

# **Literature Review and Previous Flood Barrier Tests - Slide Package**

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March 2020



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# ***Literature Review and Previous Flood Barrier Tests***

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**NRC Flood Barrier Testing Strategies Workshop**  
**March 12, 2020**  
**Rockville, MD USA**

## ***Presentation Outline***

- Literature Review
- Plant-Specific Flood Barrier Types and Performances
- Examples of Previous Flood Barrier Tests

# ***I. Literature Review***

## **➤ Reviewed Materials from a Variety of Sources**

### **☐ Domestic Agencies**

- United States Nuclear Regulatory Commission (NRC)
- United States Army Corps of Engineers (ACE)

### **☐ International Agency**

- Organisation for Economic Co-operation and Development Nuclear Energy Agency (OECD NEA)

### **☐ Industry and Academia**

- Nuclear Energy Institute (NEI)
- Electric Power Research Institute (EPRI)
- Licensee flooding walkdown reports
- Nuclear power plant (NPP) decommissioning information
- Idaho National Laboratory (INL) and Idaho State University (ISU)
- Relevant publications in scientific journals and conferences
- Publicly available information from flood barrier vendors

## *I. Literature Review (cont.)*

### ➤ **List of Reviewed Materials**

#### ☐ **NRC**

##### ■ **Materials Related to Flood Barriers**

- Regulatory Guide 1.102, Rev. 1, "Flood Protection for Nuclear Power Plants," 1976
- Japan Lessons-learned Project Directorate, Interim Staff Guidance, JLD-ISG-2012-05, Rev.0, "Guidance for Performing the Integrated Assessment for External Flooding," 2012
- Draft NUREG report, "Development of a Performance Testing Protocol for Nuclear Power Plant Flood Penetration Seals," in progress
- Reports prepared by NRC contractors, including Fire Risk Management, Inc. and Center for Nuclear Waste Regulatory Analyses

##### ■ **Materials Related to Fire Barriers or Fire Tests**

- NUREG/CR-0152, "Development and Verification of Fire Tests for Cable Systems and System Components," 1978
- NUREG/CR-2377, "Tests and Criteria for Fire Protection of Cable Penetrations," 1981
- NUREG-1552, "Fire Barrier Penetration Seals in Nuclear Power Plants," 1996

## ***I. Literature Review (cont.)***

### **➤ List of Reviewed Materials (cont.)**

#### **☐ ACE Engineering Research and Development Center (ERDC)**

- ERDC TR-07-3, "Flood-Fighting Structures Demonstration and Evaluation Program: Laboratory and Field Testing in Vicksburg, Mississippi," 2007
- ERDC/CHL TR-15-3, "Technical Basis for Flood Protection at Nuclear Power Plants," 2015

#### **☐ OECD NEA**

- NEA draft report, "Concepts and Terminology for Protecting Nuclear Installations from Flood Hazards," in progress

#### **☐ NEI**

- NEI 12-07, Rev. 0-A, "Guidelines for Performing Verification Walkdowns of Plant Flood Protection Features," 2012

#### **☐ EPRI**

- Product 3002005423, "Flood Protection Systems Guide," 2015
- Presentation, "External Flood Seal Risk-Ranking Process," 2019

## ***I. Literature Review (cont.)***

### **➤ List of Reviewed Materials (cont.)**

#### **☐ Licensee Walkdown Reports**

- Flooding walkdown reports of a reference NPP, 2013 – 2014

#### **☐ INL & ISU**

- Pope et al., “Light Water Reactor Sustainability Program, Nuclear Power Plant Mechanical Component Flooding Fragility Experiments Status (INL/EXT-17-42728),” 2017
- Wells et al., “Non-watertight door performance experiments and analysis under flooding scenarios,” Results in Engineering, 2019

#### **☐ Others (ongoing)**

- NPP decommissioning info, vendor info, and scientific publications

### **➤ Outputs of Literature Review**

- ☐ Generic categorization of flood barriers in NPPs
- ☐ Plant-specific flood barrier types and performances (to be presented in part II)
- ☐ Existing and potential flood barrier testing facilities
- ☐ Examples of previous flood barrier tests (to be presented in part III)
- ☐ Insights for future flood barrier testing strategy development



## ***II. Plant-Specific Flood Barrier Types and Performances***

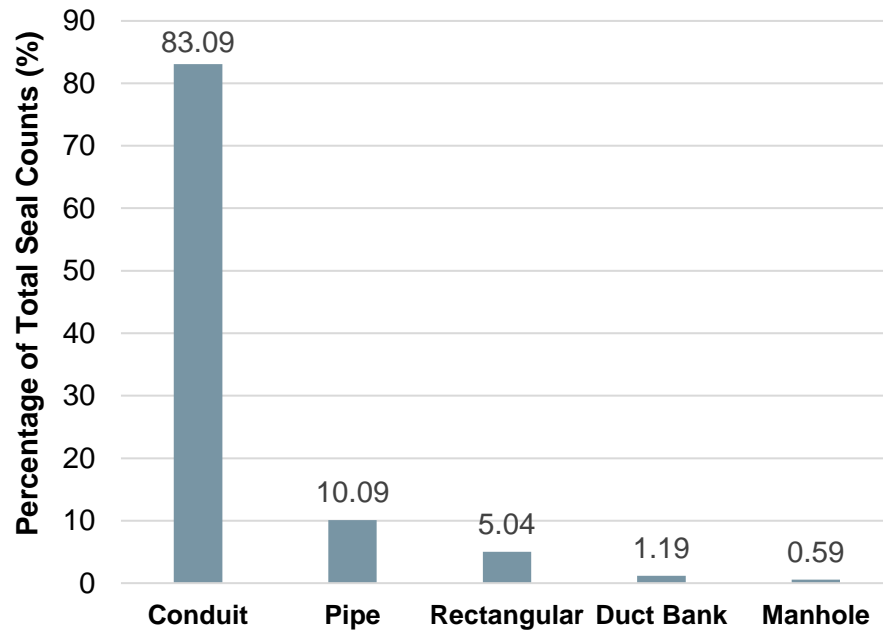
### **➤ Reviewed Flooding Walkdown Reports of a Reference Plant**

- ☐ Most of inspected protection features in the plant are flood barriers
- ☐ Most of inspected flood barriers are incorporated into the plant

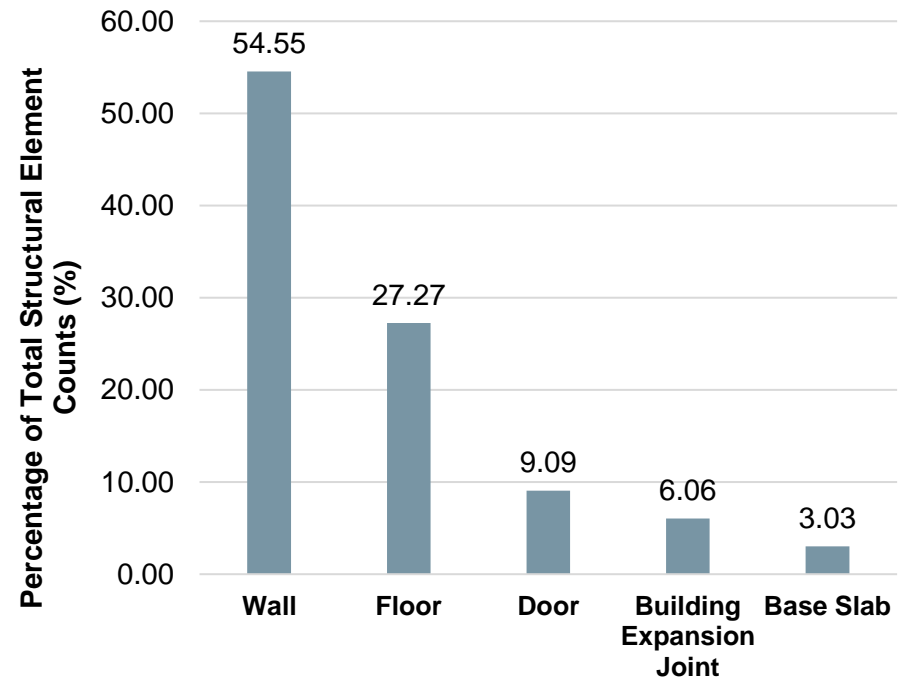
Feature Type	Classified as Barrier	Barrier Type	Percentage
Seal	Yes	Incorporated	79.11%
Structure	Yes	Incorporated	7.75%
Drain	No	n/a	7.51%
Scupper	No	n/a	3.76%
Dike	Yes	Exterior	0.94%
Sump	No	n/a	0.70%
Monitor Well	No	n/a	0.23%
Percentage of Barrier-Type Features			87.79%
Percentage of Non-Barrier-Type Features			12.21%

## II. Plant-Specific Flood Barrier Types and Performances (cont.)

### ➤ Flood Barrier Types in the Reference Plant



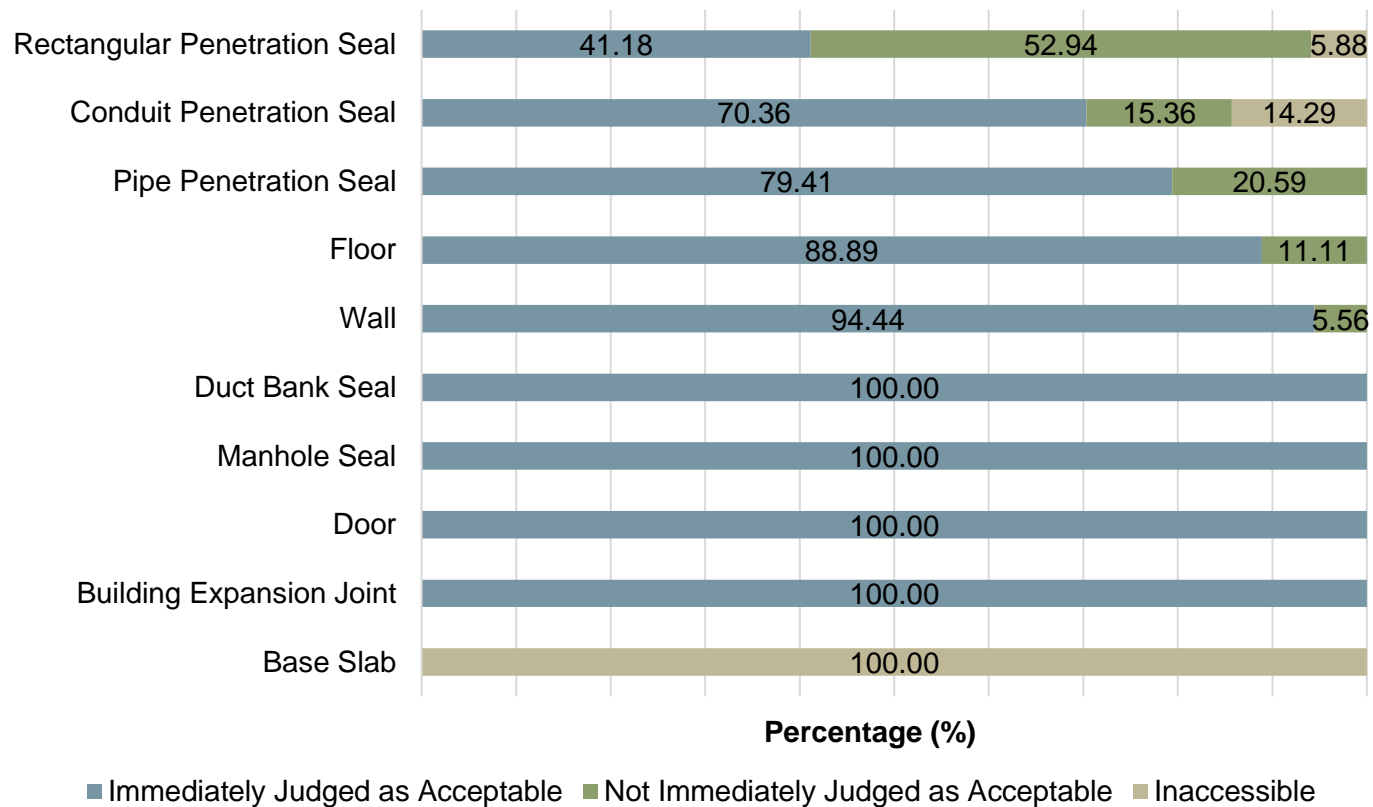
**Penetration Seals**



**Structural Elements**

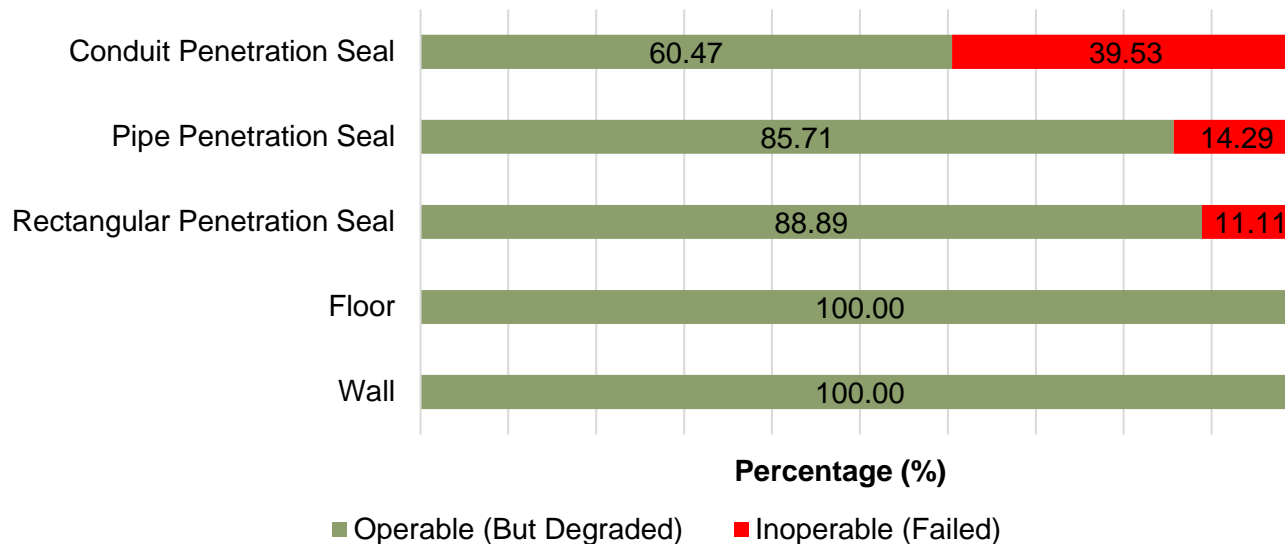
## II. Plant-Specific Flood Barrier Types and Performances (cont.)

### ➤ Flood Barrier Performances in the Reference Plant



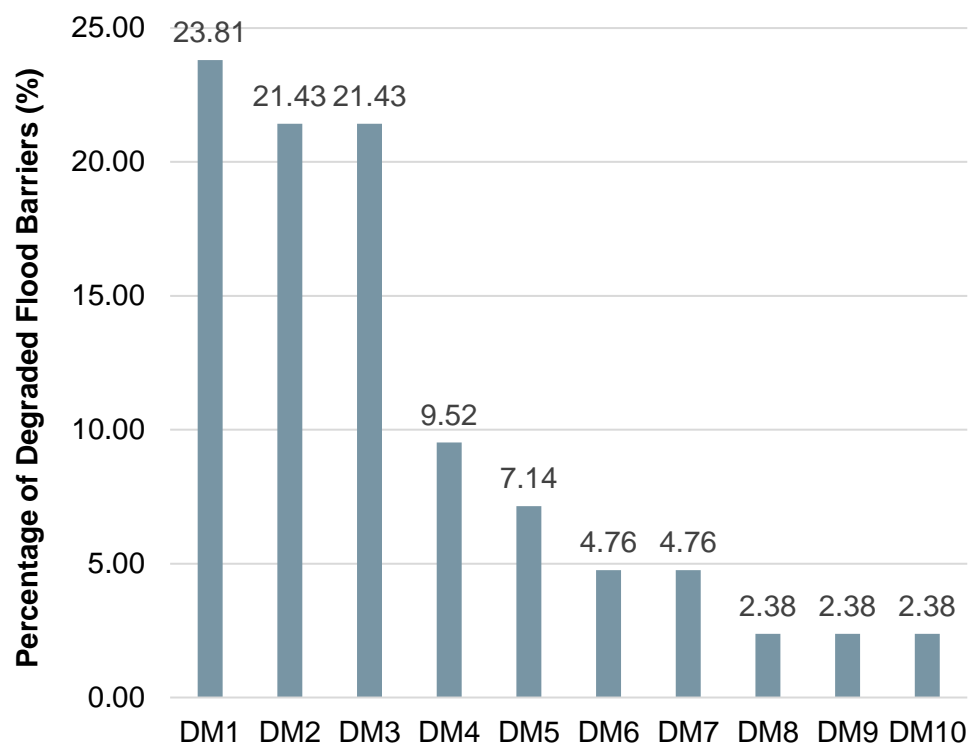
## II. Plant-Specific Flood Barrier Types and Performances (cont.)

### ➤ Flood Barrier Performances in the Reference Plant (cont.)



## II. Plant-Specific Flood Barrier Types and Performances (cont.)

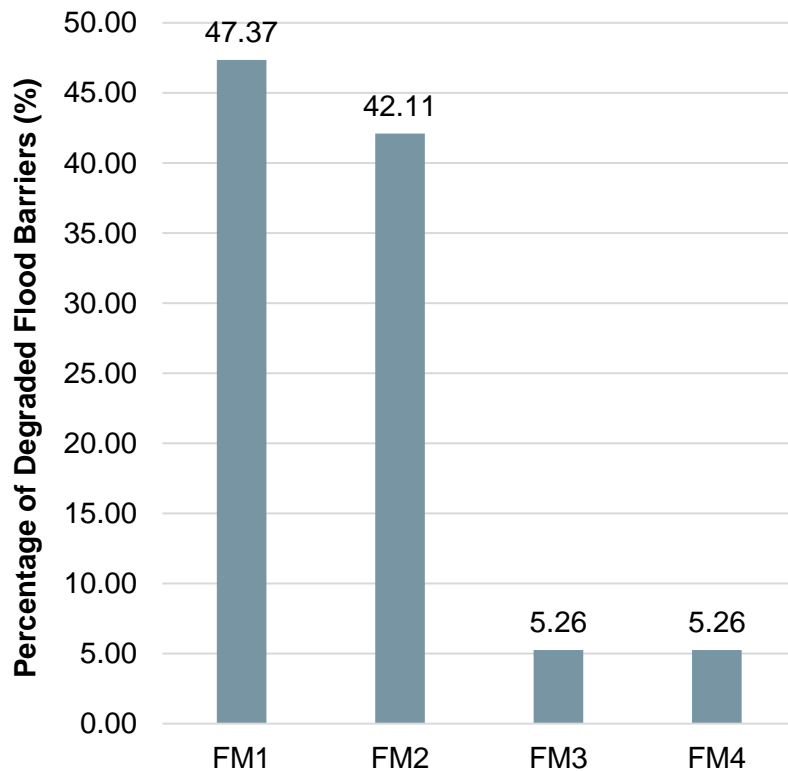
### ➤ Degraded Flood Barriers in the Reference Plant



No.	Degradation Mode (DM)
DM1	Corrosion on penetration and signs of water seepage on wall.
DM2	Staining on wall below penetration or at construction joints of penetration and immediately below.
DM3	No seal could be observed for this penetration.
DM4	Staining on wall and corrosion on penetration.
DM5	Extensive corrosion on penetration sleeves and stalactite growth underneath the penetration and cap.
DM6	Cracks greater than 0.04" wide in the wall/floor slab.
DM7	Penetration covered by a catch and inaccessible. Staining on the wall below the catch.
DM8	Staining on penetration and signs of water seepage on wall.
DM9	Cracks greater than 0.04" wide in the grout sealing penetration and slight staining below pipes.
DM10	Due to an obstructed view, an internal seal for this pipe sleeve could not be verified.

## II. Plant-Specific Flood Barrier Types and Performances (cont.)

### ➤ Failed Flood Barriers in the Reference Plant



No.	Failure Mode (FM)
FM1	Penetration seals appeared severely degraded. Signs of past water intrusion on walls underneath.
FM2	Water intrusion through penetrations observed at roughly 40 drops per minute during a light rainstorm.
FM3	Penetrating conduit was cut and uncapped.
FM4	Penetrating conduit was cut and uncapped. A seal inside the penetrating conduit was not visible.

## II. Plant-Specific Flood Barrier Types and Performances (cont.)

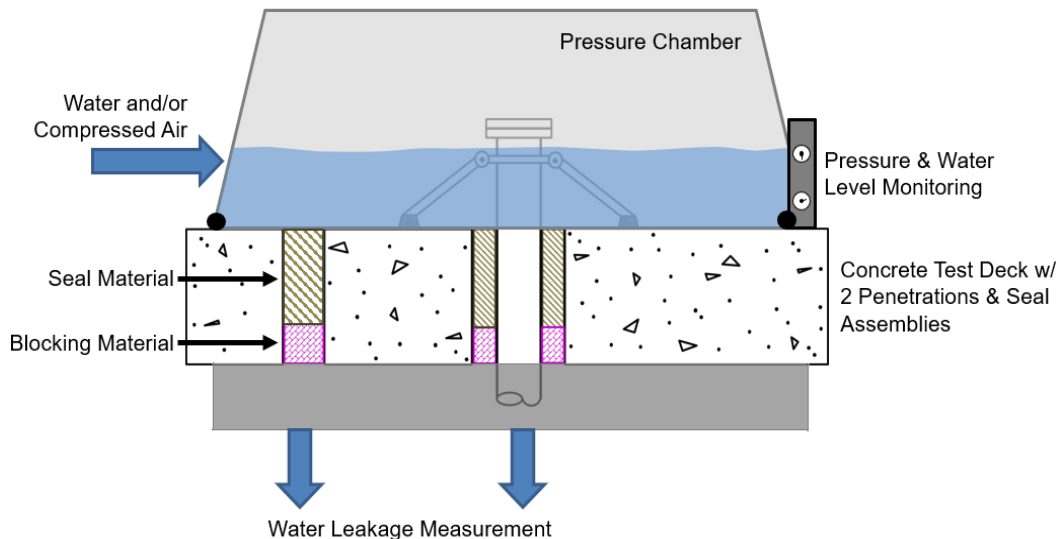
### ➤ Performance Metrics of Flood Barriers in the Reference Plant

- ❑ Could possibly act as an input for development of flood barrier testing strategy
  - Failure probability could be one of multiple factors to be considered for test prioritization

Flood Barrier	Probability		
	Success	Degradation	Failure
Conduit Penetration Seal	0.82	0.11	0.07
Rectangular Penetration Seal	0.44	0.50	0.06
Pipe Penetration Seal	0.79	0.18	0.03
Floor	0.89	0.11	0.00
Wall	0.94	0.06	0.00
Building Expansion Joint	1.00	0.00	0.00
Door	1.00	0.00	0.00
Manhole Seal	1.00	0.00	0.00
Duct Bank Seal	1.00	0.00	0.00

### III. Examples of Previous Flood Barrier Tests

#### ➤ Test 1 – Penetration Seals, Ex-Situ



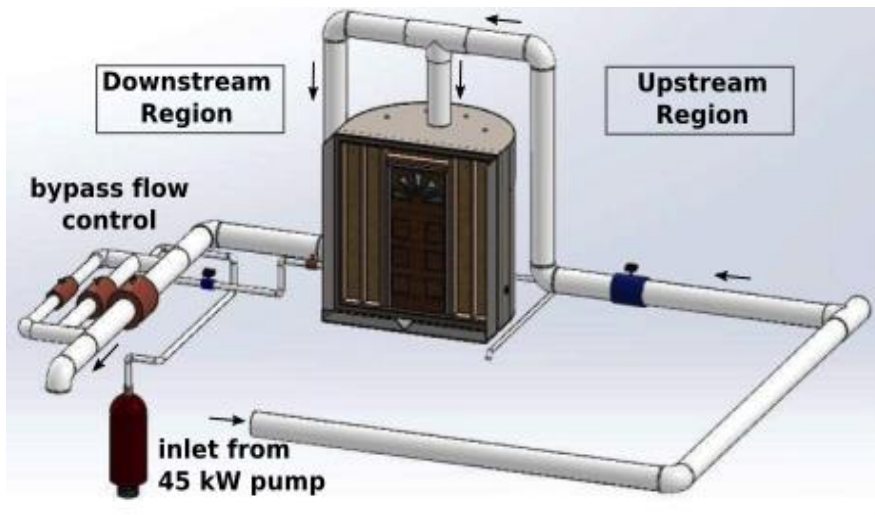
**Framatome Laboratory Flood Testing Facility  
(Lynchburg, VA)**

Flood Barrier Type	Penetration seals
Testing Location	Ex-situ
Facility Type	Test deck with pressure chamber
Testing Type	Destructive
Included Tests	Hydrostatic, hydrodynamic
Test Variables	Water pressure, duration of applied pressure, rate of pressure change
Test Measurements	Test chamber pressure, water temperature, water volumetric flow rates from individual seals
Test Termination	Until maximum test duration was exceeded, or seal failure occurred
Test Outputs (Numerical)	Test duration, maximum water pressure, pressure vs. time graphs, leakage flow rates vs. time graphs



### III. Examples of Previous Flood Barrier Tests (cont.)

#### ➤ Test 2 – Non-watertight Doors, Ex-Situ



**Idaho State University Flood Testing Facility  
(Pocatello, ID)**

Flood Barrier Type	Doors
Testing Location	Ex-situ
Facility Type	Tank
Testing Type	Destructive
Included Tests	Hydrostatic, hydrodynamic
Test Variables	Tank filling rate
Test Measurements	Flow rates into the tank, tank water depth, water temperature, small leakage rates, pressures for simulated hydrostatic head
Test Termination	Until door failure, the water leakage rate equalizing, or exceeding the filling rate
Test Outputs (Numerical)	Time to failure, failure water depth, water depth vs. time graphs

### ***III. Examples of Previous Flood Barrier Tests (cont.)***

#### **➤ Tests 3 & 4 – Temporary Flood Barriers, Ex-Situ**

##### **□ Test Sample**

- ACE sandbag barrier
- Three commercial barriers

	<b>Test 3</b>	<b>Test 4</b>
<b>Flood Barrier Type</b>	Temporary barriers	Temporary barriers
<b>Testing Location</b>	Ex-situ	Ex-situ
<b>Facility Type</b>	Natural site	Research basin
<b>Testing Type</b>	Destructive	Destructive
<b>Included Tests</b>	Hydrostatic, hydrodynamic	Hydrostatic, hydrodynamic, overtopping, debris impact
<b>Test Variables</b>	Natural flooding	Water level, wave size, wave duration, debris size
<b>Test Measurements</b>	Water levels in seepage collection pits, time history of construction/testing/removal of tested barriers, barrier dimensions	Water levels in seepage collection pits, time history of construction/testing/removal of tested barriers, barrier dimensions
<b>Test Termination</b>	Until a barrier was overtopped by water flowing freely over the barrier and exceeding pump capacity on the protected side	Until maximum test duration was exceeded or barrier failure occurred
<b>Test Outputs (Numerical)</b>	Seepage flow rates, seepage rate vs. wetted perimeter area graphs, seepage rate vs. stage of the river graphs, operational concerns (e.g., ease of construction, barrier durability and reusability)	Seepage flow rates, barrier displacements, seepage per linear foot vs. time graphs, seepage & overtopping vs. time graphs, operational concerns (e.g., ease of construction, barrier durability and reusability)

### ***III. Examples of Previous Flood Barrier Tests (cont.)***

#### **➤ Summary**

- ☐ Tested flood barriers included:
  - Permanent barriers
  - Temporary barriers
- ☐ All the tests were ex-situ
- ☐ All the tests were destructive
- ☐ All the tested flood barriers were new without aging or degradation

