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# **Joint IAEA-ICTP Essential Knowledge Workshop on Nuclear Power Plant Design Safety**

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## **Assessment of Internal Hazards**

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# OUTLINE

1. Definitions of Internal Hazards
2. Applicable IAEA Safety STANDARDS
3. Importance of Internal Hazards
4. General approach for design and assessment
5. Examples of Application (Pipe break-flooding)
6. Discussion

# Internal Hazards

- Internal hazards originate from sources located on the site of the nuclear power plant, both inside and outside of plant buildings. Sources may or not be part of the process equipment.
- Examples of internal hazards include:
  - Internal fires
  - Pipe whip
  - Internal floods
  - Turbine missiles
  - Drop of heavy loads
  - On-site explosions

- **Requirement 17:**

All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated.

**Hazards shall be considered for the determination of postulated initiating events** and generated loadings for use in the design of relevant items important to safety for the plant.

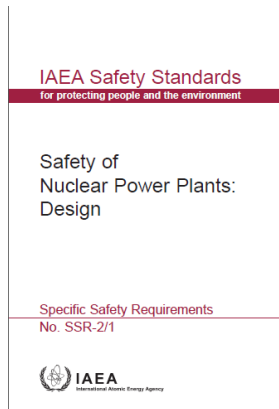
... The design shall take due account of internal hazards such as fire, explosion, flooding, missile generation, collapse of structures and falling objects, pipe whip, jet impact, and release of fluid from failed systems or from other installations on the site. Appropriate features for prevention and mitigation shall be provided to ensure that safety is not compromised

## **Related to fire protection:**

Requirement 36: Escape routes from the plant

Requirement 65: Control room

Requirement 66: Supplementary control room



## Requirement 74: Fire protection systems

Fire protection systems, including fire detection systems and fire extinguishing systems, fire containment barriers and smoke control systems, shall be provided throughout the nuclear power plant, with due account taken of the results of the fire hazard analysis.

- The fire protection systems installed at the nuclear power plant shall be capable of dealing safely with fire events of the various types that are postulated.
- Fire extinguishing systems shall be capable of automatic actuation where appropriate. Fire extinguishing systems shall be designed and located to ensure that their rupture or spurious or inadvertent operation would not significantly impair the capability of items important to safety.
- Fire detection systems shall be designed to provide operating personnel promptly with information on the location and spread of any fires that start.
- Fire detection systems and fire extinguishing systems that are necessary to protect against a possible fire following a postulated initiating event shall be appropriately qualified to resist the effects of the postulated initiating event.
- Non-combustible or fire retardant and heat resistant materials shall be used wherever practicable throughout the plant, in particular in locations such as the containment and the control room.

# Safety Guides on Plant Design against internal Hazards

## IAEA Safety Standards

for protecting people and the environment

Protection against  
Internal Hazards other  
than Fires and Explosions  
in the Design of  
Nuclear Power Plants

Safety Guide

No. NS-G-1.11



## IAEA SAFETY STANDARDS SERIES

Protection against  
Internal Fires and  
Explosions in the Design  
of Nuclear Power Plants

SAFETY GUIDE

No. NS-G-1.7



These safety guides are being revised and combined into a single one

# GENERAL APPROACH

- **Prevention on the internal hazard from occurring. Reducing frequency and magnitude**
- **Early detection and suppression of the internal hazard.**
- **Limiting the impact and propagation of the hazard on the plant: Layout, design / protection against the hazard. Avoiding secondary hazards**
- **Ensure mitigation of the consequences on the plant (e.g. PIE and additional damages): Safe shutdown of the plant after the internal hazard**

## Prevention of Hazards

- Very few hazards may be totally eliminated
- Physically impossible or by very high quality of design, e.g. no load drop if there is no lifting equipment / 2A pipe break for pipes designed as 'Leak before break'.
- **Frequency can be reduced** by appropriate design and operation provisions.
  - e.g. Occurrences of a load drop can be minimized by lifting the heavy loads with cranes of a high reliability.
  - Occurrences of fires can be minimized by reducing the fire load in a room, controlling the use of transient fuels, etc.
  - Regular inspection of piping and vessels.



## **Early detection and suppression of the internal hazard.**

- When possible early detection and suppression reduces the likelihood of an internal hazards of a sufficient magnitude to cause damage, or limits the extension of the damage
- Examples:
  - Fire detection and extinguishing
  - Flood detection and isolation
- Detection and suppression can be automatic or manual
  - Direct automatic detection (fire detectors, flood detectors)
  - Indirect detection:
    - Automatic: system alarms, equipment malfunctioning originated by the hazards
    - Manual detection: human presence, plant walkdown
  - Automatic suppression: Fire extinguishing systems, flood isolation, etc. triggered by automatic detection
  - Manual suppression: remote or local human intervention

## Limiting the impact and propagation of the hazard on the plant.

- Limiting the impact: **Adequate plant layout** and design building.  
Adequate protection features for the equipment
  - Prevention of PIEs to the extent possible.
    - AOOs should be prevented, but is not always possible.
    - Internal/external hazards should not or very rarely lead to accidents.
  - Prevention of damage to safety significant equipment ( design against the hazard exposure, qualification for conditions, protection, etc).
  - Physical separation of safety divisions by barriers with adequate resistance to the hazards to the extent possible.
  - Confinement of the effects of the fire to limited areas of the plant
- **Prevention of secondary hazards**, e.g. pipe break leading to flooding can cause also pipe whip damages, water impingement, etc. Load drop can cause pipe break and flooding, etc.

## Mitigation of the hazard consequences. Plant safe shutdown

- After the internal hazard is controlled, sufficient plant equipment should remain operable for the safe and durable shutdown of the plant.
- External hazards (e.g. earthquakes) can challenge equipment of different safety divisions, but the design of the equipment (e.g. design of seismic equipment category I) can prevent its failure. A safety system can remain fully functional
- For internal hazards, e.g. internal fire, the failure of one division may be unavoidable, e.g. fire originated in the room of division I. Redundancy level should ensure the single failure criterion may not be longer met.
- Safe shutdown analysis identifies the set of systems and minimal number of division that cannot be affected by the hazard for accomplishing the fundamental safety function and shutdown the plant safely.

- **PIE generated by internal hazards**

- An internal/external hazard should not lead to an initiating event for which the plant is not designed
- Identification of PIEs must be thorough and consider potential effects of internal/external hazards.
- The operation of the systems credited in the PIE analysis shall not be jeopardized by secondary consequences of the internal hazard
- Systems and components to be protected from the effects of the internal hazard are those required for its mitigation of the PIEs that can be originated, i.e. the systems required to operate the plant **to a safe and durable state.**

# GENERAL APPROACH

- It is often not possible or impractical to prevent that an internal/external hazards doesn't lead to an AOO. The operator may even trigger it.
- Hazards initiating an accident condition should be prevented to the extent possible by design. If not, the frequency of occurrence shall be consistent with the severity of the consequences according to the principle 'the higher the consequences the lower the probability'
- Shutting down and bringing the reactor to the normal cold shutdown after **any hazard shall be possible** (e.g. in case of a fire, flood, heavy load drop)

# GENERAL APPROACH

- Consideration of hazards is of first importance in the layout of the plant buildings and its structures, systems and components.
- When the layout is not optimal or cannot sufficient to prevent the impact of a hazard on multiple equipment, other type of protections are necessary.
- Each hazard requires specific types of protection
- The total failure of a system important to safety designed to accomplish one of the three main safety functions (reactivity control, decay heat removal from the core or the spent fuel, confinement of radioactive materials) is not acceptable, even if the system important to safety is not required following the hazard .

## Guidance for design against internal hazards

### Provisions in the layout:

To the extent possible, for new plants, the safety divisions are installed in separate safety buildings with the objective to limit the effects to the concerned division .

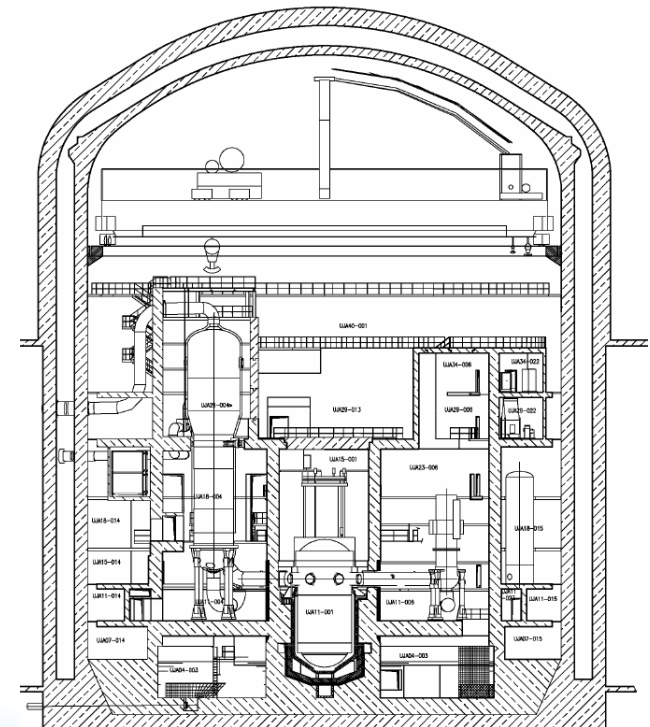
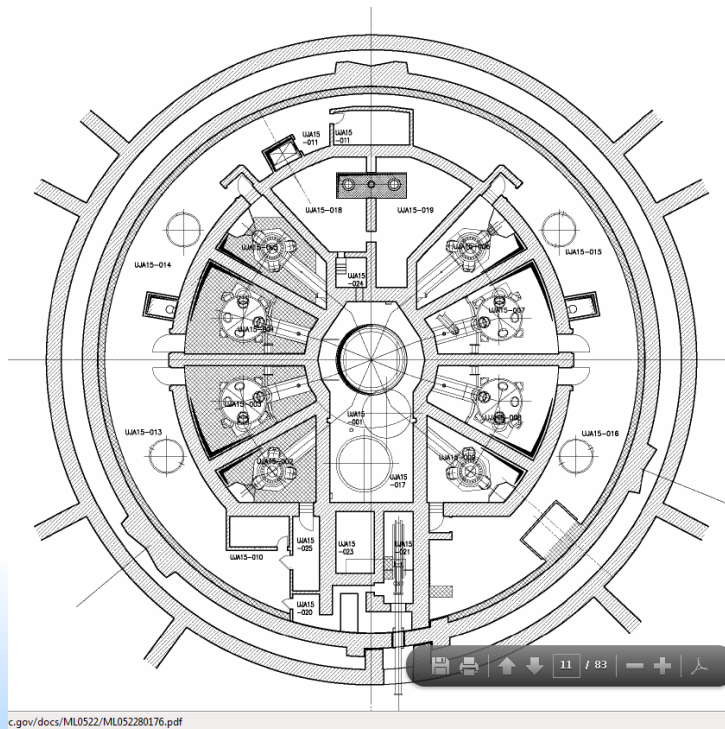
- Structures of these buildings that are necessary to prevent the spreading of the hazard should be designed to withstand the loads caused by the internal hazard.
- Propagation of internal hazard consequences through divisional interconnections should be prevented by minimizing their number and providing isolation or decoupling means.



## Guidance for design against internal hazards

### Provisions in the layout:

Where the safety divisions are routed in a same building (e.g. inside reactor building), the layout of equipment shall be based as far as possible on the principle of physical separation in order to prevent the worsening of the initial event and to avoid common cause failures among redundancies.





## Guidance for design against internal hazards

### Protection of the SSCs important to safety

Generally, most of SSCs can not be and are not designed to withstand the loads caused by the hazard, but SSCs important to safety can be protected from the effects of some hazards by

- an appropriate layout (e.g. by distance)
- or by local design provisions (e.g. In PWR the inner containment is protected from the missiles by a barrier) .

Qualification to harsh ambient conditions is required to protect SSCs important to safety when all redundant items are simultaneously exposed to the global effects of effect of a high energy pipe break.

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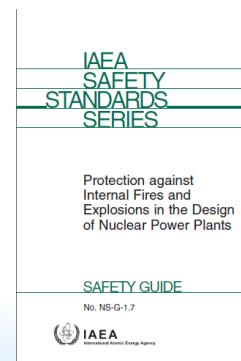
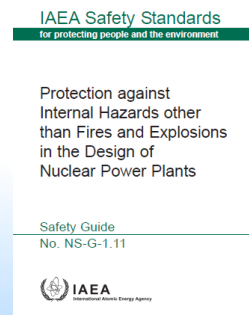
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## Guidance for design against internal hazards

### Limitation of the effects

- Secondary effects should be avoided by stopping the cascading effect (domino effect) as much as possible, e.g. in the event of a high energy pipe break, structures supporting heavy items might be modified to withstand the loads cause by the jet effects if its failure results in further damages.
- A hazard shall not be a CCF for all the divisions of a same system. This layout requirement is generally fulfilled by a physical separation between divisions or redundant items.



## Guidance for design against internal hazards

### Mitigation of the effects

- For some hazards a mitigation of the consequence can be possible by crediting some automatic actions (e.g. fire extinguishing system, closing valves or | starting pumps in the event of a flooding). Generally for new designs, this not credited (confinement principle)
- For hazards resulting in a PIE, the failures caused by the hazard need to be within the envelop considered in modeling of the plant response to the PIE.
- The internal hazard cannot lead to an initiating event that is not postulated in the design

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## Hazard analysis

- Hazards analyses (deterministic and/or probabilistic) are required to demonstrate that the layout of the structures, systems, and individual components is adequate to limit the effects of hazards taking into account design provisions implemented for the protection of SSCs or the mitigation of the consequences.
  - Analysis of generated PIEs and additional failures, proving that the radiological consequences are kept below the limits, are not jeopardized
  - Operation of the reactor to a safe and durable state is possible
  - A hazard can not be a CCF for the redundancies of the systems required for the mitigation of accidents
- Plant walkdowns are necessary or helpful to check the correctness.

# EXAMPLE OF HAZARD: Pipe failure

- Pipe failure is a generic hazard and therefore the general approach discussed before is applicable.
- Specific effects and their consequences need to be considered and evaluated by applying proven rules and methodologies (e.g. US NRC BTP 3-4).
- SSCs to be protected are derived from the approach described before
  - Possible PIEs
  - systems required for the mitigation of the PIE should not be failed by the hazard
  - No secondary failures which would significantly aggravate the PIE
  - All the 3 main safety functions can still be accomplished.

# EXAMPLE OF HAZARD: Pipe failures and their consequences

- **Pipe failures to be postulated**
- Depending on the characteristics of the pipe (energy, diameter, stress values, fatigue factors, quality):
  - For low energy pipes: leaks only,
  - For high energy pipes, except for those qualified break preclusion/leak before break: a circumferential rupture and if relevant a longitudinal through wall crack.

Locations and effects to be considered depend on the energy and size.

- Depending on the impact: Catastrophic failures of low energy piping with very high consequences should not be neglected
- Human induced failures should be also considered

# EXAMPLE OF HAZARD: Pipe failures and their consequences

- **Break location**

Generally, in a deterministic approach, breaks are postulated to occur :

- For piping of DN less than 50 mm, or for piping supplied without nuclear quality grade : at any location
- For piping supplied with a nuclear quality grade
  - At the terminal ends ( fixed points or connections to a large component) and
  - At intermediate locations, in high stress areas where stress criteria given by the manufacturing codes are exceeded. The stresses shall be calculated using equations given by the design/manufacturing code selected for the design and manufacturing of the piping.

# EXAMPLE OF HAZARD: Pipe failures and their consequences

## Effects to be considered:

### 1. Pipe whip

Pipe whip are considered at circumferential welds and in case of a 2A break.

The direction of the pipe whip is considered to identify the potential targets surrounding the broken pipe.

The effects on the identified targets (to stop cascading failures the targets are not restricted to items important to safety) should be evaluated by performing dynamic analysis. As such an analysis is very sophisticated, others simplified but proven engineering practices can be used if judged as conservative.

e.g :Impacted target pipes of a DN equal to or larger than the impacting pipe need not be assumed to loose their integrity

Impact of a whipping pipe onto a pipe of similar design but smaller DN than that of the impacting pipe results in a break to the impacted pipe.



# EXAMPLE OF HAZARD: Pipe failures and their consequences

## 2. Jet impingement forces

A same approach than that used for the pipe whip forces applies:

- the shape and the orientation of the jet are defined to identify the targets.
- Simplified but proven engineering practices are generally applied and dynamic and sophisticated analyses are used, if needed, to better assess the damages to a component or structure.
- Proven methodologies are documented in the public literature, and distances up to jet effects should be considered are generally supported by tests.
- The damages caused by the jet impingement forces onto insulation materials are of particular importance in the LOCA analysis.

# EXAMPLE OF HAZARD: Pipe failures and their consequences

## 3. Reaction forces

Reaction forces are the counteracting forces caused by the fluid escaping via the break and / or caused by the fluid pressure at the break and acting on the break cross section. Reaction forces are taken into consideration for the design of equipment supports, support anchors and the associated building structures.

These forces are dynamic forces but their effects may be evaluated by applying a static model

# EXAMPLE OF HAZARD: Pipe failures and their consequences

## 4. Pressure wave forces, flow forces

Safety classified components and their internal equipment (e.g. RPV internals, steam generator tubes) are designed to withstand flow forces resulting from postulated leaks and breaks.

In the case of transient blowdown conditions, the effects of pressure wave forces, including possible water hammer effects, should be taken into consideration.

Pressure wave forces (de-pressurization wave forces) are forces which act on piping sections between two bends and which occur from the blowdown compression wave transferred through the fluid from the break.

The effects on the structures are modeled using 3D dynamic codes

# EXAMPLE OF HAZARD: Pipe failures and their consequences

## 5. Pressure build-up and differential pressure forces

In the event of a leak or break in a high energy line with a temperature  $\geq 100^{\circ}\text{C}$  or a gas line, mass and energy released could result in a significant global pressure built up in the building.

The pressure and temperature build up are calculated by using thermo-hydraulic codes.

During the blow down transient, differential pressures may occur due to some flow restrictions causing additional loads on the structures in the safety classified buildings.

# EXAMPLE OF HAZARD: Pipe failures and their consequences

## 6. Humidity, temperature, radiation

Humidity, temperature and radiation doses are also effects to be considered following a high energy pipe break. Each of these effects could prevent the normal operation of equipment required for the mitigation if this equipment was not qualified to operate under conditions prevailing before and during its mission time.

## 7. Flooding

**Flooding** resulting from a pipe break is analysed in the frame of the flooding hazard analysis. The release of fluid cannot be prevented. The extent of the flooding depends on building characteristics, amount and rate of water released, etc.

# EXAMPLE OF HAZARD: Pipe failures and their consequences

## Which effects need to be considered?

- In principle all effects stated in are considered for high energy pipe leaks and breaks. Nevertheless:
  - ✓ Pipe whip is considered for 2A pipe break only,
  - ✓ Dynamic forces are considered for breaks only. For leaks, it is more realistic to consider continuous pressure drop,
  - ✓ For piping of DN less than 50 mm all the effects may not be considered,
  - ✓ Pressure and temperature built up are only considered for or piping with a temperature  $\geq 100^{\circ}\text{C}$ , or gas lines for pressure built up only .
- For low energy pipe, less effects are relevant, and **flooding** is generally the consequence of most interest.

**High energy pipe breaks analyses are complex analyses with multiples consequences on the plant design**

# FLOODING

- Release of water/steam through pipe opening (e.g. maintenance errors) or pipe/equipment (e.g. tank) break. Also secondary impact of fires on sensitive parts of fluid systems
- Sensitive equipment (e.g. electrical equipment) damaged by submersion, water spray, etc. A PIE is possibly caused.
- Structural damage could potentially occur by sufficient accumulation of water on some structures.
- Propagation by gravity through any paths covered by the water, including door gaps, defective or unqualified seals, and drainage, ventilation ducts, etc. Possible PIE or further damages caused.

# FLOODING

- Flood detectors available in some rooms. Detectors on building sumps? Floods may be automatically detected, but are rarely automatically isolated
- The flooding source can be a system affecting plant operation, possibly triggering a PIE or an auxiliary system not connected to the process, e.g. fire protection system
- Flood propagation is calculated by hydrodynamic models involving a source, several compartments and propagation paths.
- Floods may also affect human performance



# SOME EXAMPLES OF FLOOD EVENTS

## EXAMPLE TURBINE BUILDING FLOOD EVENTS

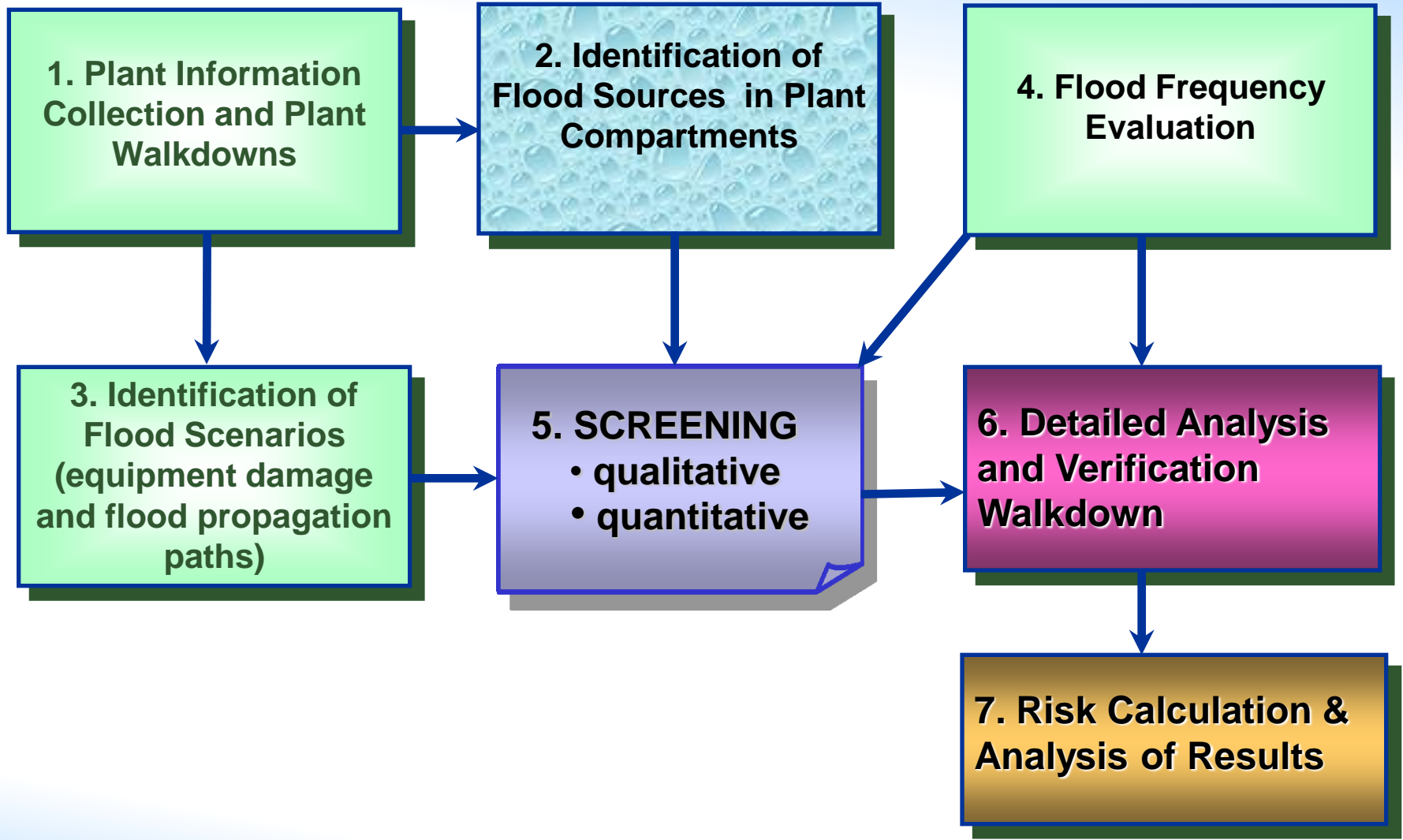
<b><u>NO.</u></b>	<b><u>PLANT</u></b>	<b><u>EVENT DESCRIPTION</u></b>	<b><u>SEVERITY</u></b>
<b>1</b>	<b>Duane Arnold</b>	<b>Total of 123000 gal accumulated in Turbine Building due to tank overflow caused by valve malfunction.</b>	<b>Unknown (123000 gal total spill)</b>
<b>2</b>	<b>Quad Cities</b>	<b>Valve closed inadvertently and water hammer rupture expansion joint.</b>	<b>Very large Spill (150000 gal)</b>
<b>3</b>	<b>Oconee 3</b>	<b>During maintenance solenoid failure caused condenser outlet valve to open while water box manways were removed.</b>	<b>Large Spill (60000 gpm)</b>
<b>4</b>	<b>Crystal River</b>	<b>Seawater inlet block valve was opened due to solenoid failure causing seawater to accumulate in Turbine Building.</b>	<b>Large Spill (65000 gpm)</b>
<b>5</b>	<b>Peach Bottom</b>	<b>Vent valve on condenser waterbox inadvertently left open following maintenance. Operators ignored high sump alarm. 6-8 ft of water in pump room.</b>	<b>Large Spill</b>

# SOME EXAMPLE OF FLOOD EVENTS (Cont.)

## AUXILIARY BUILDING FLOODING EVENTS

	<b>NPP</b>	<b><u>Event Description</u></b>	<b><u>Severity</u></b>
<b>1</b>	<b>Browns  Ferry 3</b>	<b>Supply line to condensate ring header failed at welded joint, resulting in spillage of 80,000 gal on condensate onto core spray pump room floor. Probable cause was weld fatigue caused by line movement during repeated pump starts.</b>	<b>Severe  flood from ECCS</b>
<b>2</b>	<b>Brunswick 1</b>	<b>Rupture of flange gasket on RHR SW heat exchanger outlet valve resulted in water accumulation which damaged pump and valves.</b>	<b>Severe  flood from SW system</b>
<b>3</b>	<b>Brunswick 1</b>	<b>Water accumulated in HPCI pump room, producing backflow through sump drain system, and HPCI turbine tripped due to shorted oil pump.</b>	<b>Smal</b>

# FLOODING ANALYSIS



# STEPS OF INTERNAL FLOOD ANALYSIS



- **Plant information collection and plant walkdowns:**
  - Information collected from plant documentation on:
    - Flood sources
    - Flood mitigation
    - Flood barriers
    - Plant connections and penetrations
      - Collection of data on connections and penetrations between plant compartments may require a significant effort (in case such information is not readily available)
  - Walkdowns of the plant are very important to verify actual conditions

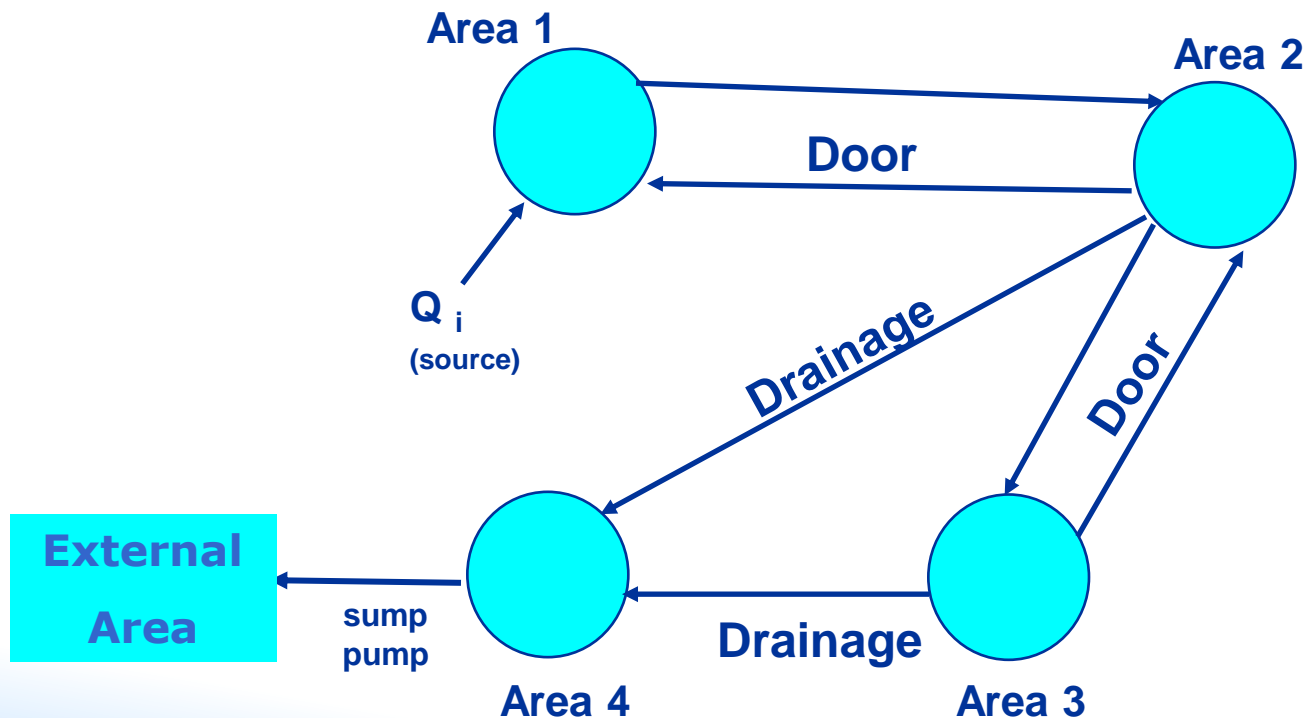
# STEPS OF INTERNAL FLOOD ANALYSIS (Cont.)

- **Identification of flooding sources:**
  - e.g., ruptures in water systems (service water, fire water, etc.)
  - location and total volume of potential flood sources
- **Identification of flooding zones:**
  - location of flood compartment boundaries/barriers
  - drains
  - connections to other compartments
  - location of flood susceptible equipment

# STEPS OF INTERNAL FLOOD ANALYSIS (Cont.)

- **Analysis of flooding scenarios**

- For each water source, the propagation of water from the break is analyzed and equipment damaged determined





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