# Severe Accident Management and Beyond Design Bases Event Response – an End-User Perspective

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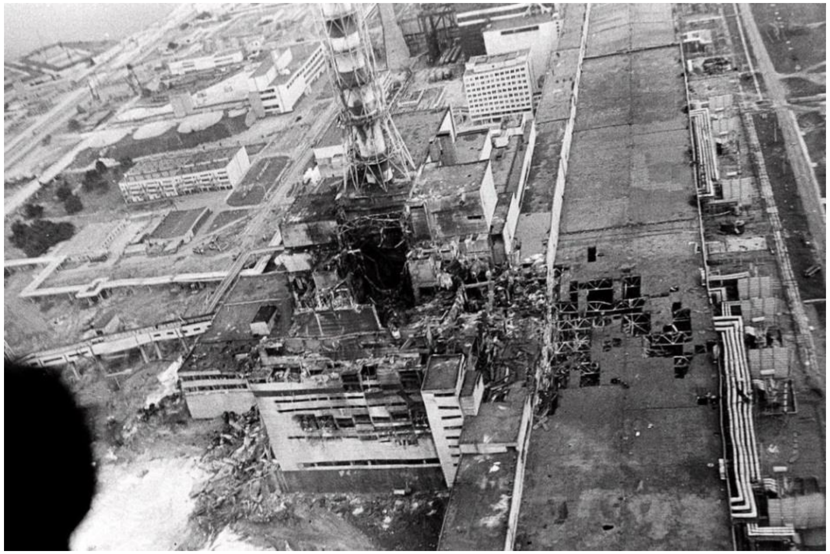
# The Nuclear Industry:

# Shaped by the Past and Poised for the Future – A Legacy of Lessons Learned

***"Nuclear power is a technology whose complexity far exceeds that of other common methods of generating electricity….***
***Admiral Hyman G. Rickover, Father of the U.S. Nuclear Navy***

# Significant Events in Nuclear Power

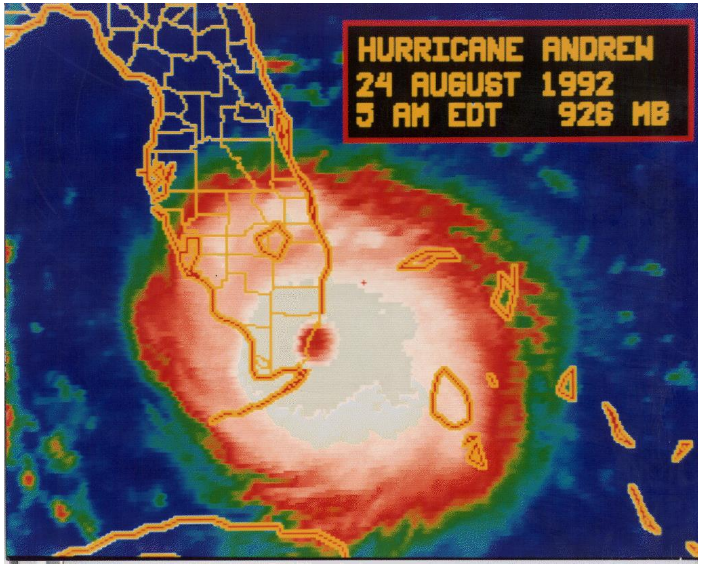


- Chalk River NRX – Core Damaging Event (December 12, 1952)
- Windscale 1 – Reactor Fire (October 10, 1957)
- SL-1 – Excessive Manual Control Rod Withdrawal Caused Violent Power Excursion (January 3, 1961)
- Fermi 1 Prototype – Partial Core Meltdown from Foreign Material (October 5, 1966)
- Browns Ferry 1 – Fire Results in Loss of Safety-Related Components (March 22, 1975)
- Three Mile Island 2 – Loss of Coolant Accident with Major Fuel Damage (March 28, 1979)
- Chernobyl 4 – Reactor Explosion (April 26, 1986)
- Davis Besse – Undetected Leak and Degradation of the Reactor Vessel Head (March 5, 2002)
- Fukushima Daichi – extended SBO from Tsunami resulted in core damage in multiple units (March 11,2011

# Beyond Design Bases External Events Represent New Challenges

Missouri River Flooding at Ft. Calhoun NPS June 2011

September 11, 2001 attacks at the WTC identified possibility of BDB Events that were security related




Hurricane Andrew Striking South Florida in August 1992

Tornadoes in Tennessee Valley resulted in extended LOOP at Browns Ferry in April 2011

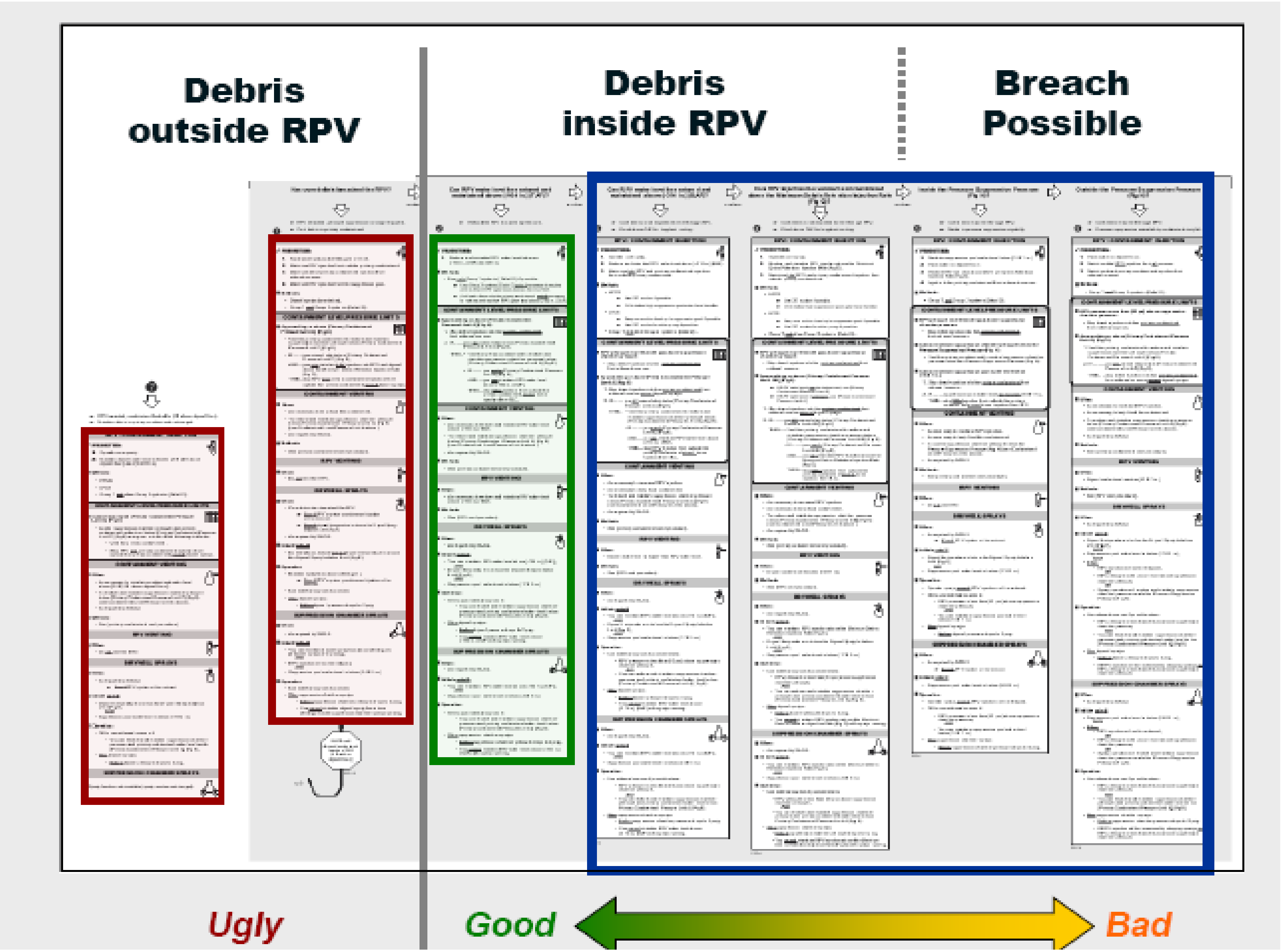
# BDB Event Response Background

## Word Hard – Do the Right Thing (Take Action)

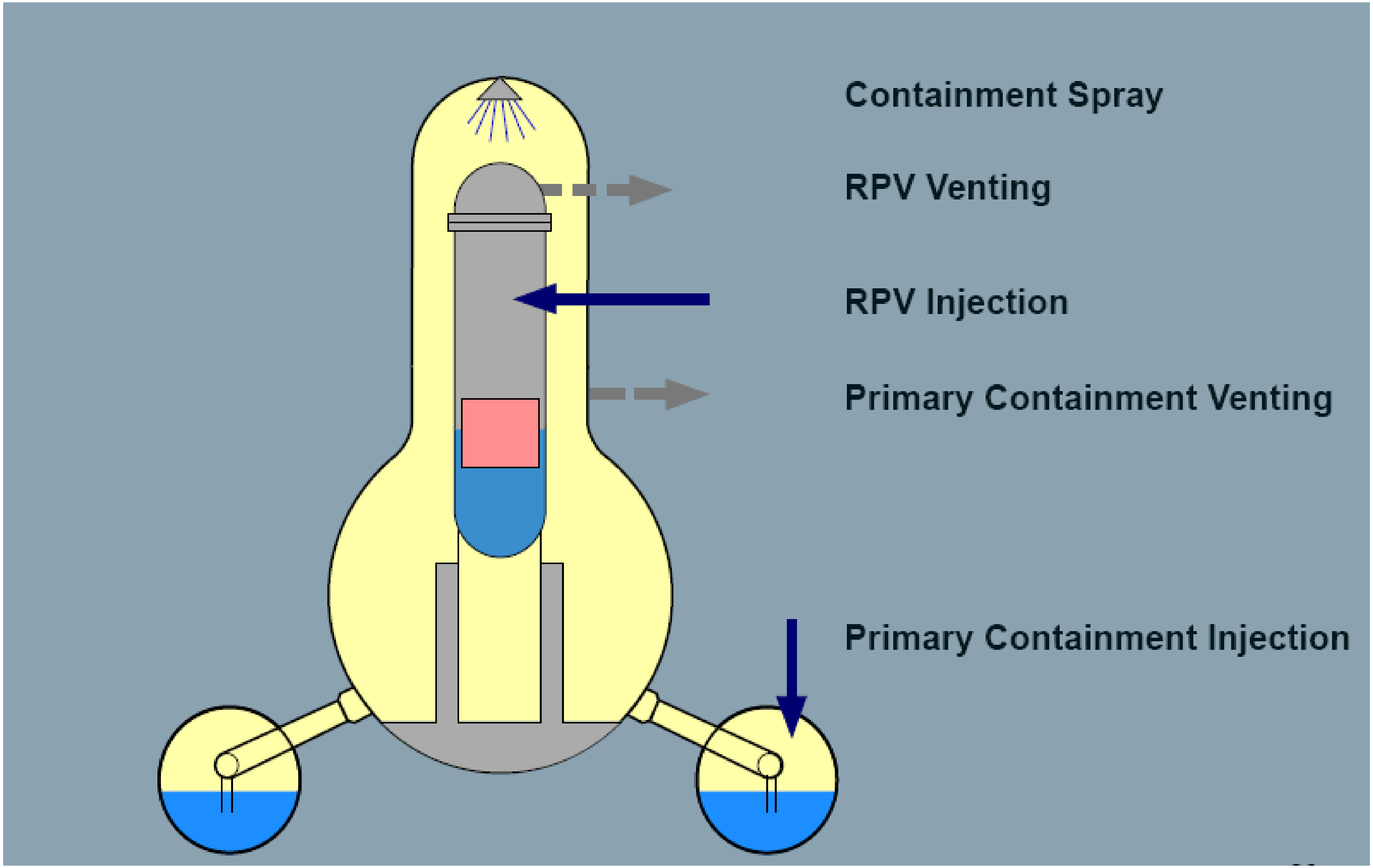
# Previous Drivers of BDB Event Response

- Three Mile Island (1979)
  - NUGREG-0737, TMI Action Plan
  - SECY-89-012: NRC policy that outlines objectives and elements of a severe accident management program
  - NEI 91-04: Defines industry initiative and SAM program
- World Trade Center & Pentagon Attacks (9/11/2001)
  - NRC Orders (B5b) - Required US nuclear plants to consider circumstances associated with loss of large areas of the plant due to explosions or fire. Plants required to develop alternate strategies to maintain or restore capabilities for:
    - Core cooling
    - Containment cooling
    - Spent Fuel Pool cooling
  - NEI 06-12: Defined industry initiatives and Extensive Damage Management Guidance

# Duane Arnold Severe Accident Guideline



# SAGs - Manage Multiple Priorities in RPV & Primary Containment Based on Damage State



# Severe Accident Management Support Procedures

- SAMP 701 - Bypass of PCIS Group 4 SDC Isolation from High DW Pressure and Low RPV Water Level
- SAMP 702 - Alternate SBDG Cooling
- SAMP 703 - RCIC Operation Following Loss of Electric Power
- SAMP 704 - Powering 125 VDC Battery Chargers from Portable Diesel Generator
- SAMP 705 - Connection of Temporary Power to Non-essential 480 VAC Bus using Portable Diesel Generator
- SAMP 706 - Venting Primary Containment Following Loss of Pneumatic Supply/DC Power
- SAMP 707 - Emergency SRV Operation using Portable DC Power
- SAMP 708 - Emergency RPV Makeup with the Portable Diesel Fire Pump
- SAMP 709 - Emergency Hotwell Makeup with the Portable Diesel Fire Pump
- SAMP 710 - Emergency CST Makeup with the Portable Diesel Fire Pump
- SAMP 711 - Emergency Drywell Makeup with The Portable Diesel Fire Pump
- SAMP 712 - Spent Fuel Pool Makeup and Spray
- SAMP 713 - Fission Product Scrubbing
- SAMP 714 - Manually Isolating RWCU
- SAMP 715 - Portable Diesel Fire Pump Operation
- SAMP 716 - Initial Response Extensive Damage Mitigation Guidelines (EDMG)
- SAMP 717 - Cross-connecting ESW Loops

# Technical Support Guidelines (TSGs)

- **Control Parameter Assessment Guideline (CPAG) - to evaluate the operability and reliability of instrumentation used to determine key parameters and to develop a best estimate value for each parameter**
- **Plant Status Assessment Guideline (PSAG) - to forecast the future values of parameters, specify the current state of the plant with respect to existing conditions, and provide alternate EOP/SAG limit curves as appropriate**
- **System Status Assessment Guideline (SSAG) - to evaluate the operability and reliability of plant systems used for event response**
- **EOP/SAG Action Assessment Guideline (EAAG) - to determine the priority with which systems should be restored to service and identify timing for actions directed during event response**

***TSGs are tools developed for TECHNICAL Support Staff that are analyzing plant conditions, assessing available equipment, and determining optimum strategies***

# B5b Accident Mitigation Strategies Required For All US Plants

## BWR Mitigation Strategies

- Manual Operation of RCIC or Isolation Condenser
- DC Power Supplies to Manually Depressurize RPV to support injection with Portable Pump
- Utilize Feedwater and Condensate
- Makeup to Hotwell with portable pump
- Makeup to CST with portable pump
- Maximizing CRD flow
- Manually Isolating RWCU
- Manually Opening Containment Vent Lines
- Injecting Water into Drywell with portable pump
- Portable Sprays

## PWR Mitigation Strategies

- Makeup to RWST
- Manually Depressurize Steam Generators to Reduce Inventory Loss
- Manual Operation of Turbine (or Diesel)-Driven AFW Pump
- Manually Depressurize Steam Generators and Use Portable Pump
- Makeup to CST
- Containment Flooding with Portable Pump
- Portable Sprays

***New strategies primarily involved the use of portable equipment to provide defense-in-depth for critical safety functions***

# B5b Accident Mitigation Strategies

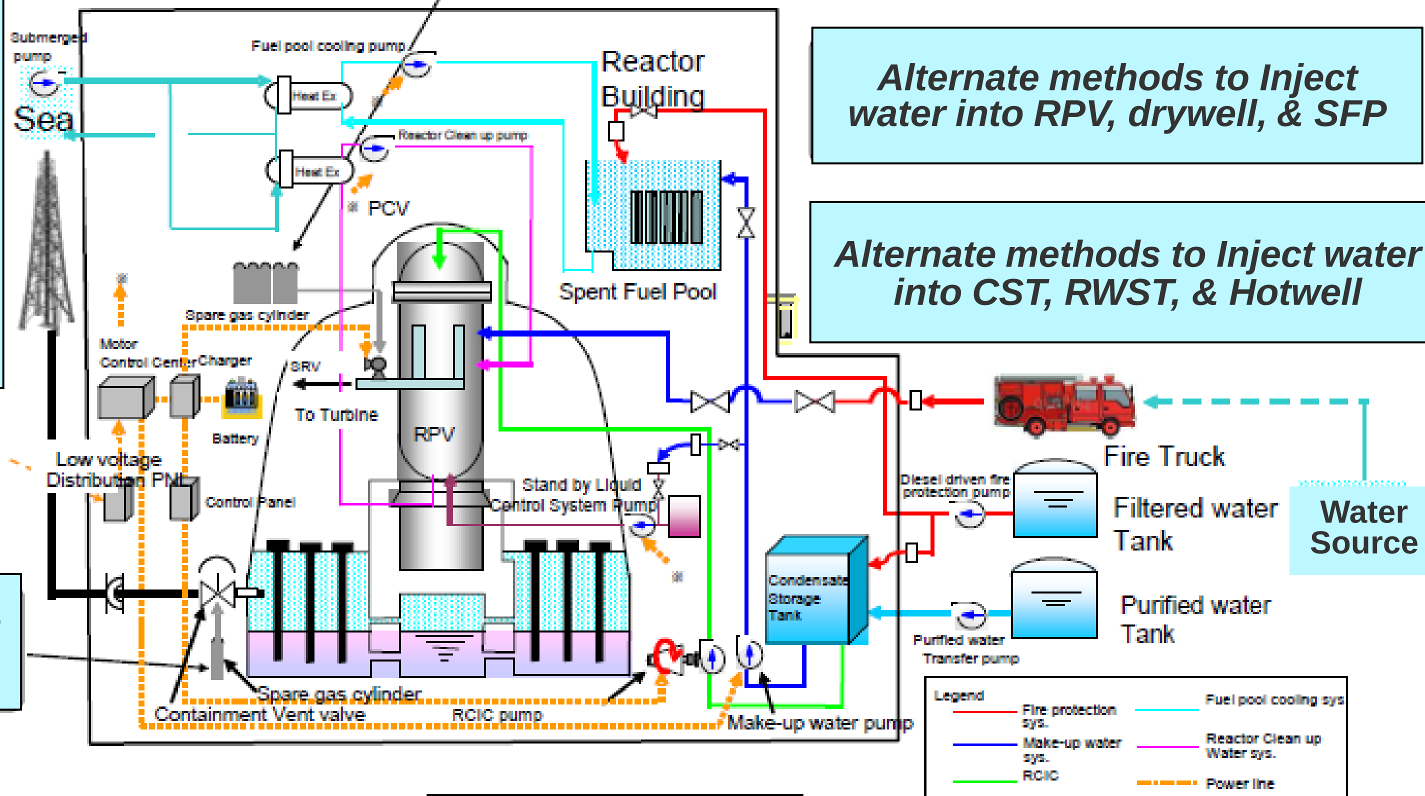
***Alternate methods to depressurize RPV***

***Emergency Power***

- ***Power Restoration***
- ***Portable Generators***
- ***Spare Cables***

***Alternate methods to Inject water into RPV, drywell, & SFP***

***Alternate methods to Inject water into CST, RWST, & Hotwell***




***Manual operation of PCV***

***Manual operation of RCIC***

# Fukushima OE Insight

- *During the Fukushima event, factors such as loss of power and tsunami damage significantly hindered efforts to vent the containments. Procedures did not exist to address how to vent containment when all power, compressed air, and indications were lost. This contributed to the delay in implementing actions to depressurize the RPV and vent the primary containment.*

***The delay in venting significantly increased the magnitude of the radiological release to the environment.***

**Voices from the Field: "In total darkness, I could hear the unearthly sound of SRV dumping steam into the torus. I stepped on the torus to open the S/C spray valve, and my rubber boot melted."**

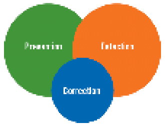
# Understanding Design & Vulnerabilities

## Effectively Evaluate Consequences of Events


DILIGENT PREPARATION + ORGANIZED RESPONSE
= SUCCESSFUL RECOVERY

# Understanding Design & Vulnerabilities

## DAEC - Key PRA Results

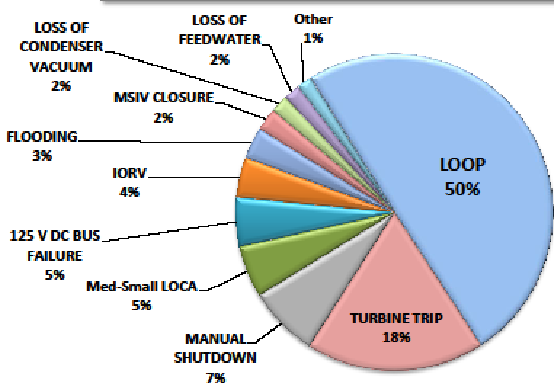


Baseline Core Damage Frequency (CDF) =3.45E-06 /yr
Baseline Large Early Release Frequency (LERF) = 1.21E-06 /yr

DAEC Internal Events Rev 6 Model [June 2011]

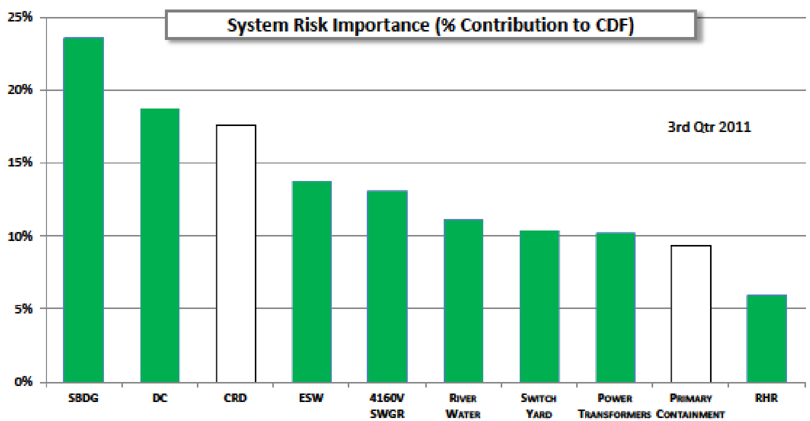
**Internal Events**

Initiating Event Importance (% Contribution to CDF)




| Top 10 Risk Important Components (% Contribution to CDF) | | | |
|---|---|---|---|
| | Component | Description | CDF % |
| 1 | 1A311/1A411 | EDG Output Breakers [Close] | 10.1% |
| 2 | 1P44A/B | EDG Fuel Oil Transfer Pumps [Start] | 6.7% |
| 3 | 1G21/1G31 | EDG [Start/Run] | 6.4% |
| 4 | PSV 4400-4407 | Relief Valves [Reseat] | 4.9% |
| 5 | 1D1/1D2 | 125 VDC Batteries [DC Power] | 4.6% |
| 6 | CV2080/CV2081 | ESW Cooling Supply Valves to EDGs [Open] | 4.3% |
| 7 | 1A302/1A402 | Start Up Transformer Supply Breakers [Open] | 3.8% |
| 8 | CV4914/CV4915 | Stilling Basin Valves [Open] | 2.6% |
| 9 | TSC DG | TSC Diesel [Run] | 1.8% |
| 10 | 1P226 | RCIC Pump [Run] | 0.9% |

System Risk Importance (% Contribution to CDF)




| Top 10 Risk Important Operator Actions (% Contribution to CDF) | | |
|---|---|---|
| | Operator Action | CDF % |
| 1 | CONTROL FEEDWATER FOLLOWING SCRAM | 19.5% |
| 2 | INITIATE FEEDWATER | 18.9% |
| 3 | INITIATE RPV EMERGENCY DEPRESS | 12.1% |
| 4 | INITIATE TORUS COOLING | 10.3% |
| 5 | VENT PRIMARY CONTAINMENT | 9.3% |
| 6 | INJECT SLC EARLY | 7.6% |
| 7 | INITIATE CONDENSATE FOR ALTERNATE INJECTION | 7.1% |
| 8 | BYPASS HPCI LOW RPV PRESSURE TRIP | 7.0% |
| 9 | MANUALLY OPEN RHR CROSSTIE VALVE MO1942 (DIV 1 AC UNAVAILABLE) | 7.0% |
| 10 | ALIGN ALTERNATE LP INJECTION – RHRSW, ESW or GSW | 6.2% |

10/10/2011

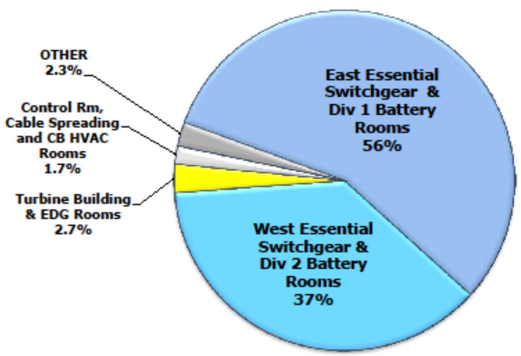
# Understanding Design & Vulnerabilities

DAEC FIRE PRA Model [February 2011]

## DAEC - Key FIRE PRA Results

Core Damage Frequency (CDF) =5.706E-05 /yr
Large Early Release Frequency (LERF) = 3.591-05 /yr

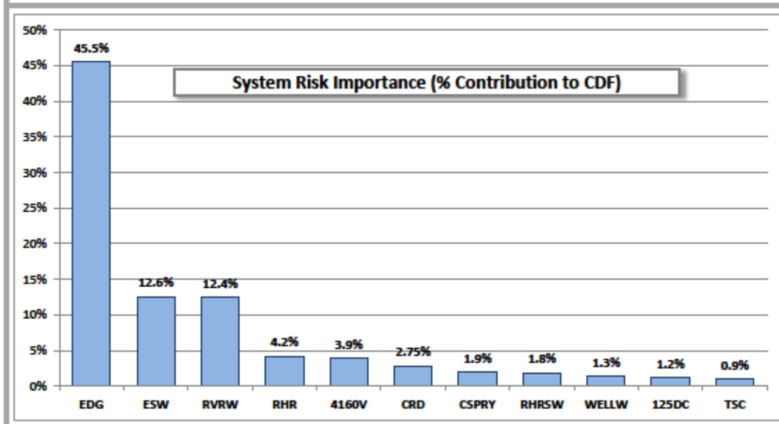
### Initiating Event Importance (% Contribution to CDF)




### Top 10 Risk Important Components (% Contribution to CDF)

| | Description | CDF % |
|---|---|---|
| 1 | EDG 1G21 FAILS TO START/RUN | 9.3% |
| 2 | EDG 1G31 FAILS TO START/RUN | 6.6% |
| 3 | ESW CV2081 FAILS TO OPEN | 2.2% |
| 4 | 4160 V CIRCUIT BREAKER 1A411 FAILS TO CLOSE ON DEMAND | 2.2% |
| 5 | EDG FUEL OIL TRANSFER PUMP B FAILS TO START/RUN | 2.0% |
| 6 | CV 4914, 1P-117B/D INLET TO STILLING BASIN FAILS TO OPEN | 1.7% |
| 7 | ESW CV2080 FAILS TO OPEN | 1.6% |
| 8 | 4160 V CIRCUIT BREAKER 1A311 FAILS TO CLOSE | 1.6% |
| 9 | EDG FUEL OIL TRANSFER PUMP A FAILS TO START/RUN | 1.4% |
| 10 | CV 4915, 1P-117A/C INLET TO STILLING BASIN FAILS TO OPEN | 1.0% |

### System Risk Importance (% Contribution to CDF)




### Top 10 Risk Important Operator Actions (% Contribution to CDF)

| | Operator Action | CDF % |
|---|---|---|
| 1 | ALIGN STANDBY 125VDC BATTERY CHARGER | 3.19% |
| 2 | INITIATE RPV EMERGENCY DEPRESS (TRANSIENTS) | 2.74% |
| 3 | MAXIMIZE CRD FLOW FOR TRANSIENTS AND SLOCA-ST | 2.37% |
| 4 | CONTROL FEEDWATER FOLLOWING SCRAM | 1.53% |
| 5 | SHEDS BATTERIES PER AOP 301 DURING SBO | 1.18% |
| 6 | OPEN LPCI INJ MOV-1904(-2004) GIVEN MOV-2004(-1904) FAILS | 0.92% |
| 7 | ALIGN ALT LP INJECTION (TRAN, SLOCA, MLOCA, IORV) | 0.89% |
| 8 | MAXIMIZE WELL WATER TO MAINTAIN CONDENSER | 0.58% |
| 9 | CROSS TIE ESW TRAINS | 0.56% |
| 10 | OPEN PUMPHOUSE DOORS | 0.54% |

11/30/2011

# Understanding Design & Vulnerabilities

**Result:** Adequate Core Cooling >24 Hours
RCIC operable for 6.2 hours
DC battery life extended to 7 hours based on load shed
Portable equipment aligned by 6.2 hours

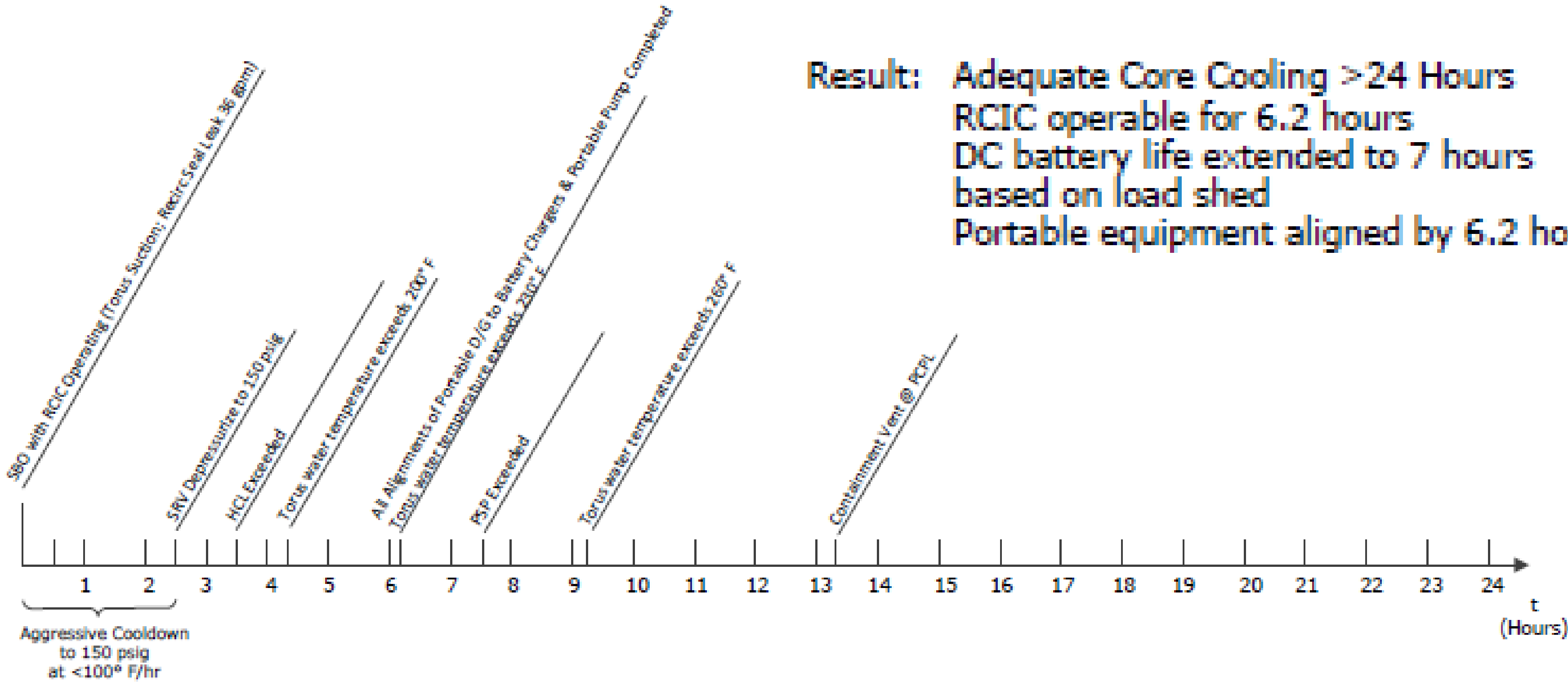


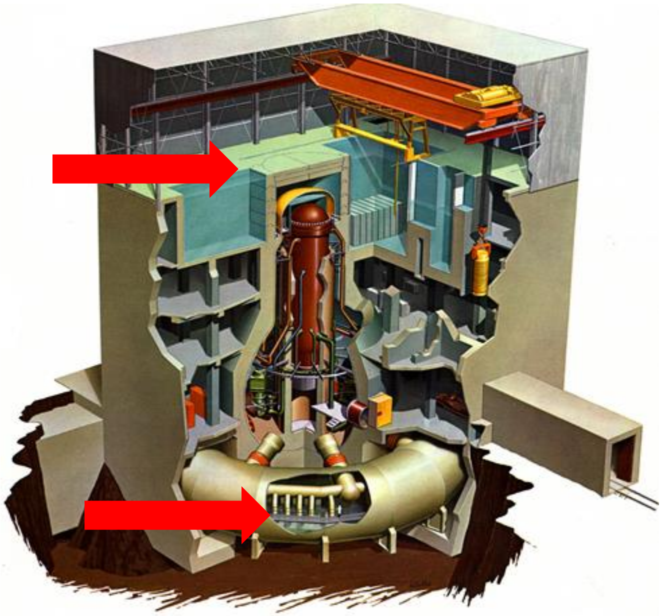

**Figure S-2**

**DAEC SBO COPING CAPABILITY (INPO IER 11-4 CASE BASED ON USE OF INSTALLED AND PORTABLE EQUIPMENT WITH ENHANCEMENTS)**

**RCIC WITH SUCTION FROM TORUS AND NO EMERGENCY DEPRESSURIZATION ON HCL(DA130831k) (PORTABLE PUMP SUCCESSFULLY ALIGNED)**

# Understanding Design & Vulnerabilities

- **In the event of containment failure due to overpressurization, PRA insights indicate that the likely failure points would be the drywell head <u>or</u> torus above the waterline.**
  - If the torus room is accessible post-event, sprays could be deployed to support fission product scrubbing.
  - Sprays cannot be deployed to directly spray the drywell head. Instead, the refuel floor area above the drywell head shield blocks may need to be sprayed to mitigate releases from the drywell head.

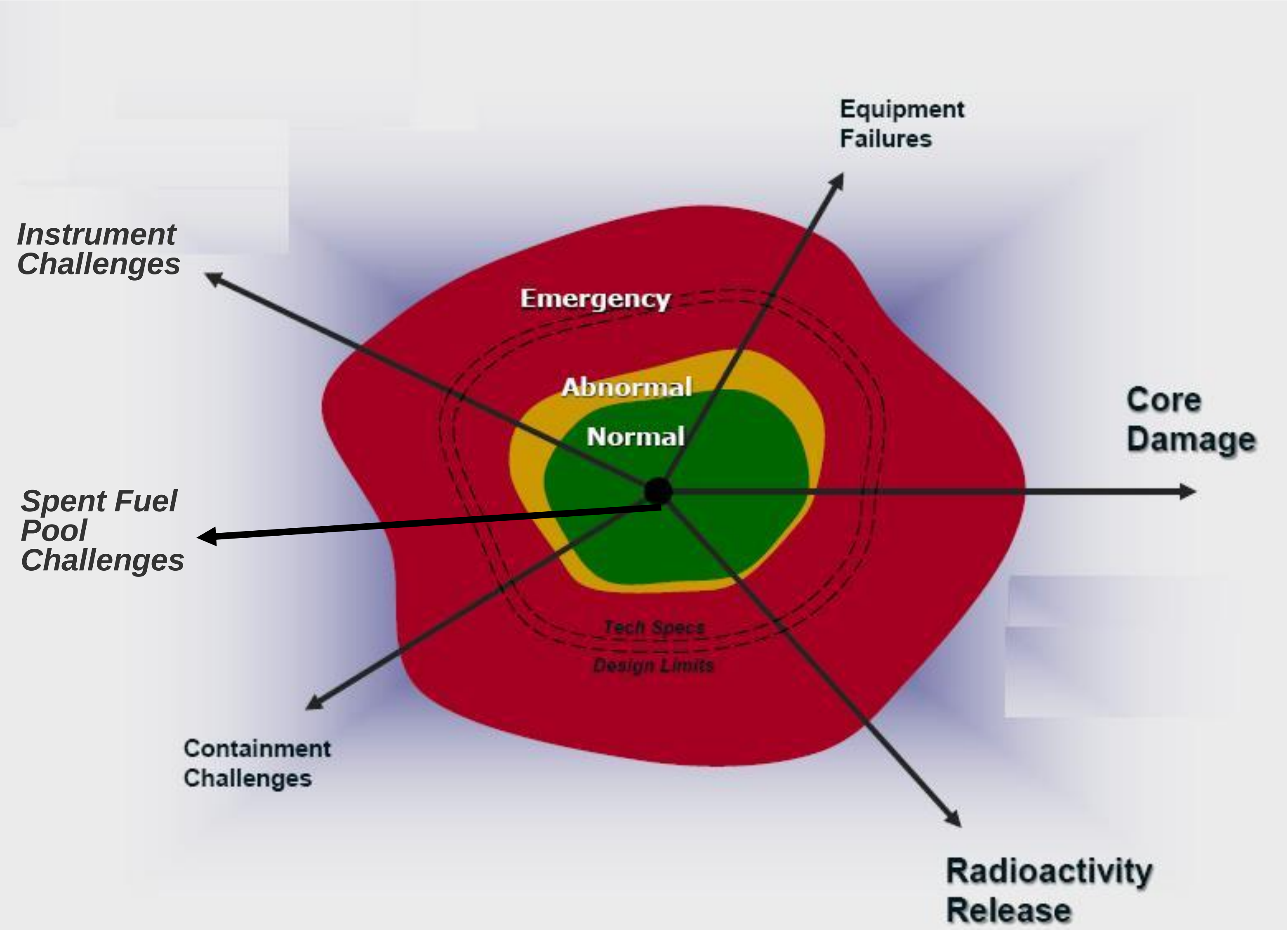


# Integration of BDB Event Response Guidance

## Begin with the End in Mind


DILIGENT PREPARATION + ORGANIZED RESPONSE
= SUCCESSFUL RECOVERY

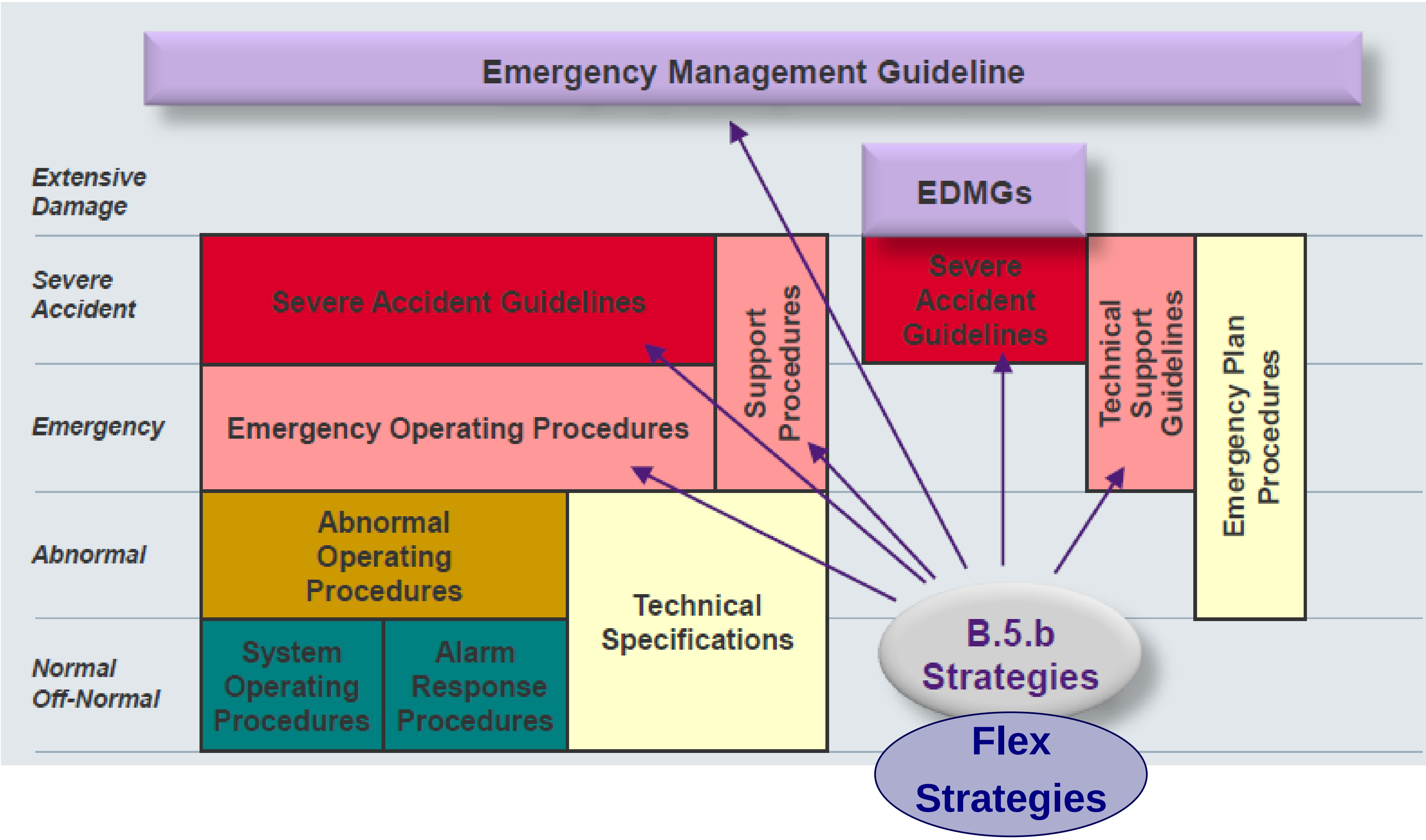
# BDB Event Response Challenges



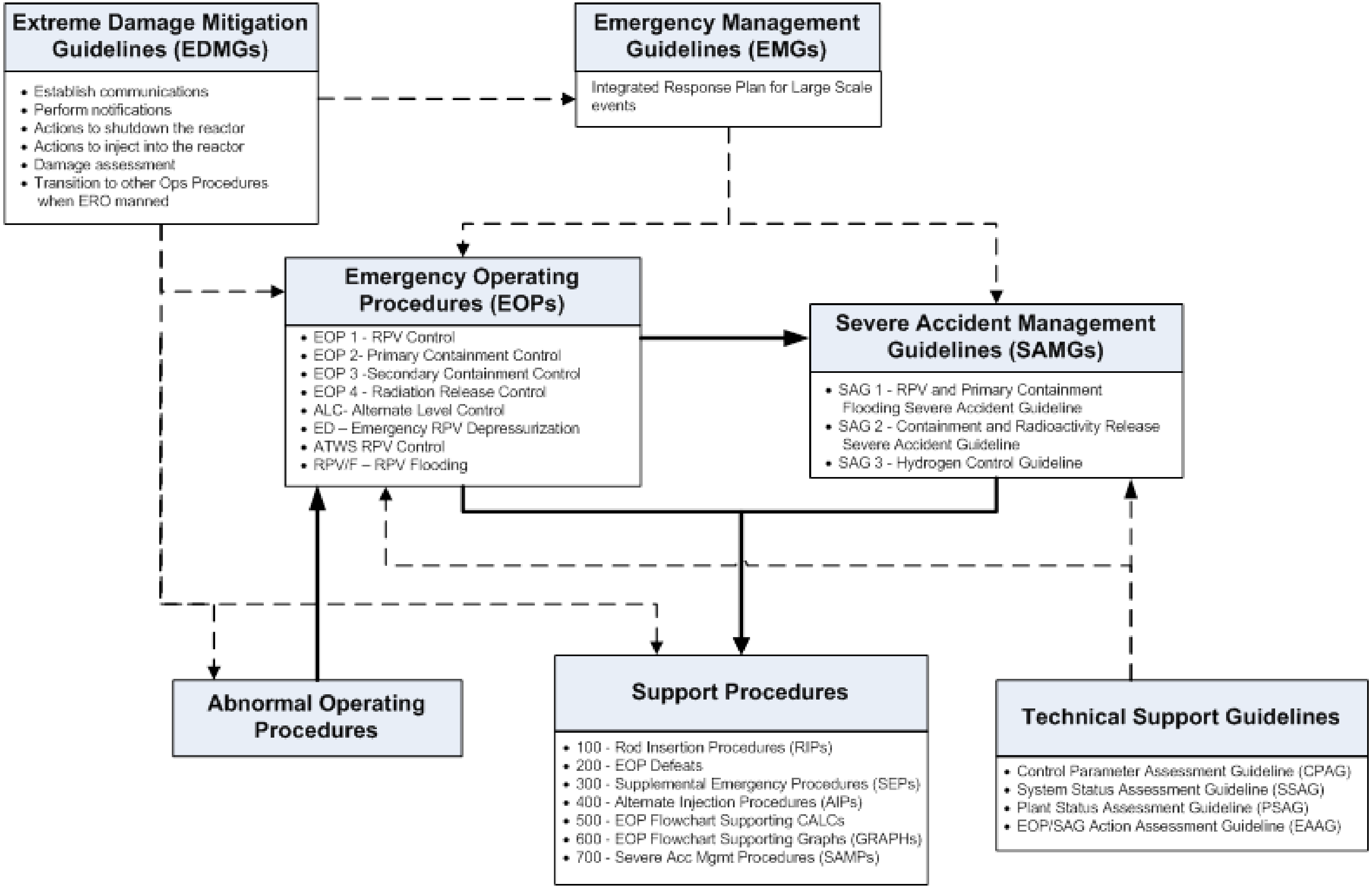
# BDB Challenge - Managing Multiple Priorities for Entire Station

- Security / Medical Response (Site Access Control, Significant Injuries, Contaminated Workers)
- Damage Control (Fire Fighting, Flooding, Hazardous Materials)
- Plant Response (Reactor, Containment, Spent Fuel Pool, Ultimate Heat Sink)
- Environment (Habitability, On-site and Offsite Releases)
- Resource Needs (Electrical Power, Fuel, Water, Pneumatics, Instrumentation, Special Equipment, Communications, People)
- Emergency Plan Functions (Evaluations, Notifications, Evacuations)
- Priorities established for use of available equipment with multiple demands for it’s use

# Integrating BDB Event Response Guidance



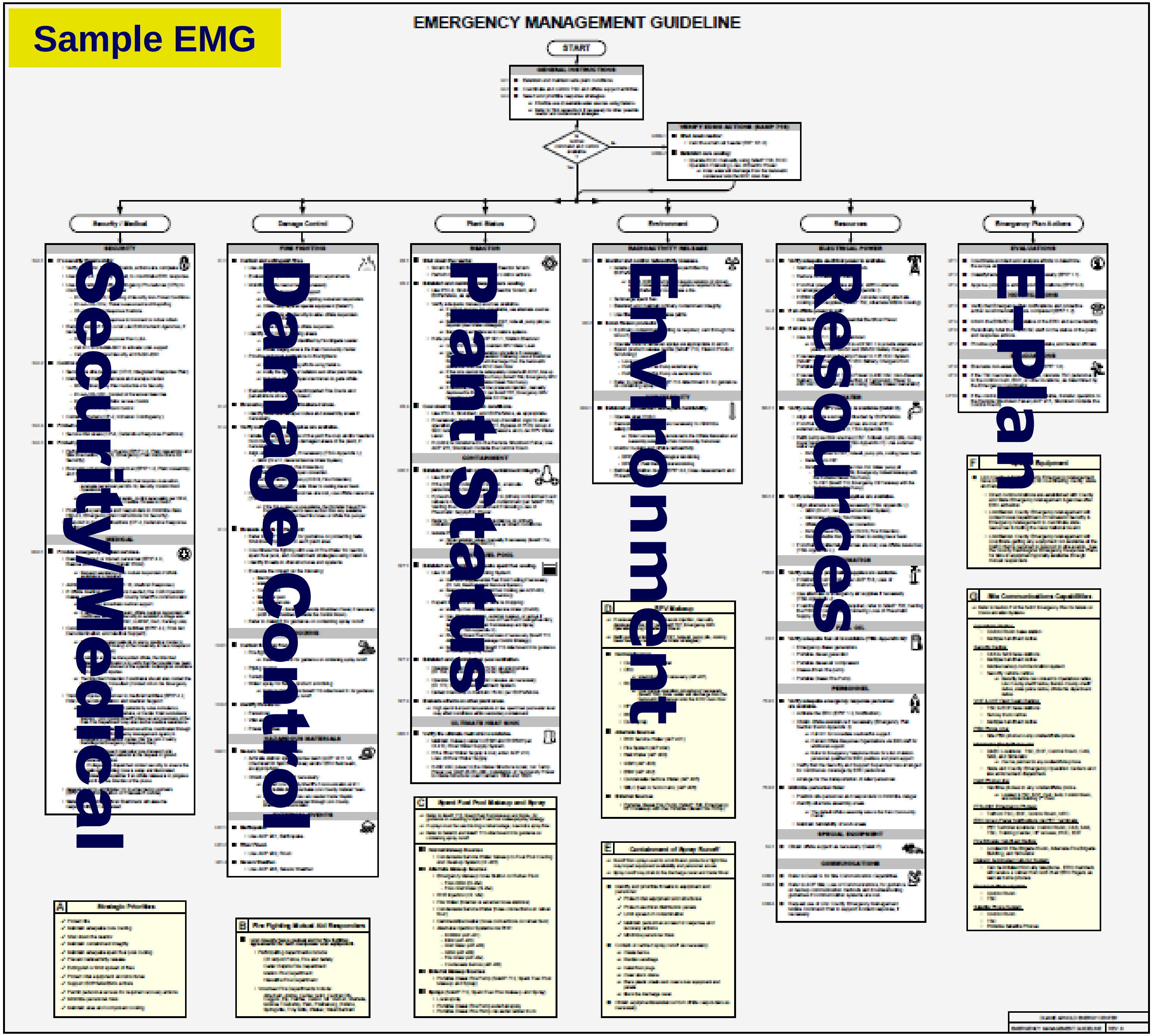
# Integrating BDB Event Response Guidance At Duane Arnold



# Duane Arnold Emergency Management Guideline (EMG)

- **Manage response to large complex events – design bases and beyond design bases**
- **Used by ERO Decision Makers**
- **Directed in ERO Activation Checklists**
- **Establishes objectives, strategies, and priorities**
- **Coordinates guidance in:**
  – Emergency Plan Implementing Procedures
  – Security procedures
  – Operations Procedures (AOPs, EOPs, SAGs)
  – Technical Support Guidelines (TSGs)
  – Severe Accident Management Support Procedures (SAMPs)

# Sample EMG



EMERGENCY MANAGEMENT GUIDELINE
START
Security/Medical
Damage Control
Plant Status
Environment
Resources
E-Plan

# Duane Arnold Accident Management Program

## Doing The Right Thing Voluntarily


DILIGENT PREPARATION + ORGANIZED RESPONSE
= SUCCESSFUL RECOVERY

# Key Elements of Duane Arnold Accident Management Program

- **Administrative procedures describe program requirements**
- **Accident Management Procedures / Guidelines**
  - Integrated into procedure network (Operations and Emergency Planning)
  - Engineering evaluations for key strategies including the use of portable equipment
  - Transitions and entry conditions clearly defined
  - Human Factored and tailored to users
  - Formally validated (time sensitive actions)
  - Procedure revision and configuration control
- **Configuration Control of Accident Management Program**
  - Configuration changes are evaluated against the design and licensing basis, including associated safety evaluations
  - All modifications screened for impact on BDB Equipment and Response Strategies

– **Command & Control defined for all conditions**

# Fukushima OE Insight

- ***INPO IER 13-10:*** ***The command-and-control structure and the roles and responsibilities assigned to some control room, site ERC, corporate ERC, and government agency personnel did not function as planned during this complex, long-duration, multi-unit event. As a result, the severity of the accident was exacerbated by an unclear chain of command.***

•28

# Key Elements of Duane Arnold Accident Management Program

- **Event Response Equipment**
  - Preventive Maintenance performed on key equipment
  - Periodic Testing of key equipment
  - Periodic inventory of key equipment
  - Deficiencies entered into Corrective Action and Work Control Programs
  - Clearly labeled and controlled
  - Controls for use of equipment

# Key Elements of Duane Arnold BDB Accident Management Program

- **Training**
  - Initial and Continuing Training requirements incorporated into training program descriptions
  - Qualification criteria established
  - Utilize Systematic Approach to Training principles - Analysis, Design, Development, Instruction, Evaluation (ADDIE)
  - Training encompasses procedures, command & control, severe accident phenomenon, technical bases, Operating Experience
  - Includes on-site & offsite responders, Requires formal class-room training, table top exercises, in-plant demonstrations, and full-scale drills with state, county, and local emergency responders
  - Training includes comprehensive understanding of important operator actions, risk significant equipment and their limitations, and design vulnerabilities
  - Adaptive Leadership, working under high stress conditions similar to those that might be experienced

# Training for BDB Event Response – How Comprehensive Should It Be?

**Voices from the Field: “The radiation level in the main control room was increasing by 0.01 mSv (1 mrem) every 3 seconds but I couldn’t leave - I felt this was the end of my life.”**

**He who stops being better stops being good…….** Oliver Cromwell, British military leader

# Fukushima Response:

# Being a Self-Improving Culture and Learning Organization

# Post Fukushima Industry Response

- **US Industry – "The Way Forward" Roadmap**
- **NRC Regulatory Response – Orders & Rulemaking**
- **INPO**
  - IER L1-11-1: Validated B5b, SAG, flooding, and fire response strategies
  - IER L1-11-2: Spent Fuel Pool (SFP) risk management
  - IER L1-11-4: Extended SBO Response
  - IER L1-13-10: Organizational contributors to Fukushima
  - Common Operator Training on FLEX
- **EPRI & Government Labs**
  - Revised Severe Accident Management Technical Bases Document based on Fukushima Lessons Learned
  - Extensive research such as MAAP Analysis of Accident
- **Nuclear Energy Institute**
  - Coordinating common industry approaches

# BWROG Fukushima Response

- **Revised EOPs/SAGs based on Fukushima Lessons Learned**
  - Improved guidance for Station Blackout Event (SBO) aimed at preserving RCIC & HPCI for injection and utilizing flexible equipment in the EOPs/SAGs
  - Coordination of Spent Fuel Pool control actions with RPV and containment control strategies
  - Developed guidance for Secondary Containment Hydrogen Control
  - Enhanced SAG Strategies related to Containment Flooding
- **Analysis of Equipment Capabilities & Vulnerabilities (RCIC)**
- **Evaluations for optimized containment venting practices**
- **Supporting industry implementation of FLEX**
- **Supporting industry response to NRC orders such as severe accident capable Hard Pipe Vents**
- **Multiple US and international training sessions on Fukushima Lessons Learned and improved guidance**

# Closing Thoughts

- **Beyond Design Basis Events can and do happen!**
- **Station Blackout is a significant risk contributor to BDB Events!**
  - Extended SBO events can result from external events
- **While focus must remain strong on PREVENTION; we must implement actions to improve response capabilities and minimize challenges should an event occur.  We all have a role in this endeavor!**

***Fukushima OE - Comprehensive BDB event response guidance was not developed in advance, equipment was not pre-staged and readiness maintained, and personnel were not sufficiently trained to deal with Beyond Design Events – this significantly impacted event response.***