Consequence Assessment for Spent Fuel Pool Accidents

Presentation to the Advisory Committee on Reactor Safeguards

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Overview

As a result of radioactive decay:

- lower inventory available for release from spent fuel.
- lower decay heat, providing time for early evacuation.

It was initially thought that at one year after final shutdown the radiological consequences from a spent fuel pool accident might be negligible.

If consequences were negligible, requirements for emergency planning and insurance could be eliminated.

Therefore, performed offsite radiological consequence calculations with MACCS to quantify the consequences.

Overview (cont.)

Issues examined

- **reduced inventory (at 1 year)**
- **early vs. late evacuation (at 1 year)**
- **importance of cesium**
- **importance of ruthenium**
- **number of assemblies releasing fission products**
- **fission product release fractions**
- **plume heat content**
- **plume spreading**
- **decay times beyond 1 year**
- **reassessment of source term**

Results of large number of MACCS calculations were used to understand decommissioning risk in staff's generic study.

Consequence Assessment

Original objective: evaluate effect of one year of decay on offsite consequences

- **reduced inventory available for release**
- **reduced decay heat (i.e., early vs. late evacuation)**

Summary of approach

Update of spent fuel pool accident study in NUREG/CR-4982 (GSI-82)

Used the MACCS consequence code with fission product inventories for 30 days, 90 days, and 1 year after final shutdown

Source Term	Release Fractions								
	noble gases	iodine	cesium	tellurium	strontium	barium	ruthenium	lanthanum	cerium
NUREG/CR-4982	1	1	1	.02	.002	.002	$2x10^{-5}$	$1x10^{-6}$	$1x10^{-6}$

Representative Results

Decay Time Prior to Accident	Mean Consequences for Surry Population Density (0-100 miles)		
	Early Fatalities	Societal Dose (rem)	Cancer Fatalities
30 days	1.75	$4.77x10^6$	2,460
1 year	1.01	$4.54x10^6$	2,320
1 year[a]	.0048	$4.18x10^6$	1,990

[a]Based on early evacuation.

<u>Conclusions</u>

Effect of reduced inventory

- **Early fatalities reduced by about a factor of 2 from 30 days to 1 year.**
- **Cancer fatalities and societal dose unaffected.**

Effect of reduced decay heat (early evacuation)

- **Early fatalities reduced by up to a factor of 100.**
- **Cancer fatalities and societal dose unaffected.**

Effect of Cesium

As a follow-up, evaluated the impact of cesium to better understand why consequence reduction from a year of decay not greater.

Cesium release fraction: 1.0
Cesium half-lives: Cs-134, 2 years; Cs-136, 13 days; Cs-137, 30 years

Decay Time Prior to Accident	Mean Consequences for Surry Population Density (0-100 miles)		
	Early Fatalities	Societal Dose (rem)	Cancer Fatalities
1 year	1.01	4.54×10^6	2,320
1 year (without cesium)	0.00	1.46×10^5	42

Effect of Ruthenium

Small-scale Canadian tests with an air environment showed significant ruthenium release following cladding oxidation.

MACCS calculations show that release of all ruthenium increases early fatalities by a factor of 20 to 100, because the assumed form (oxide) has a large dose per Ci inhaled due to its long clearance time from the lung.

Mitigating factors for ruthenium releases in spent fuel pool accidents

- **rubbling of the fuel limits air ingression**
- **1 year half-life of ruthenium**

PHEBUS test planned to examine effect of air ingression on a larger scale in an integral facility

Effect of Ruthenium (cont.)

Decay Time Prior to Accident	Mean Consequences for Surry Population Density (0-100 miles)		
	Early Fatalities	Societal Dose (rem)	Cancer Fatalities
1 year	1.01	4.54×10^6	2,320
1 year (100% ruthenium release)	95.3	9.53×10^6	9,150
1 year (100% ruthenium release)[a]	.13	6.75×10^6	6,300

[a]Based on early evacuation.

Conclusion: Ruthenium release can increases consequences, but can be offset by early evacuation.

Effect of Number of Fuel Assemblies Releasing Fission Products

- **Original calculations assumed entire spent fuel pool inventory of Millstone 1 was involved in heatup and release (3.5 cores).**

- **Depending on reductions in decay heat from radioactive decay, less fuel may be involved in heatup.**

- **Performed MACCS calculations for two cases: (a) entire spent fuel pool inventory (3.5 cores) and (b) inventory in final core offload.**

Effect of Number of Fuel Assemblies Releasing Fission Products (cont.)

Ruthenium Release Fraction	# of cores	Mean Consequences for Surry Population Density (0-100 miles)		
		Early Fatalities	Societal Dose (rem)	Cancer Fatalities
$2x10^{-5}$	3.5	1.01	$4.54x10^6$	2,320
$2x10^{-5}$	1	.014	$3.23x10^6$	1,530
1	3.5	95.3	$9.53x10^6$	9,150
1	1	50.5	$7.25x10^6$	7,360

Number of cores reduced for cases with and without large ruthenium release

Smaller consequence reduction for case with large ruthenium release because most ruthenium is in final core offload due to its one year half-life

Other Issues

Results with and without large ruthenium releases presented to ACRS in April 2000.

ACRS comments

Fission product release fractions from spent fuel pool accident study in NUREG/CR-4982 not supported

Plume-related parameters

- **Plume heat content**
- **Plume spreading**

Sensitivity calculations were performed to follow-up on ACRS comments.

Effect of Release Fractions

Case	Release Fraction							Mean Consequences (0-100 miles)		
	I,Cs	Ru	Te	Ba	Sr	Ce	La	Early Fatali-ties	Societal Dose (rem)	Cancer Fatalities
1	1	$2x10^{-5}$	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	1.01	$4.54x10^{6}$	2,320
45	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	92.2	$9.50x10^{6}$	9,150
45a	1	1	.02	.01	.01	.01	.01	103	$1.33x10^{7}$	11,700
45b	.75	.75	.02	.01	.01	.01	.01	54.9	$1.17x10^{7}$	10,300
46[a]	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	1.32	$6.84x10^{6}$	6,430
46a[a]	1	1	.02	.01	.01	.01	.01	1.54	$8.89x10^{6}$	8,160
46b[a]	.75	.75	.02	.01	.01	.01	.01	.543	$7.94x10^{6}$	6,880
46c[a]	.75	.75	.75	.01	.01	.01	.01	.544	$7.94x10^{6}$	6,880
46d[a]	.75	.75	.75	.75	.01	.01	.01	.544	$7.94x10^{6}$	6,880
46e[a]	.75	.75	.75	.75	.75	.01	.01	.644	$1.01x10^{7}$	8,350

[a]Based on early evacuation.

3 1/2 cores

Effect of Release Fractions (cont.)

Results

Increased fuel fines release fraction: increased consequences for cases with early and late evacuation.

Increased tellurium and barium release fractions: no change in consequences due to short half-lives.

Increased strontium release fraction: increased consequences.

Also evaluated the effect of evacuation percentage (99.5% vs. 95%).

Main difference involved early evacuation; factor-of-ten increase in early fatalities.

Effect of Plume Heat Content

Potential for plume heat content to be higher than that of a reactor accident —> staff performed sensitivity calculations using different plume heat contents

Base Case: plume heat content from NUREG-1150 (3.7 MW)

Staff estimated plume heat content to be about 256 MW for complete oxidation of one core in 30 minutes

SNL performed a more detailed estimate of plume heat content (about 43 MW)

Effect of Plume Heat Content (cont.)

Case	Release Fraction							Plume Heat Content (MW)	Mean Consequences (within 100 miles)		
	I,Cs	Ru	Te	Ba	Sr	Ce	La		Early Fatalities	Societal Dose (rem)	Cancer Fatalities
1	1	$2x10^{-5}$	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	3.7	1.01	$4.54x10^{6}$	2,320
45	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	3.7	92.2	$9.50x10^{6}$	9,150
47	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	83.0	57.3	$9.24x10^{6}$	9,280
49	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	256.0	18.3	$8.24x10^{6}$	8,380
46[a]	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	3.7	1.32	$6.84x10^{6}$	6,430
48[a]	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	83.0	.00509	$7.28x10^{6}$	7,060
50[a]	1	1	.02	.002	.002	$1x10^{-6}$	$1x10^{-6}$	256.0	.00357	$6.96x10^{6}$	6,650

[a]Based on early evacuation.

Increasing plume heat content mainly affects early fatalities.

Effect of Plume Spreading

MACCS uses a Gaussian plume model with the amount of spreading determined by the model parameters σ_y and σ_z.

As part of international cooperative effort on consequence assessment codes, experts provided updated values for σ_y and σ_z.

Experts provided distributions for σ_y and σ_z, instead of point estimates.

SNL performed MACCS calculations using values for σ_y and σ_z selected by sampling from the distributions; a total of 300 MACCS calculations were run.

Results: Factor of 1.1 to 15 decrease in prompt fatalities. Up to a 60% increase in cancer fatalities and population dose. (Expect similar effects for reactor accidents.)

Decay Times Beyond One Year

Performed calculations at longer decay times (out to 10 years) with and without early evacuation.

As part of these calculations, reassessed the source terms used.

In these calculations, used release fractions from NUREG-1465 (both in-vessel and ex-vessel releases) instead of NUREG/CR-4982.

> **NUREG-1465 has received significant peer review and is representative of a low pressure core-melt accident**
>
> **Performed consequence calculations for two cases**
>
> - **NUREG-1465**
> - **NUREG-1465, with the ruthenium and fuel fines release fractions changed to .75 and .035, respectively**

Source Terms

Source Term	Release Fractions								
	noble gases	iodine	cesium	tellurium	strontium	barium	ruthenium	lanthanum	cerium
NUREG/CR-4982	1	1	1	.02	.002	.002	$2x10^{-5}$	$1x10^{-6}$	$1x10^{-6}$
NUREG-1465	1	.75	.75	.31	.12	.12	.005	.0052	.0055
NUREG-1465 (mod)	1	.75	.75	.31	.12	.12	.75[a]	.035[b]	.035[b]

[a]Ruthenium release fraction is that of a volatile fission product.
[b]Fuel fines release fraction is that of the Chernobyl accident (*Chernobyl Ten Years On, Radiological and Health Impact, An Appraisal by the NEA Committee on Radiation Protection and Public Health*, November 1995).

Results for Decay Times Beyond One Year (NUREG-1465)

Case	Decay Time	Mean Consequences (0-100 miles)		
		Early Fatalities	Societal Dose (rem)	Cancer Fatalities
77a	30 days	2.21	$7.15x10^6$	4540
77b	90 days	1.37	$6.99x10^6$	4420
77c	1 year	.736	$6.81x10^6$	4190
77d	2 years	.481	$6.65x10^6$	4020
77e	5 years	.192	$6.47x10^6$	3800
77f	10 years	.0778	$6.26x10^6$	3620
78a[a]	30 days	.0720	$5.69x10^6$	3240
78b[a]	90 days	.0461	$5.58x10^6$	3150
78c[a]	1 year	.0301	$5.48x10^6$	3020
78d[a]	2 years	.0208	$5.40x10^6$	2930
78e[a]	5 years	.00882	$5.33x10^6$	2820
78f[a]	10 years	.00400	$5.24x10^6$	2730

[a]Based on early evacuation.

Results for Decay Times Beyond One Year (NUREG-1465 modified)

Case	Decay Time	Mean Consequences (0-100 miles)		
		Early Fatalities	Societal Dose (rem)	Cancer Fatalities
79a	30 days	192	2.62×10^7	21100
79b	90 days	162	2.49×10^7	20000
79c	1 year	76.9	2.15×10^7	17400
79d	2 years	19.2	1.90×10^7	15400
79e	5 years	1.34	1.66×10^7	12600
79f	10 years	.360	1.53×10^7	11400
80a[a]	30 days	6.65	1.60×10^7	15400
80b[a]	90 days	3.95	1.52×10^7	14300
80c[a]	1 year	.951	1.34×10^7	11500
80d[a]	2 years	.149	1.20×10^7	9480
80e[a]	5 years	.0162	1.07×10^7	7620
80f[a]	10 years	.00601	1.00×10^7	6490

[a]Based on early evacuation.

Summary

Issues examined

- **reduced inventory (at 1 year)**
- **early vs. late evacuation (at 1 year)**
- **importance of cesium**
- **importance of ruthenium**
- **number of assemblies releasing fission products**
- **fission product release fractions**
- **plume heat content**
- **plume spreading**
- **decay times beyond 1 year**
- **reassessment of source term**

Results of large number of MACCS calculations were used to understand decommissioning risk in staff's generic study.