ICONE28-POWER2020
28th International Conference on Nuclear Engineering
August 2–6, 2020, Anaheim, CA, USA

SAND2020-6941C

MELCOR Demonstration Analysis of Accident Scenarios at a Spent Nuclear Reprocessing Plant

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Acknowledgement

The authors gratefully acknowledge the contributions from Clint Shafer (ARES) for the development of the Barnwell MELCOR model. Nate Bixler, Fred Gelbard, and Jesse Phillips provided the technical methods for the analysis of reprocessing accidents from the previous NUERG/CR-7232 project. Mark Fuhrmann provided valuable technical guidance, independent review, and comments as the NRC Contract Officer's Representative. The authors appreciate the managerial and technical review provided by David Luxat.

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Outline

- Overview
- Description of the Barnwell Nuclear Fuel Plant (BNFP) facility
- Description of the BNFP MELCOR model
- Description of fire and explosion accident modeling
- Simulation results
- Conclusions

Project Overview

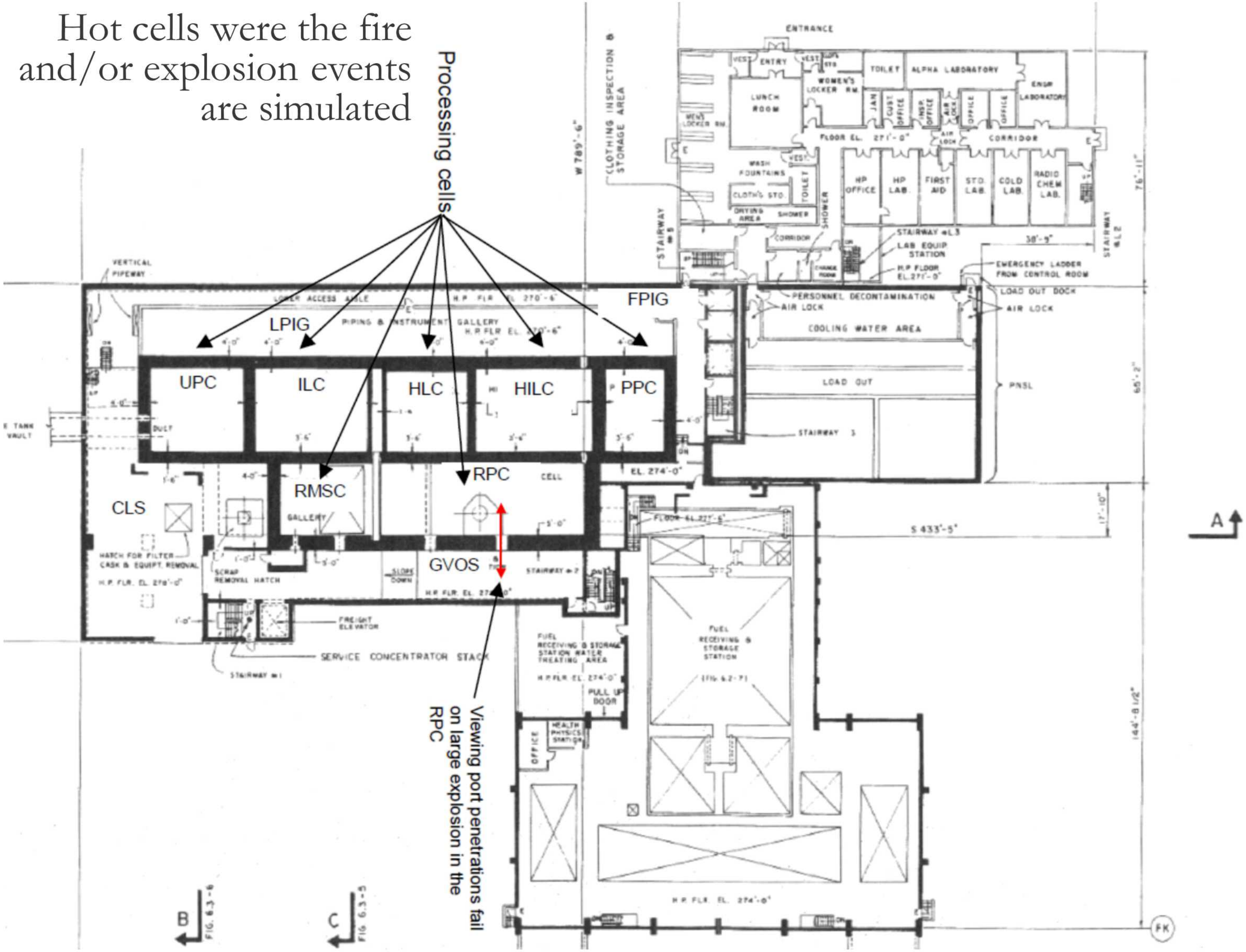
- BNFP was selected as a representative facility to MELCOR demonstrate best-estimate, non-reactor facility accident capabilities
  - Available technical drawing information and safety analysis for accident descriptions
  - Facility was de-commissioned prior to operation
- The best-estimate methodology used modeling for the source term, aerosol generation, aerosol transport, and filter performance
  - Best-estimate spent fuel inventories developed using ORIGEN-S from the Scale 6.1.3 package
  - Uses MELCOR's best-estimate aerosol behavior models to calculate the source term to the environment
  - One-step approach to the source term (i.e., not a leak path factor analysis)
- Demonstration analysis included explosion, fire, and combined explosion and fire accidents

MELCOR Model Description

- Detailed model of the BNFP facility
  - 208 control volumes
  - 354 flow paths
  - 294 heat structures
  - Includes major rooms and the supply and exhaust ventilation and filtration system
- 2-dimensional nodalization of all processing cells (hot cells)
  - Allows natural circulation flow patterns, hot gas layer, and propagation of the explosion pressure pulse
- Detailed modeling of the ventilation and filtration system
  - Ventilation system used to balance to nominal room pressures prior to accident
  - Pressure zones ranged from most radioactive to least radioactive
  - Room pressures ranged from -0.49 kPa to +0.12 kPa

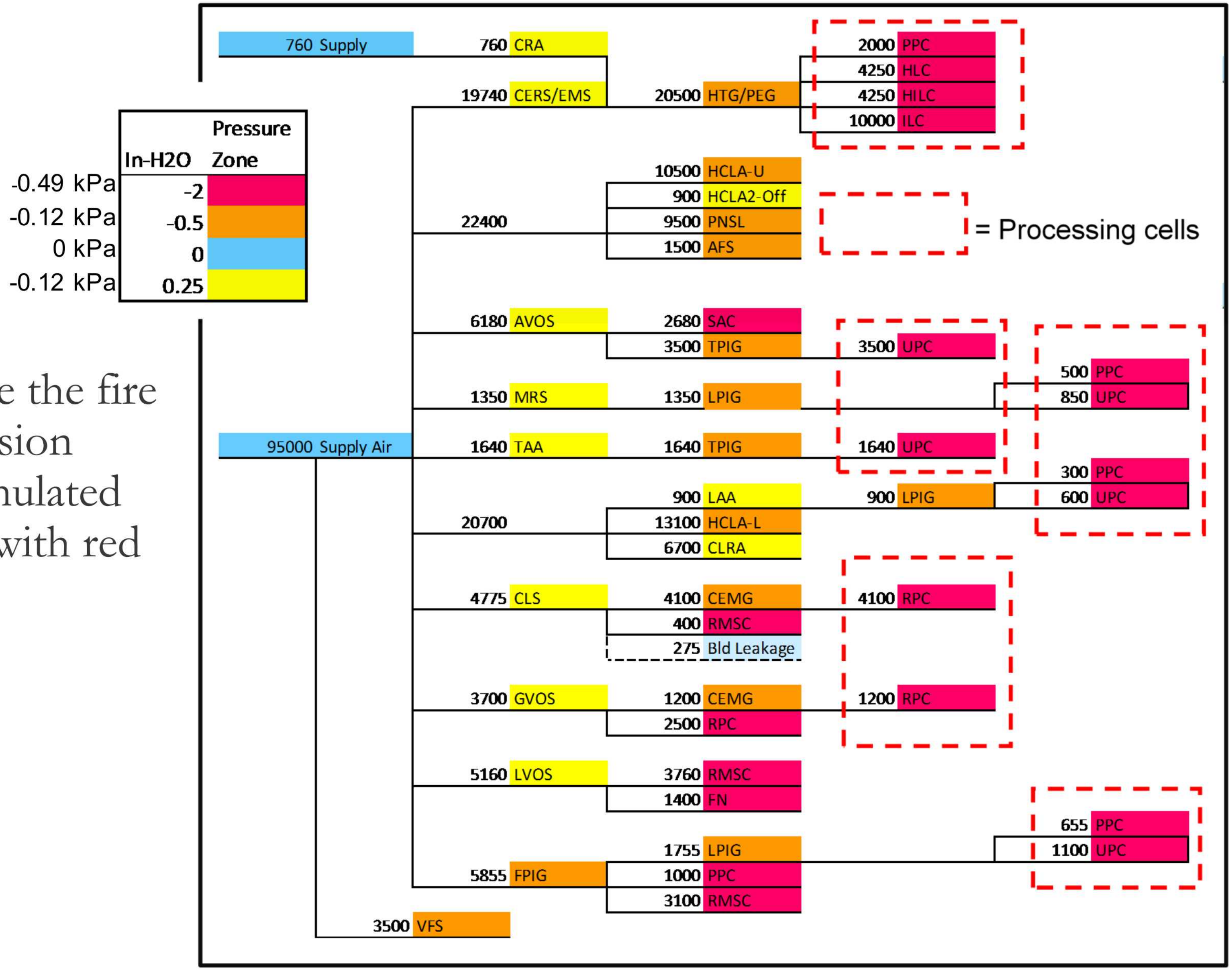
BNFP facility drawing

Hot cells were the fire and/or explosion events are simulated



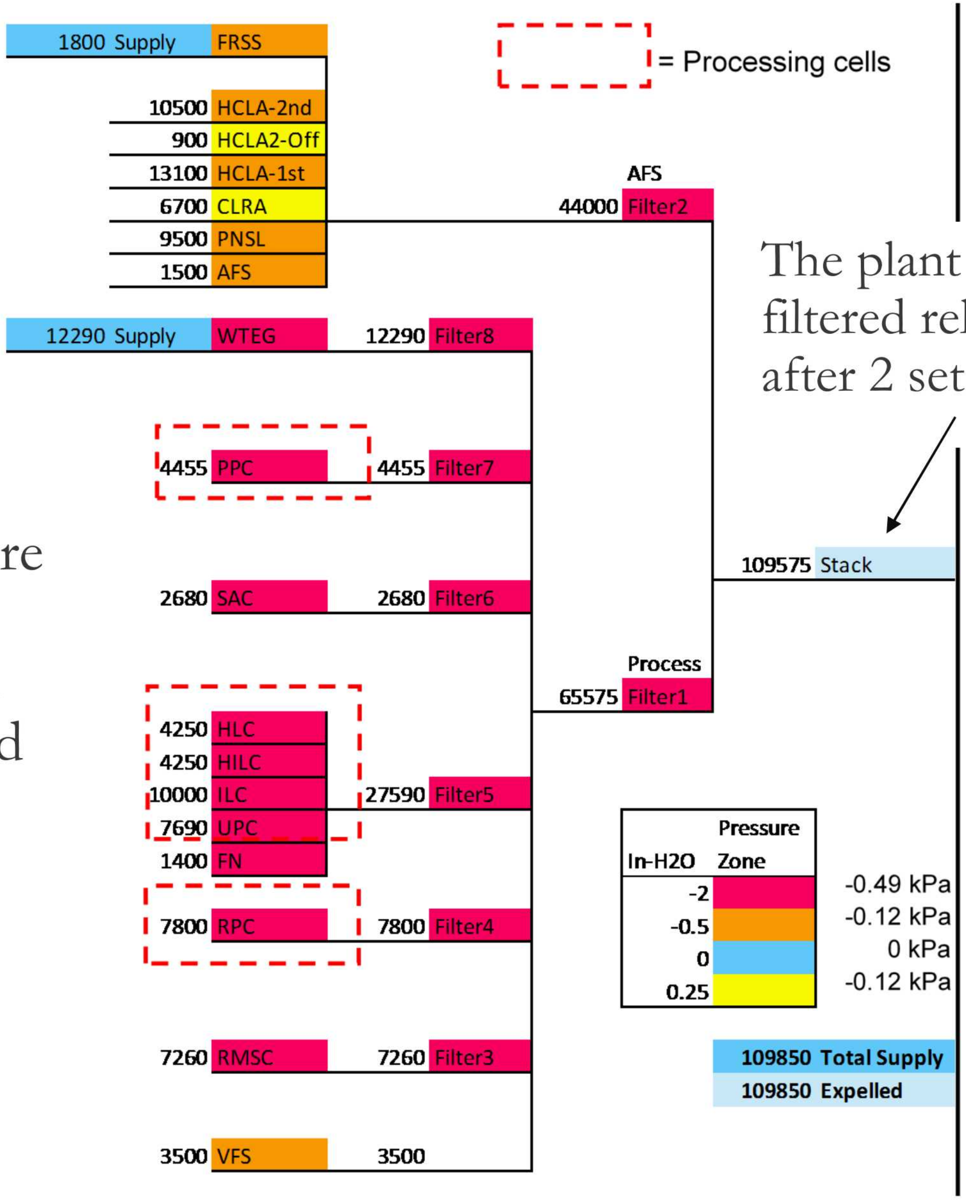
BNFP facility drawing – Supply-side ventilation

Hot cells were the fire and/or explosion events are simulated are enclosed with red dotted lines



BNFP facility drawing – Exhaust-side ventilation

Hot cells were the fire and/or explosion events are simulated are enclosed with red dotted lines



The plant stack is the filtered release pathway after 2 sets of filters

Key MELCOR Modeling Features

- Monitored for mechanical failures of filter media and ventilation dampers and ducting
  - Over-pressure events failed structures and filters between the accident location and the building boundary
  - Model also included nominal leakage pathways
- Thermal failure and plugging of HEPA filters
  - HEPA material becomes ineffective (fails) at high temperature
  - Aerosol loading increases HEPA flow resistance (e.g., fire soot)
- Variable HEPA effectiveness
  - Filtration effectiveness based on aerosol size
  - Radioactive gases pass through the filters (e.g., noble gases, gaseous iodine, and volatile ruthenium)

Accident Scenarios

- Fire modeling of the organic solvents involved in the accident
  - Chemical reaction and rate based on process-specific materials and assumed pool size
  - Includes soot production
  - Fire modeling includes oxygen consumption and gas products (e.g., CO_2)
- Some accident scenarios include red oil explosions, which occurs from the decomposition of tributyl phosphate (TBP)
  - Similar to fires, the explosion releases energy and include gas production from the rapid oxidation of the TBP with nitric acid
- The boundary conditions for the first 5 scenarios were taken directly from the facility safety analysis report (2 fires and 3 explosions)
  - The scenarios occurred in different processing cells and had varying radionuclide inventories (e.g., for example only Pu inventory in the Plutonium Product Cell explosion scenario)
  - 5 additional sensitivity calculations explored smaller fires (i.e., 3 calculations) and explosions with an induced fire (i.e., 2 calculations)

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Examples of Fire Scenario Results

Sensitivity of the Fire Size Modeling Accident – Key boundary conditions

Scenario	Location	Solvent Volume	Fire Size		
			Area	Diameter	Duration
4	Code-contamination Cycle	378 liters	100 m^2	11.3 m	72 sec
7			5 m^2	2.52 m	24 min
8			1 m^2	1.1 m	2.0 hr

- Solvent is the flammable material (378 liters is spilled)
  - The fire intensity, build-up, and duration is impacted by the pool diameter
  - The largest fire (i.e., Scenario 4) over-pressurizes the room, causing failure to the connecting dampers.
  - Scenario 4 rapidly consumes most of the room oxygen and slows to at an oxygen-limited rate (i.e., burns for 22 min versus only 72 sec at the maximum rate with unlimited oxygen). Max heat rate was 75 MW but the average was <10mMW)

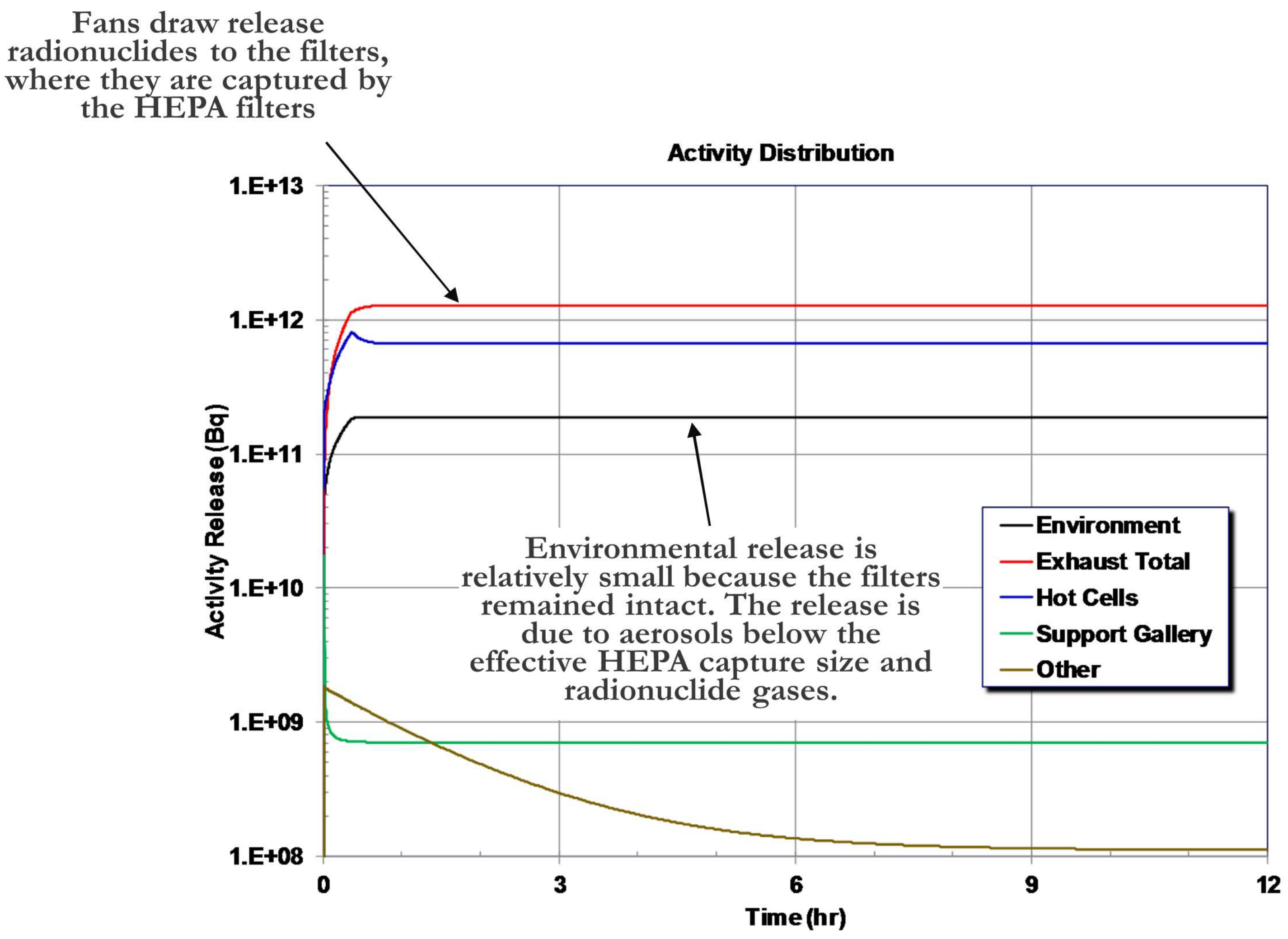
Key event timings

Event Timing [s]	Scenario		
	4	7	8
Start of building pressure/flow steady state balance	-10,000	-10,000	-10,000
Start of the solvent fire (14 liters)	0.0	0.0	0.0
Failure of the HILC outlet damper (>10.34 kPa)	4.3	9.4	n/c
Failure of the inlet damper from the HTG&PEG (>10.34 kPa)	10.2	n/c	n/c
High exhaust fan inlet temperature (>121.1 °C)	11.5	49.2	n/c
High Filter 1 ΔP (>33.8 kPa)	14.8	n/c	n/c
Filter 1 damper closes to 10% to protect filter	24.8	n/c	n/c
High Filter 5 ΔP (>33.8 KPa))	992	962	6534
Filter 5 damper closes to 10% to protect filter	1002	972	6544
All solvent is burned	1301	1575	7266
Filter 1 ΔP <33.8 kPa	1305	n/c	n/c
Filter 1 damper opens to 100%	1305	n/c	n/c

n/c = not calculated

Examples of Fire Scenario Results – Radionuclide Results

Sensitivity of the Fire Size Modeling Accident – Key boundary conditions



Example of an Explosion Scenario Result

- Scenario 3 is a red oil explosion in the plutonium product cell (PPC)
  - 25% of the TBP is involved in a explosion releasing $1.3x10^8$ J
  - The energy and combustion gases are released over 0.01 sec.
  - The static pressurization from the explosion fails the dedicated PPC exhaust filters and connecting supply dampers
  - The pressurization also leads leads to failure of the final exhaust filter

Key event timings

Event Timing [s]	Time
Start of building pressure/flow steady state balance	-10000
Explosion	0.0
PPC outlet damper to Filter 7 fails (>10.3 kPa)	<0.01
PPC inlet damper from the FPIG fails (>10.3 kPa)	<0.01
Pre-filter 7 fails (>10.3 kPa)	<0.01
HEPA filter 7 fails	<0.01
PPC inlet damper from the LPIG fails (>10.3 kPa)	<0.01
Explosion ends	0.01
PPC inlet damper from HTG&PEG fails (>10.3 kPa)	0.02
High exhaust fan inlet temperature (>121°C)	2.8
High HEPA filter 1 ΔP (>2.48 kPa)	3.3
Low fan ΔP ((>10.95 kPa, monitored only) [A]	5.4
HEPA filter 1 fails	11.9

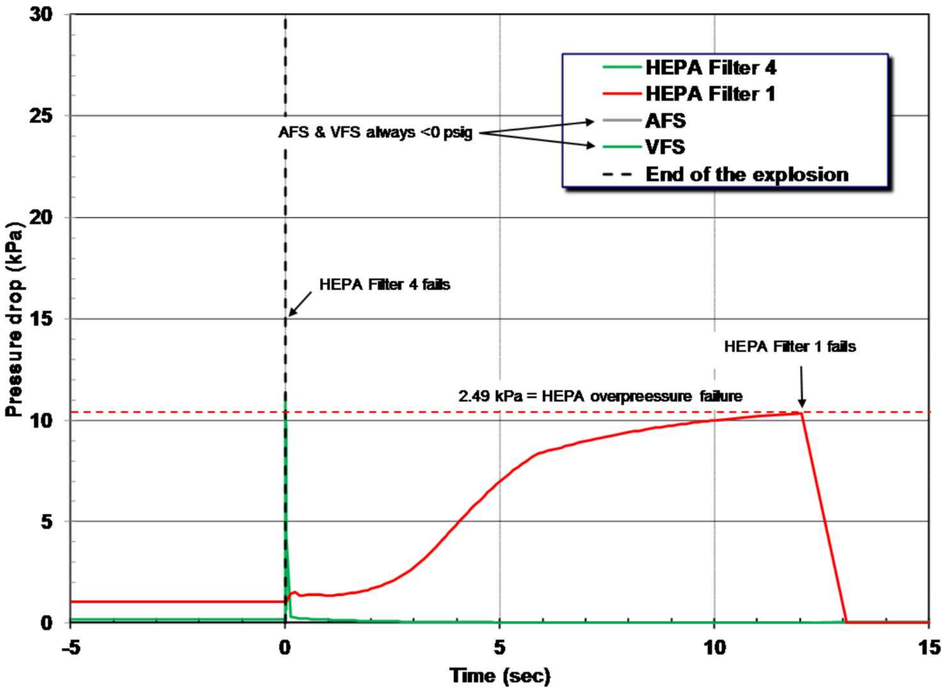
Note:

A The differential pressure generated by the fan is not a control signal identified in the BNFP FSAR but often monitored in other DOE facilities. The low differential pressure condition indicates an abnormal condition with possibly excessive exhaust flow.

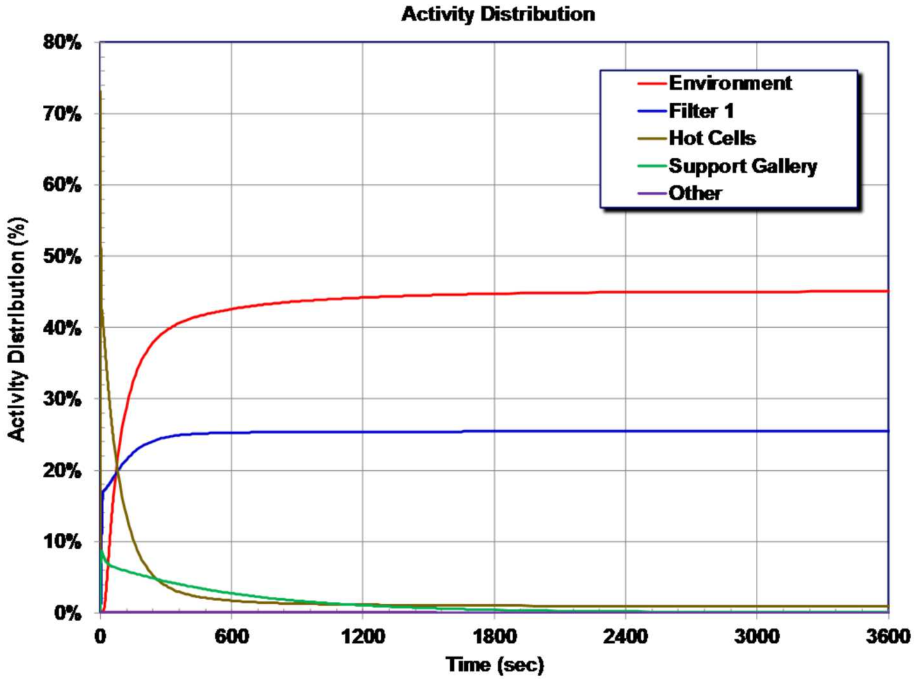
Example of an Explosion Scenario Result

- Pressure response figure below shows immediate failure of HEPA Filter 7, at the exit of the PPC
- The dissipation of the pressure from the explosion also fails the final exhaust filter

Pressure response at the filters between the PPC and the stack



Activity distribution in the first hour after the accident



- Activity distribution above shows a large release to the environment due to the failure of the two filter between the PPC and the plant stack.
- Pre-filter 1 remains intact and retains show larger aerosols

Summary

This application illustrates MELCOR capabilities for non-reactor applications, such as evaluation of the potential source term release from a nuclear spent fuel reprocessing facility due to fire and explosion accident scenarios. In contrast to the LPF used in the BNFP FSAR calculations, the MELCOR best-estimate modeling includes,

- complete radionuclide inventories characteristic of modern practices,
- thermal and mechanical filter degradation and failure,
- no filtration of very small aerosols,
- building leakage,
- structural failures,
- aerosol physics for agglomeration and deposition within the building,
- radionuclide dispersion throughout the building due to the pressurization from the explosion or fire,
- the radionuclide vapor pressure (e.g., converts some radionuclides to a gaseous form in high temperatures and condenses in cooler regions), and
- chemical reactant and product generation associated with explosions and fires (e.g., oxygen consumption and soot production)

Thank-you