From: Robert Palla , NRR
To: George Hubbard, Timothy Collins
Date: Fri, Sep 15, 2000 10:33 AM
Subject: Fwd: 30 days to 10 years

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From: Jason Schaperow
To: Robert Palla
Date: Fri, Sep 15, 2000 8:23 AM
Subject: 30 days to 10 years

Attached is my draft memo forwarding results of MACCS calculations for 30 days to 10 years. So far, John Flack and I have concurred.

CC: Charles Tinkler, John Flack

MEMORANDUM TO: Gary M. Holahan, Director
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

FROM: Farouk Eltawila, Acting Director
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: EFFECT OF FISSION PRODUCT INVENTORY AVAILABLE FOR RELEASE ON SPENT FUEL POOL ACCIDENT CONSEQUENCES

As part of its effort to develop generic, risk-informed requirements for decommissioning, NRR requested (Reference 1) that RES evaluate the offsite radiological consequences of beyond-design-basis spent fuel pool accidents. In response to that user need, RES completed an in-house analysis (References 2 and 3) using the MACCS code (Reference 4). The focus of that work was estimation of consequences at one year after final reactor shutdown. Recently, NRR requested (References 5 and 6) that RES evaluate the consequences using fission product inventories at 30 and 90 days and one, two, five, and ten years after shutdown to provide additional insight into the effect of reductions in radionuclide inventory available for release. After discussion with RES, NRR requested that consequence estimates be made for two evacuation cases, late evacuation with evacuation beginning 1.4 hours after the release begins and early evacuation with evacuation beginning three hours before the release begins.

Because of radioactive decay, spent fuel pool accidents occurring long after fuel offload will progress more slowly and have smaller fission product releases and, as a result, will have smaller consequences. Radioactive decay affects accident progression and fission product release in three ways. The first effect is that the lower decay heat results in longer times (a) for the hottest assemblies to heat up to the temperatures required to drive off fission products and (b) for the heatup to propagate to assemblies with lower decay heat. This prolonged heat-up and propagation provides more time to prevent, recover, and mitigate the accident. It also provides more time to evacuate and take other protective measures. The second effect is that the lower decay heat results in fewer assemblies heating up to the temperatures required to drive off fission products. The third effect is that, for those assemblies that heat up, there is a lower fission product inventory in each assembly available for release.

As noted above, NRR requested that RES investigate the third effect, that is, the lower fission product inventory in each assembly available for release. RES performed these consequence calculations using the release fractions in Table 1. The release fractions in the second row of Table 1 are from NUREG-1465, *Accident Source Terms for Light-Water Nuclear Power Plants* (Reference 7). For this application, RES used the complete NUREG-1465 source term including the ex-vessel and late in-vessel phase releases. The release fractions in the first row of Table 1 (i.e., the upper bound case), other than those for ruthenium and fuel fines, also are from NUREG-1465. However, in this case, the ruthenium release fraction is that for a volatile

fission product. This is considered to be bounding for a couple of reasons. First, rubbling of the spent fuel after heat-up to about 2500K is expected to limit the ruthenium release. Second, following the Chernobyl accident, ruthenium in the environment was found to be in the metallic form (Reference 8). Metallic ruthenium has a much lower dose conversion factor, that is, rem per Curie inhaled, than oxidic ruthenium which is conservatively assumed in the MACCS code. Also, the fuel fines release fraction used in the upper bound case is that from the Chernobyl accident (Reference 8). This is considered to be bounding, because the Chernobyl accident involved more extreme conditions (i.e., two explosions followed by a prolonged graphite fire) than a spent fuel pool accident.

Table 1 Fission Product Release Fractions

Source Term	Release Fractions								
	noble gases	iodine	cesium	tellurium	strontium	barium	ruthe-nium	lantha-num	cerium
upper bound	1	.75	.75	.31	.12	.12	.75	.035	.035
NUREG-1465	1	.75	.75	.31	.12	.12	.005	.0052	.00055

The results of the RES calculations for the population within 100 miles (consistent with the distance used in earlier RES analysis for NRR on spent fuel pool accidents) are given in Tables 2 and 3 for the upper bound and NUREG-1465 release fractions, respectively. These results are shown graphically in Figures 1 through 3. However, these results do not consider the additional time available to prevent, recover, and mitigate the accident and the additional time available to evacuate and take other protective measures. They also do not consider the reduced number of assemblies releasing fission products. Therefore, we believe that these results significantly overestimate the magnitude of the consequences and may not accurately portray the decline in consequences as a function of time. An integrated analysis of heatup, propagation, and release, together with explicit consideration of prevention, recovery, and mitigation and a systematic consideration of emergency response, is needed to address these deficiencies. Also, the ruthenium and fuel fines release fractions are uncertain. Because ruthenium and fuel fines releases are very important to the consequences, additional data are needed.

In Reference 5 and in subsequent discussions, NRR also requested RES estimates of the societal doses for the population within 50 miles and the cancer fatalities for the population within 1000 miles. The societal doses for the population within 50 miles are given in the last column in Tables 2 and 3. However, this memorandum does not report the cancer fatalities for the population within 1000 miles, because of the high degree of uncertainty in the atmospheric transport model at these large distances.

Table 2 Results based on Upper Bound Source Term

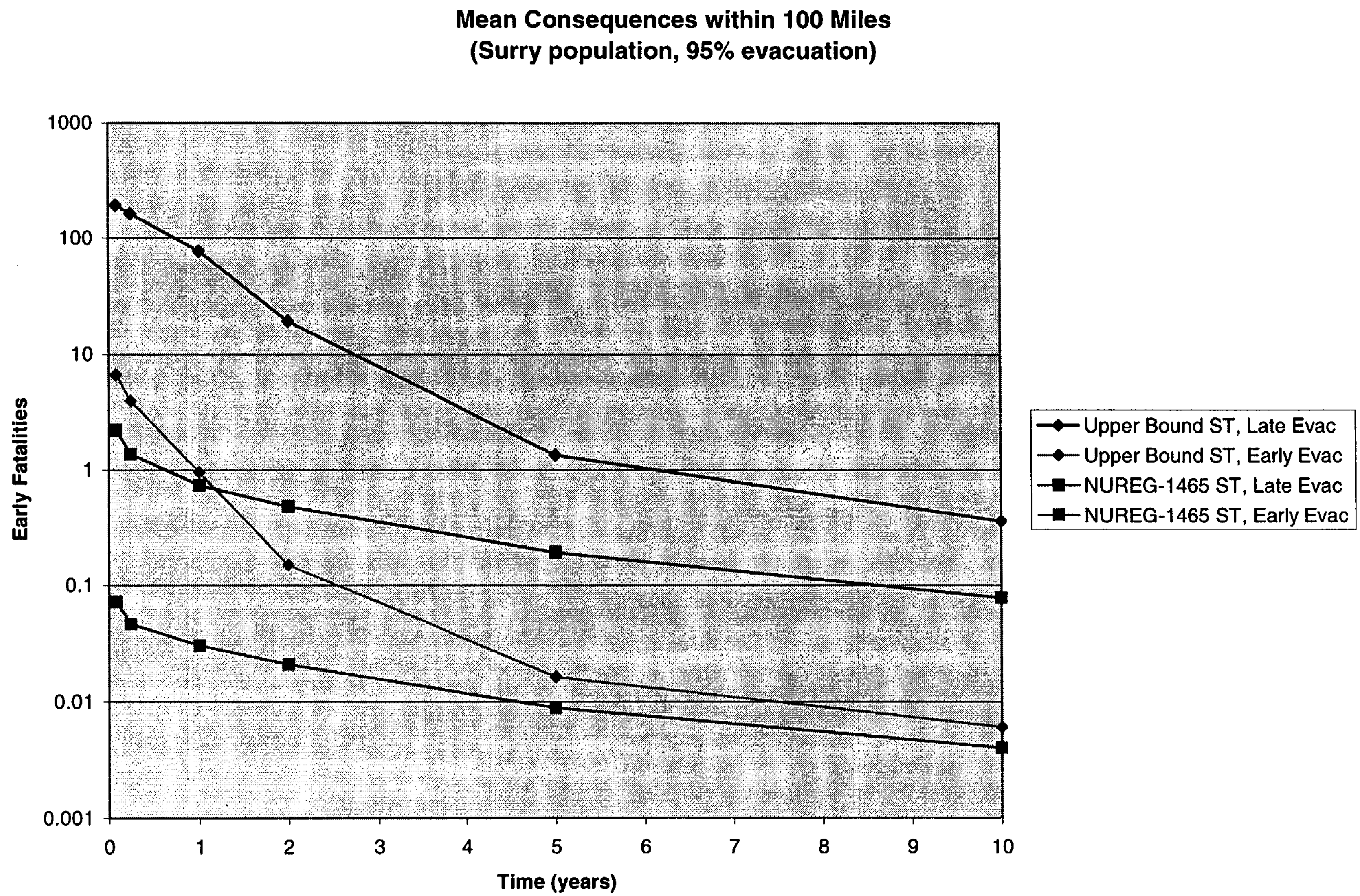
Case	Decay Time	Mean Consequences (Surry population, 95% evacuation)			
		Within 100 miles			Within 50 miles
		Early Fatalities	Societal Dose (rem)	Cancer Fatalities	Societal Dose (rem)
79a	30 days	192	$2.62x10^7$	21100	$2.37x10^7$
79b	90 days	162	$2.49x10^7$	20000	$2.25x10^7$
79c	1 year	76.9	$2.15x10^7$	17400	$1.93x10^7$
79d	2 years	19.2	$1.90x10^7$	15400	$1.69x10^7$
79e	5 years	1.34	$1.66x10^7$	12600	$1.45x10^7$
79f	10 years	.360	$1.53x10^7$	11400	$1.34x10^7$
80a[a]	30 days	6.65	$1.60x10^7$	15400	$1.35x10^7$
80b[a]	90 days	3.95	$1.52x10^7$	14300	$1.29x10^7$
80c[a]	1 year	.951	$1.34x10^7$	11500	$1.12x10^7$
80d[a]	2 years	.149	$1.20x10^7$	9480	$9.93x10^6$
80e[a]	5 years	.0162	$1.07x10^7$	7620	$8.69x10^6$
80f[a]	10 years	.00601	$1.00x10^7$	6490	$8.13x10^6$

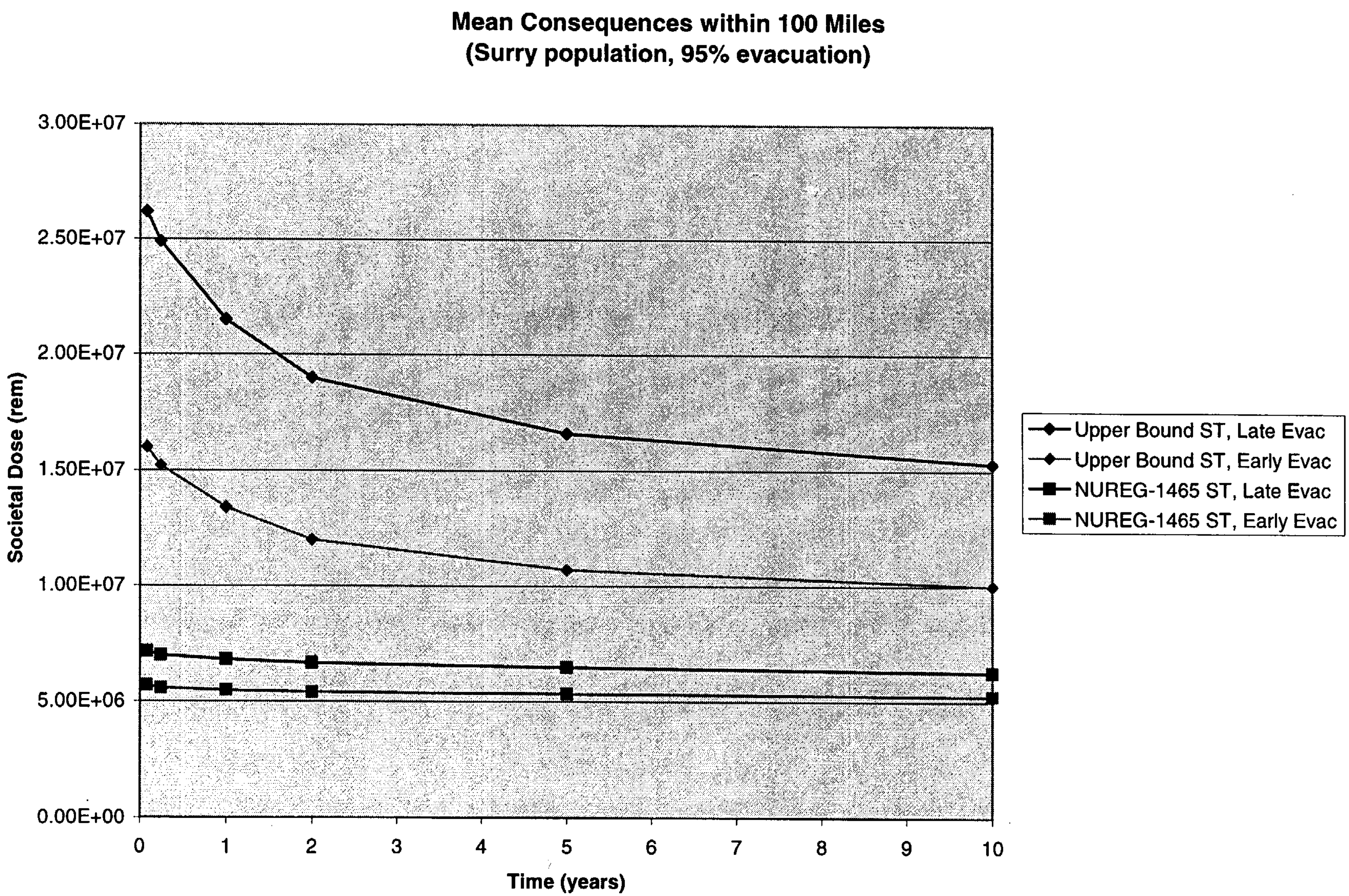
[a]Based on early evacuation.

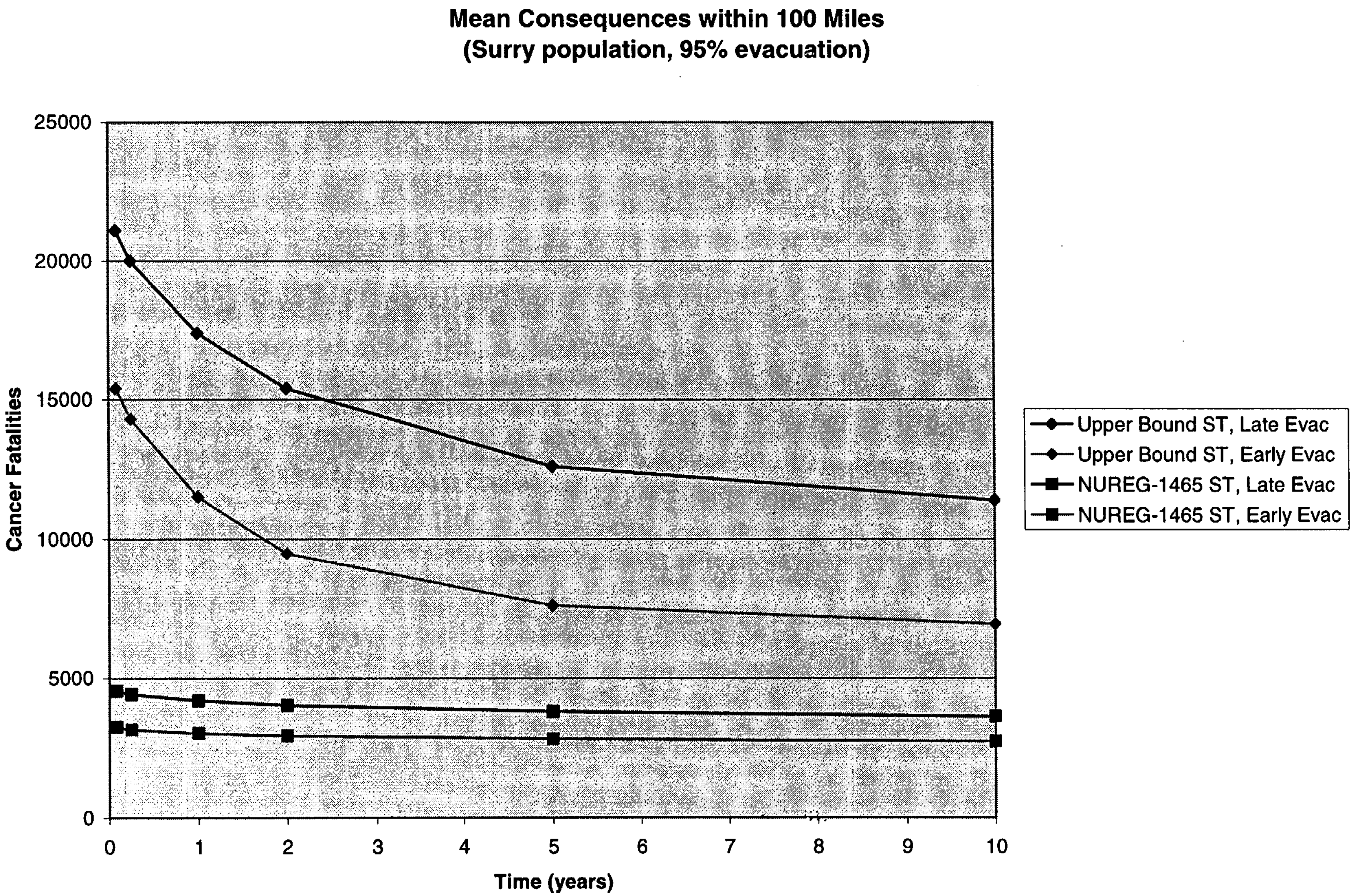
Table 3 Results based on NUREG-1465 Source Term

Case	Decay Time	Mean Consequences (Surry population, 95% evacuation)			
		Within 100 Miles			Within 50 Miles
		Early Fatalities	Societal Dose (rem)	Cancer Fatalities	Societal Dose (rem)
77a	30 days	2.21	$7.15x10^6$	4540	$5.58x10^6$
77b	90 days	1.37	$6.99x10^6$	4420	$5.43x10^6$
77c	1 year	.736	$6.81x10^6$	4190	$5.28x10^6$
77d	2 years	.481	$6.65x10^6$	4020	$5.12x10^6$
77e	5 years	.192	$6.47x10^6$	3800	$4.90x10^6$
77f	10 years	.0778	$6.26x10^6$	3620	$4.72x10^6$
78a[a]	30 days	.0720	$5.69x10^6$	3240	$4.12x10^6$
78b[a]	90 days	.0461	$5.58x10^6$	3150	$4.02x10^6$
78c[a]	1 year	.0301	$5.48x10^6$	3020	$3.95x10^6$
78d[a]	2 years	.0208	$5.40x10^6$	2930	$3.87x10^6$
78e[a]	5 years	.00882	$5.33x10^6$	2820	$3.77x10^6$
78f[a]	10 years	.00400	$5.24x10^6$	2730	$3.69x10^6$

[a]Based on early evacuation.


Mean Consequences within 100 Miles
(Surry population, 95% evacuation)
1000
100
10
1
0.1
0.01
0.001
Early Fatalities
0
1
2
3
4
5
6
7
8
9
10
Time (years)
Upper Bound ST, Late Evac
Upper Bound ST, Early Evac
NUREG-1465 ST, Late Evac
NUREG-1465 ST, Early Evac


Mean Consequences within 100 Miles
(Surry population, 95% evacuation)
Societal Dose (rem)
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
0
1
2
3
4
5
6
7
8
9
10
Time (years)
Upper Bound ST, Late Evac
Upper Bound ST, Early Evac
NUREG-1465 ST, Late Evac
NUREG-1465 ST, Early Evac


Mean Consequences within 100 Miles
(Surry population, 95% evacuation)
Cancer Fatalities
25000
20000
15000
10000
5000
0
0
1
2
3
4
5
6
7
8
9
10
Time (years)
Upper Bound ST, Late Evac
Upper Bound ST, Early Evac
NUREG-1465 ST, Late Evac
NUREG-1465 ST, Early Evac

References:
1. Memorandum from G. Holahan to T. King dated March 26, 1999
2. Memorandum from A. Thadani to S. Collins dated November 12, 1999
3. Memorandum from F. Eltawila to G. Holahan dated August 25, 2000
4. Code Manual for MACCS2, NUREG/CR-6613, May 1998
5. Memorandum from R. Barrett to J. Flack dated August 25, 2000
6. Memorandum from S. Collins to A. Thadani dated September 11, 2000
7. *Accident Source Terms for Light-Water Nuclear Power Plants*, NUREG-1465, February 1995
8. *Chernobyl Ten Years On, Radiological and Health Impact, An Appraisal by the NEA Committee on Radiation Protection and Public Health*, November 1995

cc: T. Collins
R. Barrett
J. Hannon
J. Wermiel
G. Hubbard

References:
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