March 2011, hundreds of tanks have been built behind the plant to hold contaminated water. TEPCO informed that about 270 tons of water had leaked from one of them.

1. External Natural Hazard – Tsunami / Flooding / Earthquake

- In 1945, the great earthquake of magnitude 8.3 caused 1.5 m height tsunami at Karachi harbor (~275 miles from epicenter)
- Recent study for assessment of tsunami hazard for KANUPP concluded that maximum height of the wave resulting from the tsunami would be up to 3.28 ft (~ 01 m)
- The heaviest rain fall recorded so far during last 50 years in a day ~ 10 inches (25.4 cm). The max. rain fall caused flooding in city but plant remained unaffected
- KANUPP is 39´(~ 12 m) above mean sea level, quite safe from tsunami. Distribution room, EDGs, fuel tanks, ECC DGs and EFW located at ground level (39 ft above mean sea level)





Back

1. External Natural Hazard - Earthquake
Seismic Retrofits / Anchoring (≥ 0.2g)


Strengthening of Wall above DG3 bus bar


Reinforcement of Cable Trays

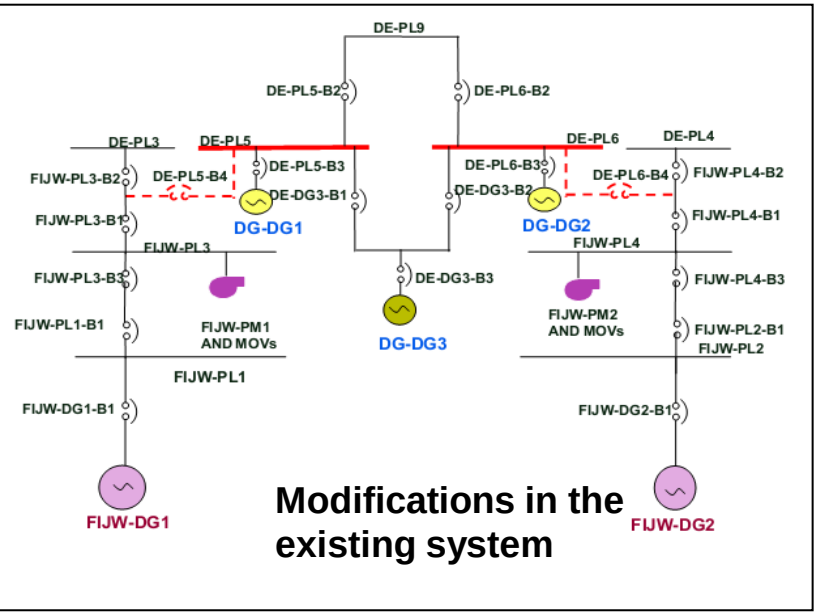

Strengthening of Wall near Bus bar


Anchoring of DGs Local Panel

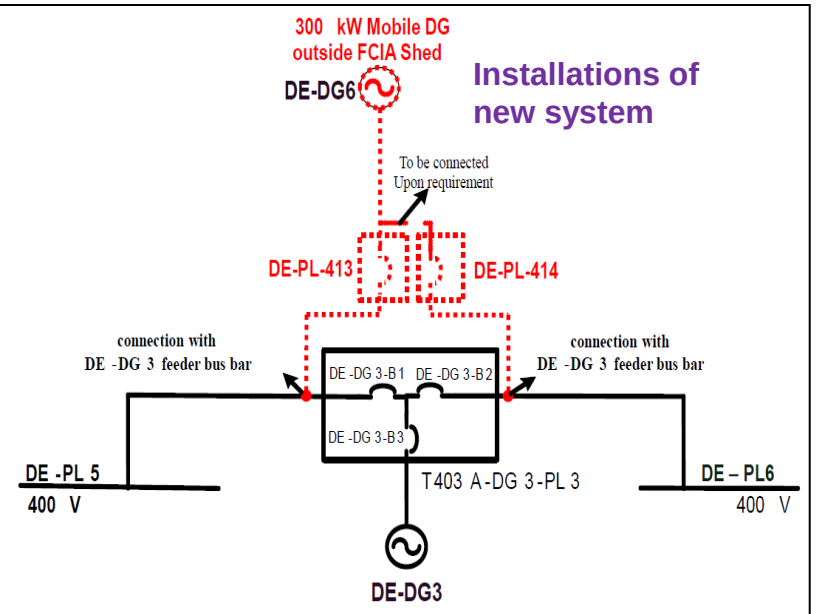

Flap and Sliding Gates

Back

2. Make-Shift Emergency Power Sources



Modifications in the existing system



Installations of new system

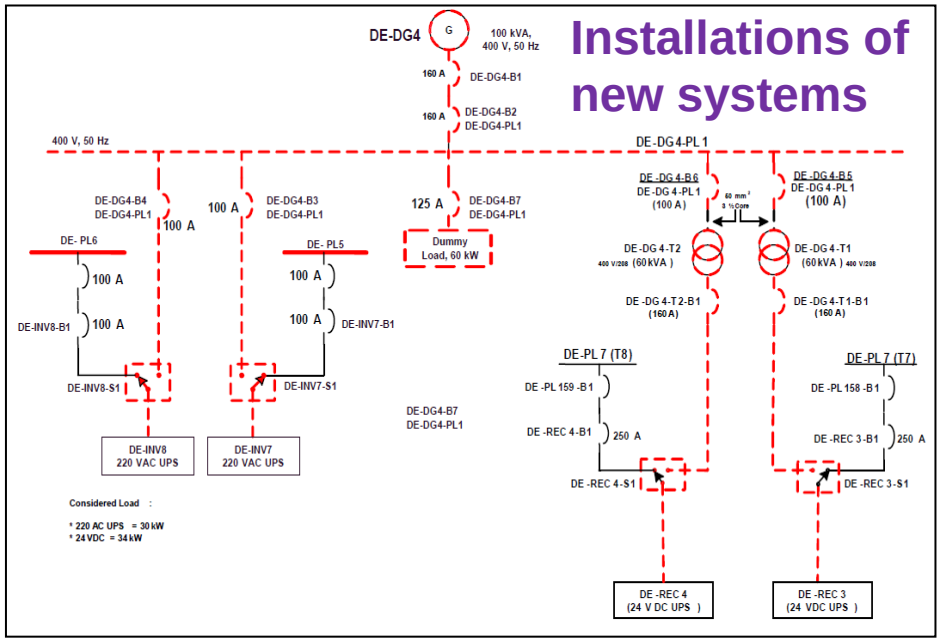
Interconnection scheme of 300 kW DG

Portable Diesel from Outside Agency

Back

3. DC Power Capacity Enhancement

- Preparation of DC conservation procedure to improve battery back time of 230V DC from 01 to 07 hrs
- Installation of a 100 kVA DG set and its integration scheme (at higher elevation, resilience from earthquake and flooding)



- To provide continuous power supply (through 24V DC UPS and 220V AC UPS systems) to control, monitoring and signaling systems in case of unavailability of essential power for longer duration
- To provide alternate power to ECC MOVs
- To supply power to station emergency lighting system

Back

DC Power Capacity Enhancement

100 kVA DG-DG4 (37’ above ground)

Transformers

Main Distribution Panel

220V AC Changeover

24V DC Changeover

ECC MOVs Changeover Switch Panels

Back

4. Fire Prevention and Control Measures

- Seismic qualification of fire water ring
- External support for controlling fire emergency
- Strengthening of Fire Fighting Crew

Refurbishment of Existing Fire Tender

New Fire Alarm System

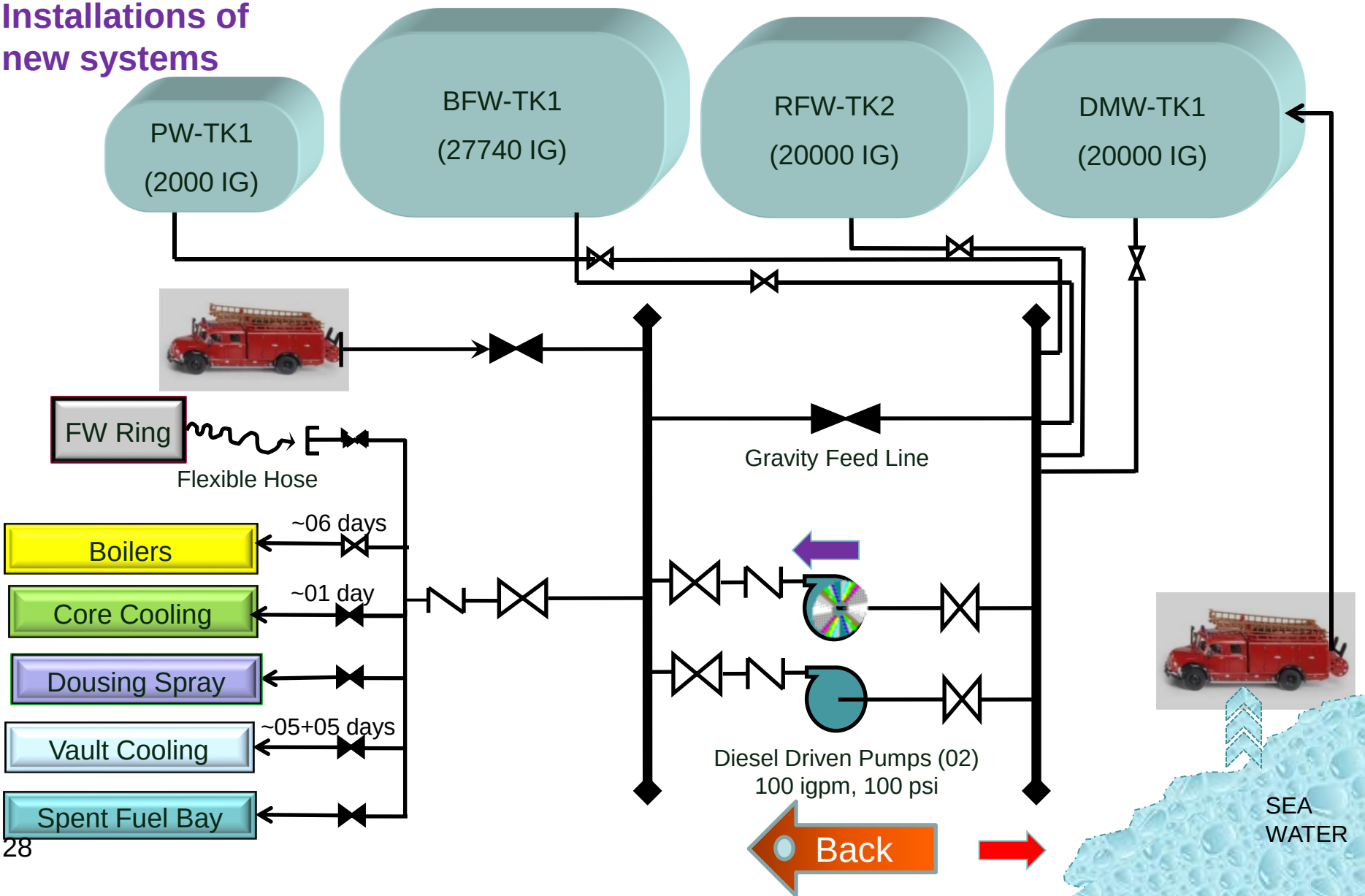
New Fire Tender procured

Back

5. Emergency Cooling (EC) Provisions

Additional Measures For Core Cooling (Direct / Indirect)

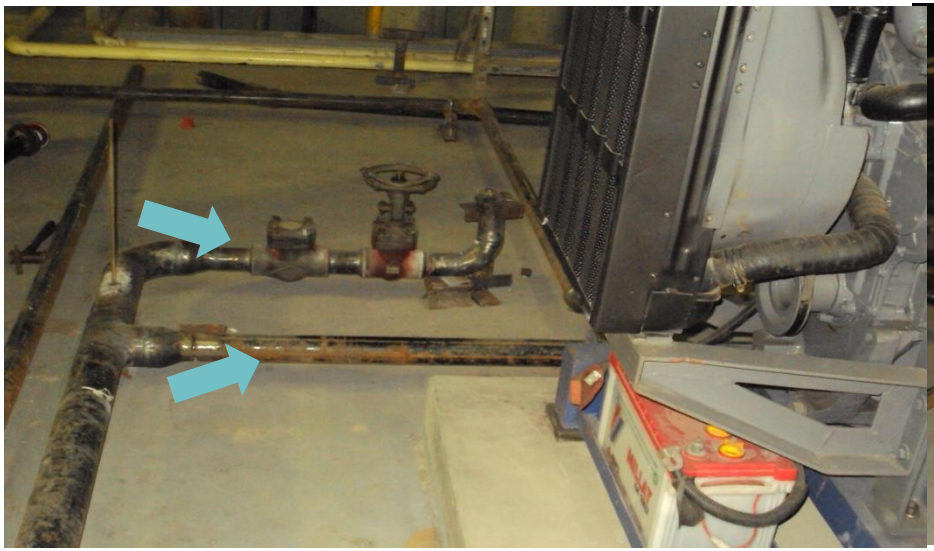
Installations of new systems



Emergency Core Cooling Measures

Diesel Driven Pump

Interconnection with Water Tank



Suction / Discharge Header

Piping Layout

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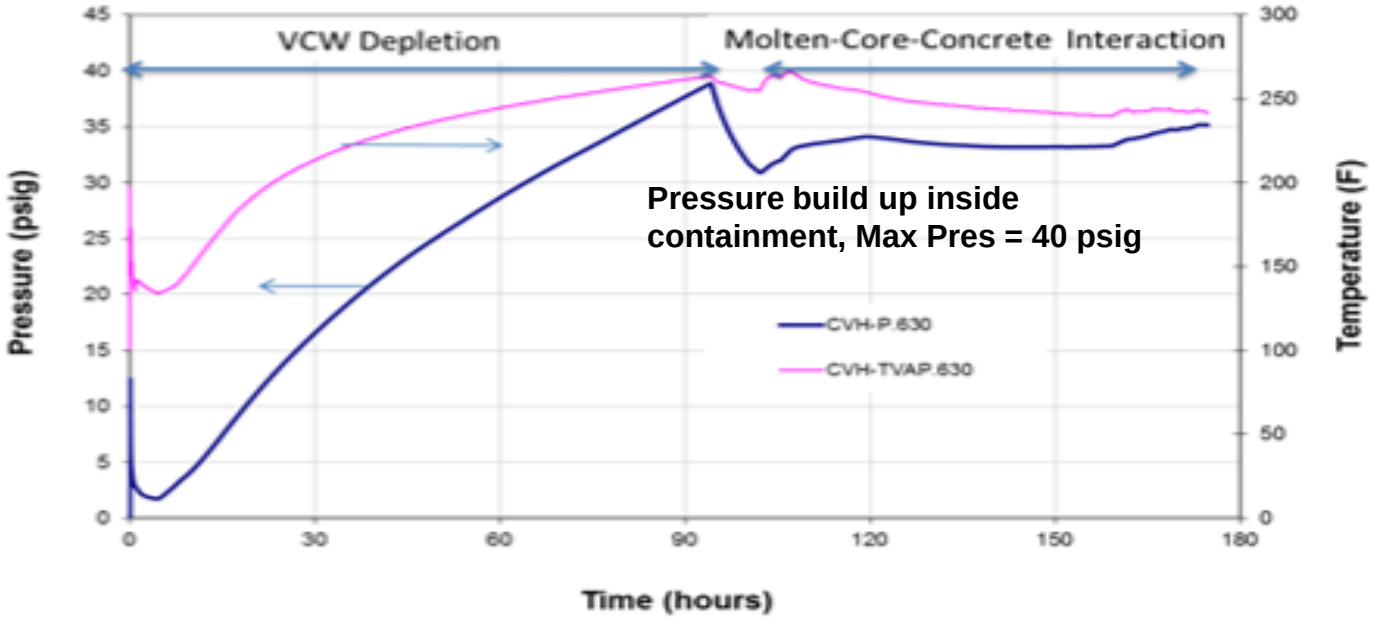
6. Hydrogen Hazard Assessment



- Hydrogen hazard assessment study concluds that short term hydrogen concentration ~ 7% if fuel cladding material (3128 kg) completely oxidized. Whereas the calculated value of long term Hydrogen due to MCCI is 430 kg
- Installation of Hydrogen Analyzer for monitoring and Installation of 12 PARs each of 1.2 kg/h capacity for controlling hydrogen is being done

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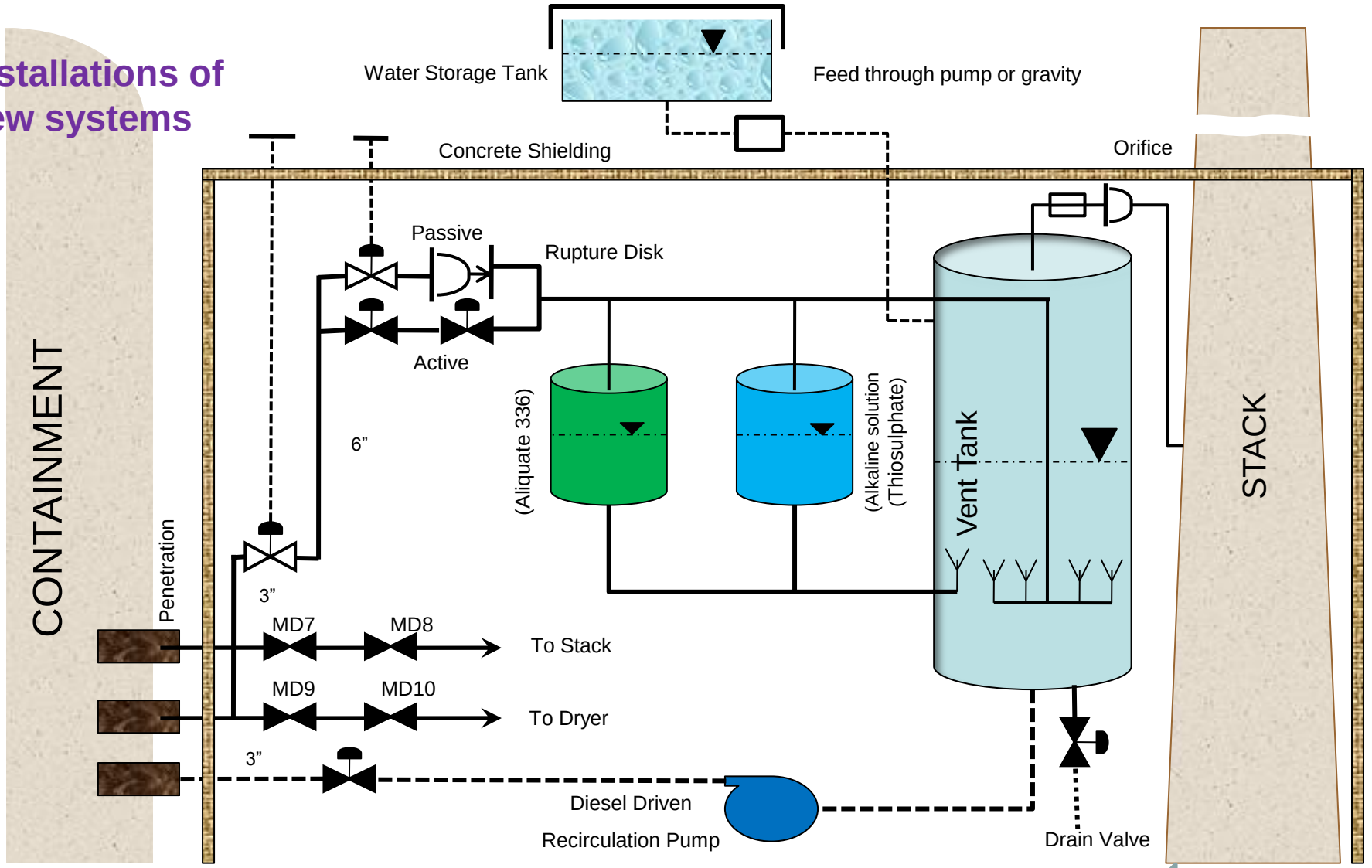
7. Containment Integrity – Filtered Venting

Installations of new systems



Containment Filtered Venting System

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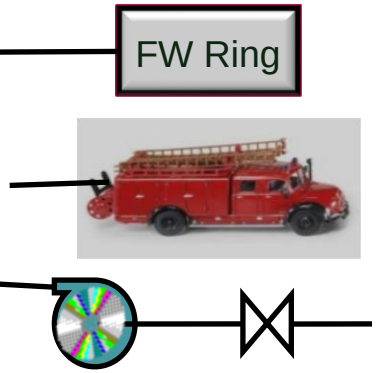
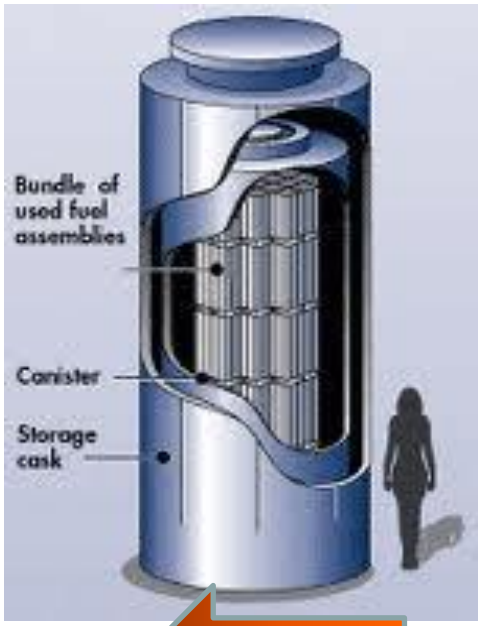
8. Spent Fuel Cooling

- Estimation of source term of Spent Fuel when water is lost or configuration is disturbed in Bay
- Calculation of dry out times of Spent Fuel Bay ~ 19 days
- Measure against loss of cooling or drainage of KANUPP Spent Fuel Bay ~ 140 days
- Design and development of Spent Fuel Dry Storage Facility by 2016





Dry Fuel Storage

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9. EOPs, SAMGs (On-Site Actions)

- EOPs developed and reviewed by IAEA experts in 2009. In 2010, revised version of EOPs issued after incorporation of IAEA experts recommendations
- In response to Fukushima
  - SAMGs for external natural hazard and Spent Fuel Cooling revisited
  - Validation and verification (V&V) of SAMGs conducted through tabletop and walkthrough
  - Revised EOPs. SAMGs issued and training imparted to operating personnel

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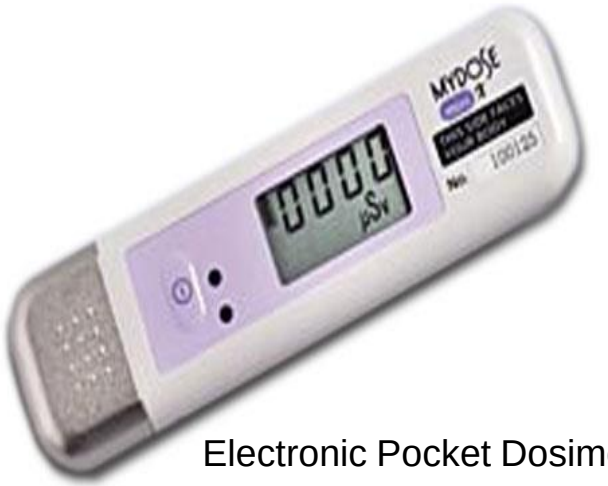
Enhancement for Emergency Preparedness

KI Tablets

Satellite Phone

Gamma Spectrometry System

Mobile Radiation Monitoring Lab (MRML)



Electronic Pocket Dosimeter

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