AREVA

CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9082288 - 002 Safety Related: ☐ Yes ☒ No

Title BBNPP Dose Rate Equation for SSES ISFSI

PURPOSE AND SUMMARY OF RESULTS:

Purpose

The purpose of this calculation is to derive an equation that describes the dose rate resulting from the ISFSI radiations on the EPR construction site of Susquehanna Steam Electric Station (SSES) as a function of distance and time. The equation will account for both position and time dependence based on projected loading of the storage facility.

Revision 002 was created solely for the purpose of removing the "proprietary" wording from the document.

Summary of Results

The ISFSI is modeled as two separate sections: the south section pre-loaded at the reference date of 2007 (loading will continue until 2010), and the north section to be loaded starting 2009. The dose rate from the ISFSI, at a distance r_S from the south section, a distance r_N from the north section , and time t (calendar year), is given by the following function:

$$D(r_N, r_S, t) = k\left[f_N(t)\varpi_N e^{-\mu r_N} + f_S(t)\varpi_S e^{-\mu r_S}\right] \text{mrem/yr}$$

$$\text{and , } f_i(t) = a_i + b_i t$$

Parameter	ISFSI Section	
	North (i=1)	South (i=2)
a_i	-233.88	-253.79
b_i (yr^{-1})	0.117	0.126
r_i (ft)	$\sqrt{(N-N_i)^2+(E-E_i)^2}$	
ϖ_i (sr)	$\varpi_i = \pi\left(1-\frac{r_i}{\sqrt{r_i^2+R^2}}\right)$	
μ (ft^{-1})	0.002056	
R (ft)	116.52	
k (mrem/sr)	1500	
N_i (ft)	341,550	341,450
E_i (ft)	2,409,100	2,409,100

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV

THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

☐ YES

☒ NO

Review Method: ☒ Design Review (Detailed Check)
☐ Alternate Calculation

Signature Block

Name and Title (printed or typed)	Signature	P/R/A and LP/LR	Date	Pages/Sections Prepared/Reviewed/Approved
Ted Messier Principal Scientist	*TA MESSIER* *6/5/2013*	LP		All changes in current revision
Edward Cumming Advisory Scientist	*ER CUMMING* *6/5/2013*	LR		All changes in current revision
Mark Rinckel Technical Manager	*MA RINCKEL* *6/5/2013*	A		Reviewer is independent

Note: P/R/A designates Preparer (P), Reviewer (R), Approver (A);
LP/LR designates Lead Preparer (LP), Lead Reviewer (LR)

Project Manager Approval of Customer References (N/A if not applicable)

Name (printed or typed)	Title (printed or typed)	Signature	Date
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Mentoring Information (not required per 0402-01)

Name (printed or typed)	Title (printed or typed)	Mentor to: (P/R)	Signature	Date
N/A				
N/A				

Record of Revision

Revision No.	Pages/Sections/Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial Release
001	Section 1.2; 1.4; 2.2;	Rewrite of sections to update dose modeling documented in Reference [2].
	Section 5.1	Rewrite of sections to update dose modeling documented in Reference [2].
	Section 6.0	Rewrite of sections to update dose modeling documented in Reference [2].
	Section 8.0	Rewrite of sections to update dose modeling documented in Reference [2].
	Section 3.1	Added Figure 3-4 and Figure 3-5 for clarification
	Section 5.1	Added text and Table 5-1 to clarify TLD analysis
	Section 7.0	Updated Open Item Section with resolution
002	All	This revision consisted only of the removal of the "Proprietary" statement from page 1, the removal of the word "Proprietary" from all other pages, the addition of the NRC accession number to Ref. 1, and the change to the latest revision of the 0402-01 template.

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1.0 ANALYTICAL METHODLOGY

1.1 Open Items

There may be cases when necessary technical input data is unavailable at the time that this calculation is released. If this happens a Product Upgrade List (PUL) is prepared as directed by AREVA NP procedure 0412-66 to indicate the changes or additions required at the time the calculation is released.

The "open items" are identified by the words "Open Item" followed by the number symbol and a reference number, all enclosed in brackets and in bold type, e.g., **{OPEN ITEM #1}**. When the required information becomes available the calculation will be revised and the PUL will be closed.

1.2 Dose Equation

TLD measurements in the vicinity of the ISFSI facility combined with historic loading data and a projected loading schedule were used to develop an equation describing the dose rate as a result of the ISFSI radiations. The ISFSI will be modeled as two separate sections, one pre-loaded at the reference date of 2007 (loading will continue until 2010 at this section), and one to be loaded starting 2009. This is modeled by the function summarized as Equation 1-1.

Equation 1-1

$$D(r_i,t) = \sum f_i(t) k \varpi(r_i) e^{-\mu r_i} \quad \textbf{(mrem)}$$

where

$f_i(t)$ = time function describing loading with time dependence

k = Fitting parameter specific to the site, given by measured TLD data (mrem/sr)

$\varpi(r_i)$ = solid angle between given source and receptor (sr)

r_i = distance from source and receptor (ft)

t = time (year)

μ = effective removal coefficient in air (ft^{-1})

i = index for each "section" of the ISFSI (North/South)

1.3 ISFSI Loading

The incremental loading of the ISFSI is modeled with a linear function. Data from the history of loadings together with projections of the expected additions were used to fit the function given as Equation 1-2.

Equation 1-2

$$f(t) = a + bt$$

where

a = fitting parameter

b = fitting parameter

t = time of dose evaluation (in format of 2007)

1.4 Dose versus Distance Function

The function used to evaluate the reference dose rate uses both the distance and the solid angle between the source and the receptor. It is a function that fits data available in the REMP report (Reference [1] and [5]) for TLD dosimeters in the area mainly under the influence of the direct exposure to radiation from the ISFSI facility. The form of the function is given by Equation 1-3. This method is fully documented in Reference [2]

Equation 1-3

$$D(r) = k\varpi(r)e^{-\mu r} \text{ (mrem)}$$

where

k = fitting parameter, specific to the installation, (mrem/sr)

$\varpi(r)$ = solid angle subtended by source (sr)

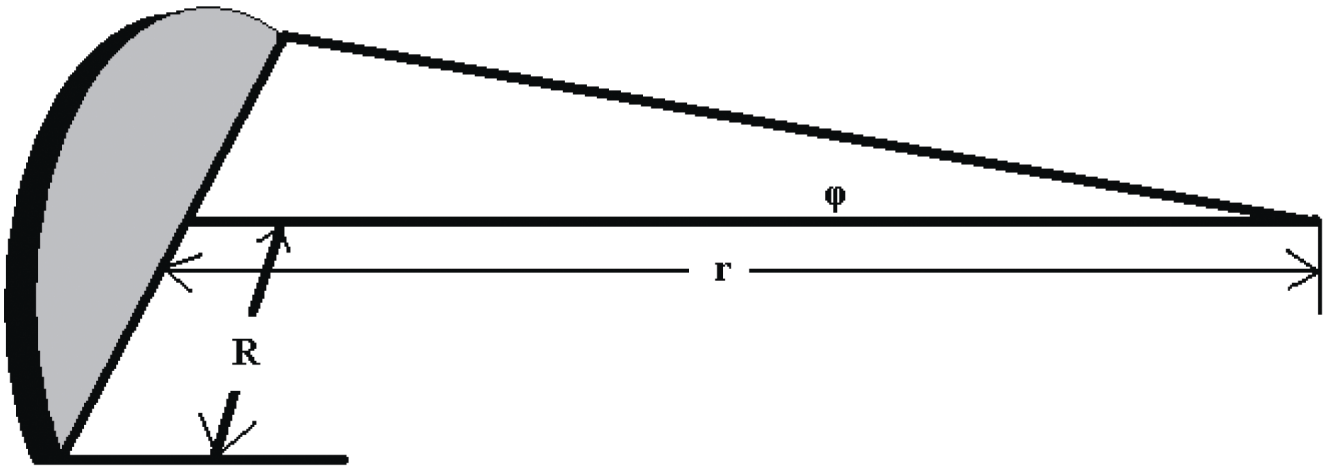
μ = fitting parameter, 0.002056 (ft^{-1})

r = distance from source surface to receptor (ft)

1.4.1 Solid Angle

The solid angle between the ISFSI source and receptor is shown in Figure 1-1.

Figure 1-1: Solid Angle Diagram



The solid angle is given by the following set of equations :

Equation 1-4

$$\varpi = \pi\left(1 - \cos\left(\varphi\right)\right)$$

Equation 1-5

$$\cos\left(\varphi\right) = \frac{r}{\sqrt{r^2 + R^2}}$$

Where,

r = Distance from source to receptor surface (ft)

R = Effective radius of ISFSI source, 116.52 (ft)

2.0 ASSUMPTIONS

2.1 Assumptions Requiring Verification

There are no assumptions requiring verification in this calculation.

2.2 Justified Assumptions

It is assumed that the proposed loading plan is an accurate prediction of additional activity to the ISFSI Facility.

The effective source is assumed to be half a disk from any direction

The ISFSI source is assumed to be 90% photons and 10% neutrons. This assumption is supported by the manufacturers Safety Analysis Report [3].

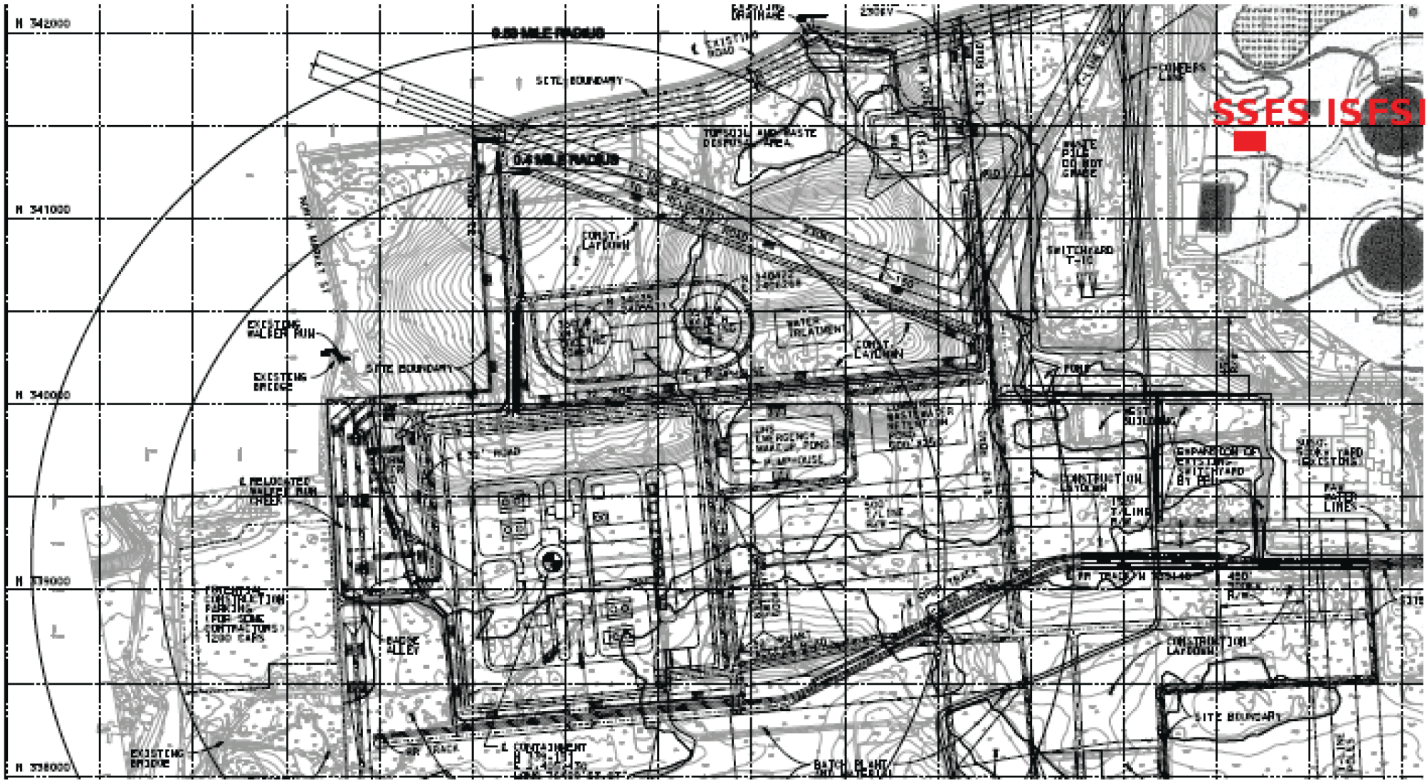
The conversion of mR to mrem is assumed to be 0.877 mrem / mR .

3.0 CALCULATION INPUTS

3.1 ISFSI Location

Figure 3-3 [4] uses satellite imagery to scale positions for the TLD locations in relation to the ISFSI facility.

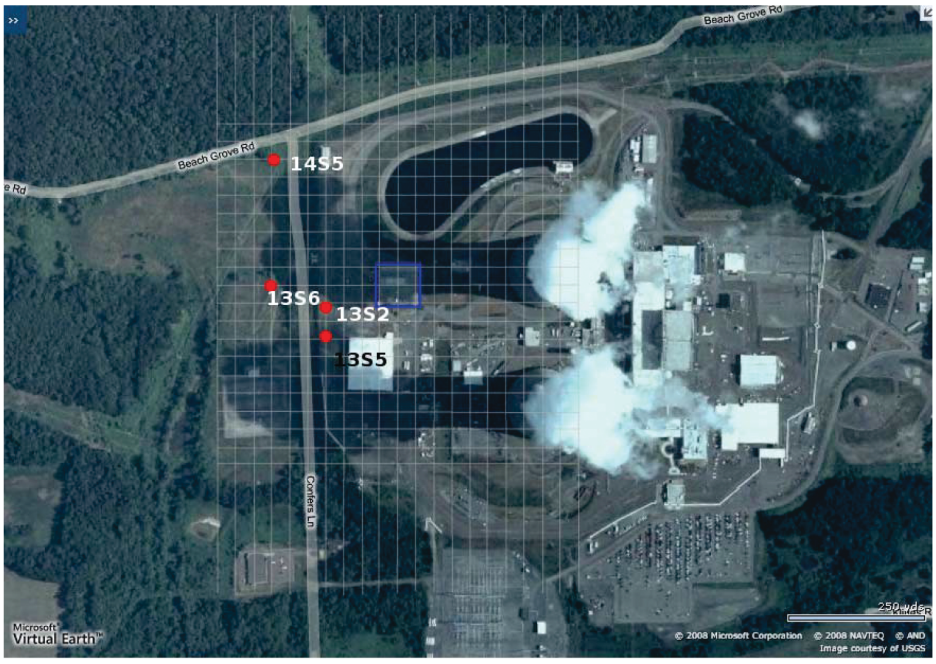
Figure 3-1: BBNPP Site and Position of SSES ISFSI



Only the red label and indication of estimated ISFSI location are pertinent. The rest of the figure is for information context only.

Figure 3-2: Satellite Image of SSES ISFSI

Figure 3-3: SSES ISFSI (Blue Border) with Relevant TLD Locations and Grid



The locations of TLDs and ISFSI sections are given in Table 3-1, according to the state plane coordinate system. The positions of the TLDs were estimated from Figure 3-4 and Figure 3-5 obtained from the 2007 SSES REMP report (Reference [1] and [5])

Figure 3-4: TLD Monitoring Locations Within One Mile

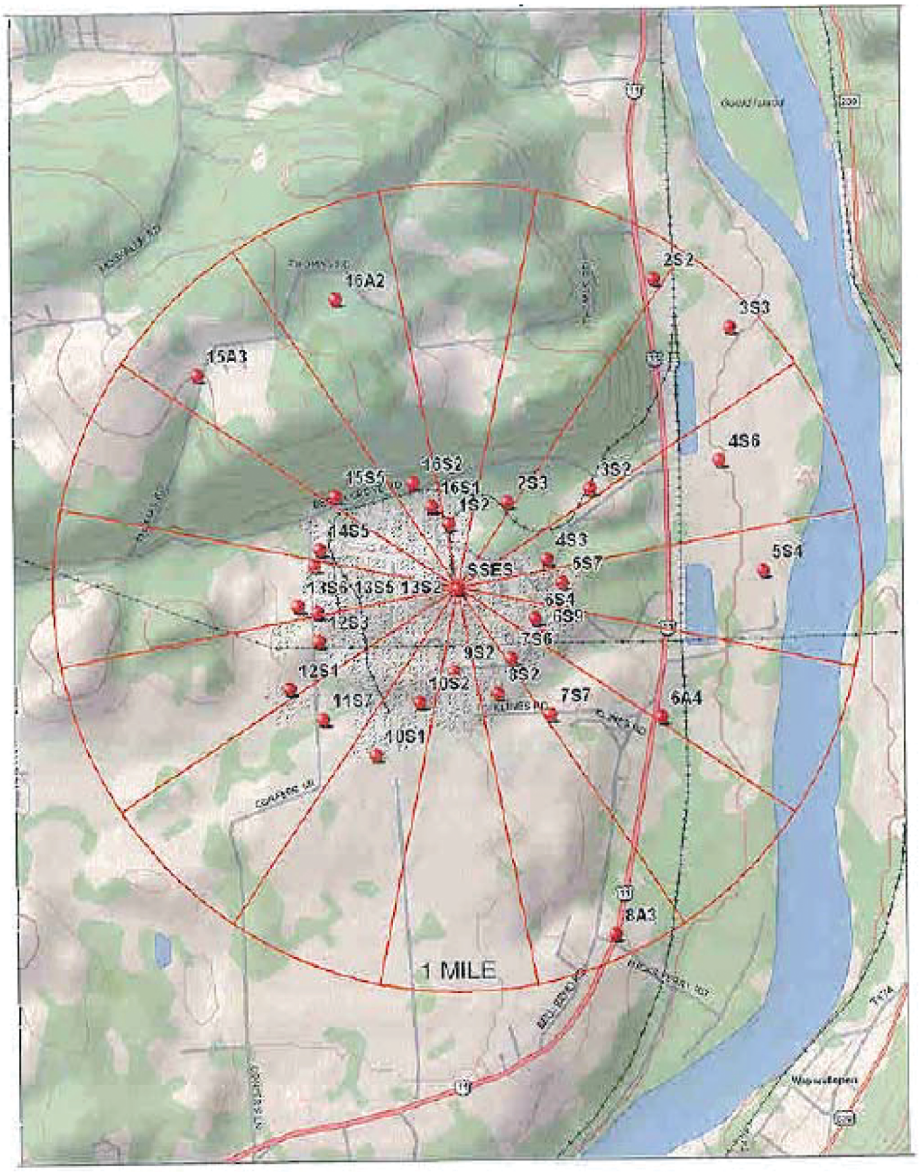


Figure 3-5: TLD Monitoring Locations One to Five Miles

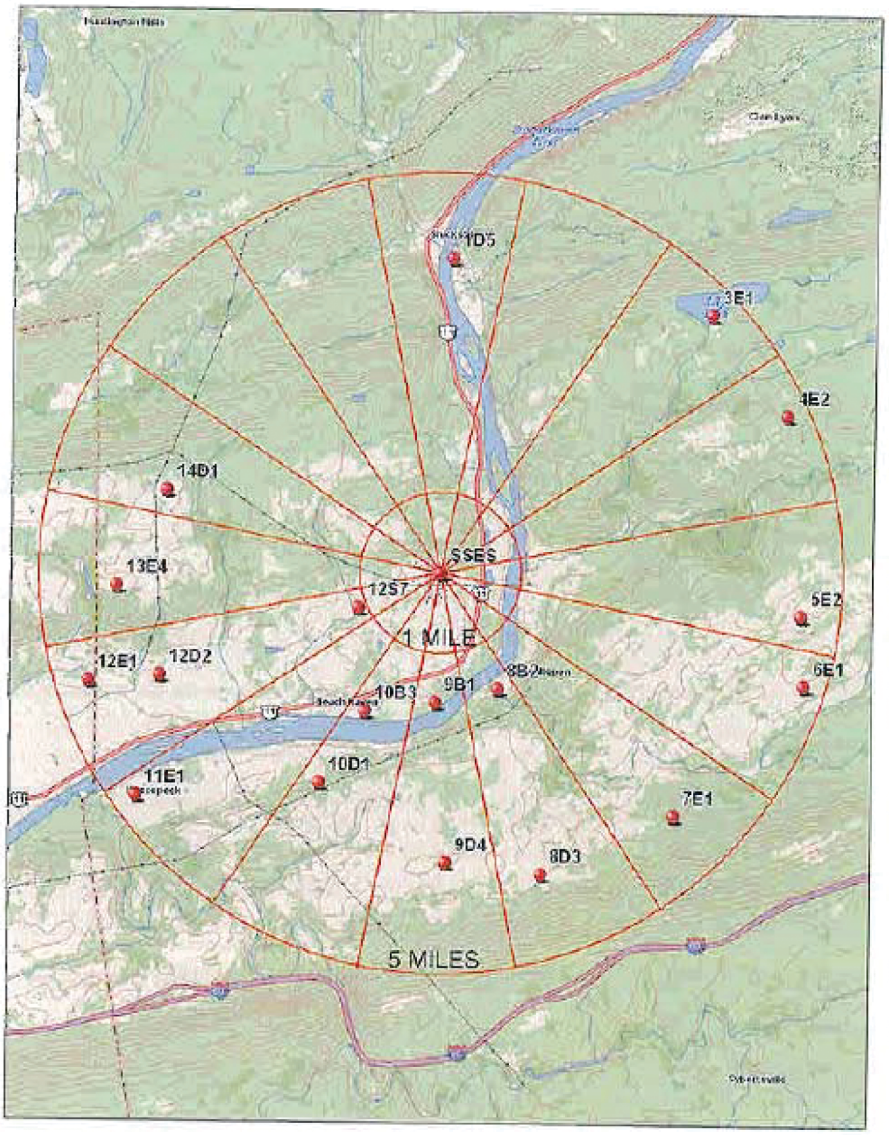


Table 3-1: Estimated ISFSI and TLD Locations

Location	N	E
ISFSI - North	341,550	2,409,100
ISFSI - South	341,450	2,409,100
TLD – 13S2	341,384	2,408,705
TLD – 13S5	341,109	2,408,705
TLD – 13S6	341,489	2,408,409
TLD – 14S5	342,186	2,408,414

3.2 TLD Measurements

The following are TLD measurements within the vicinity of the ISFSI facility at SSES from Appendix I in the REMP report submitted to the NRC for the year 2007 [1].

Table 3-2: TLD Measurements in Vicinity of SSES ISFSI (mR)

TLD location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Total Gross (per year)	Total Net (γ) (per year)
13S2	31.5 ± 2.4	27.3 ± 1.2	32.3 ± 2.0	27.4 ± 2.0	118.5 ± 3.9	26.2 ± 8.1
13S5	30.9 ± 1.7	27.2 ± 3.0	30.9 ± 2.2	27.7 ± 3.3	116.7 ± 5.3	24.4 ± 8.8
13S6	29.2 ± 1.2	23.8 ± 1.6	27.6 ± 1.5	23.5 ± 1.1	104.1 ± 2.7	11.8 ± 7.6
14S5	29.5 ± 2.4	22.6 ± 1.6	26.1 ± 1.7	23.5 ± 0.7	101.7 ± 3.4	9.4 ± 7.9
Control	25.3 ± 3.4	20.0 ± 2.9	25.7 ± 4.3	21.3 ± 3.4	92.3 ± 7.1	NA

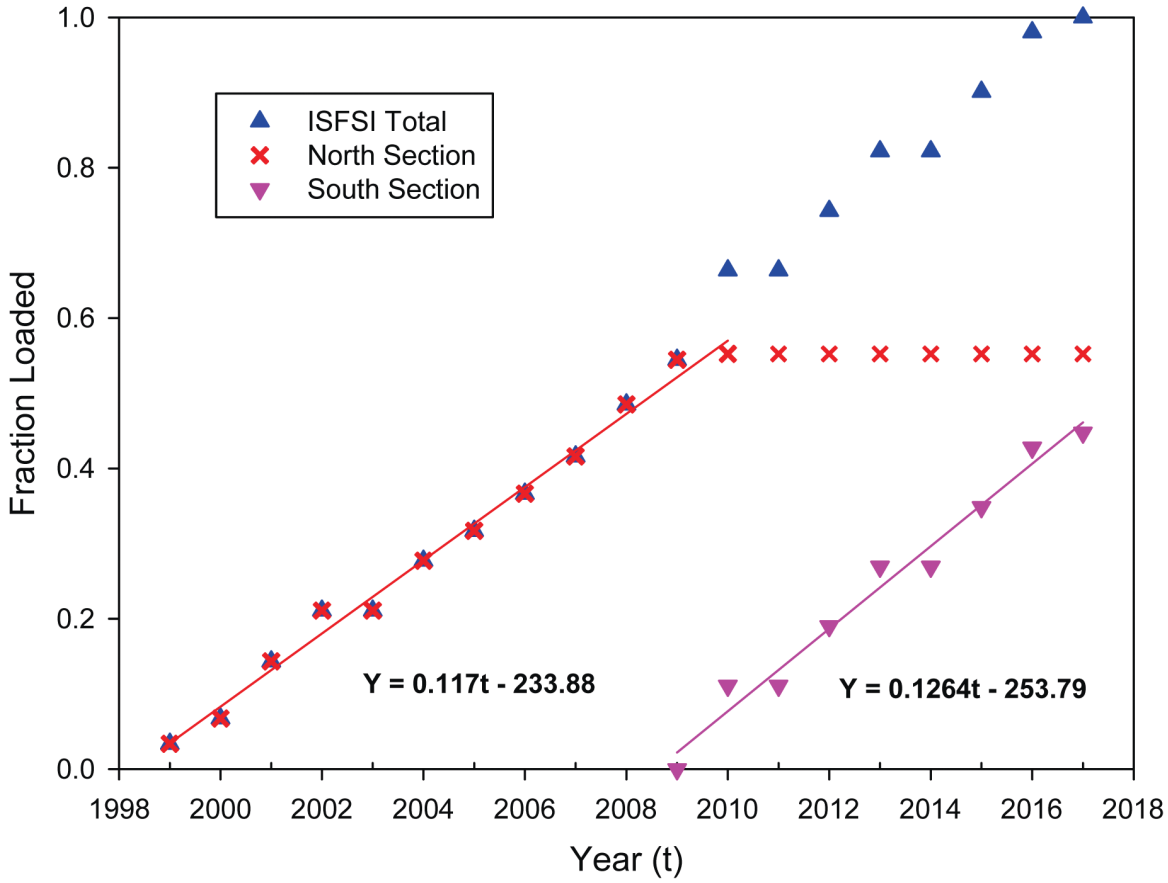
3.3 ISFSI Loading

The loading of the ISFSI at SSES is given in Table 3-3 [5]. Figure 3-6 shows the loading of each section and the fitting functions used to describe it.

Table 3-3: Historical and Projected Loading of SSES ISFSI

Year	Bundles Added	# of Bundles Total
1999	208	208
2000	208	416
2001	468	884
2002	416	1300
2003	0	1300
2004	409	1709
2005	244	1953
2006	305	2258
2007	305	2563
2008	427	2990
2009	366	3356
2010	732	4088
2011	0	4088
2012	488	4576
2013	488	5064
2014	0	5064
2015	488	5552
2016	488	6040
2017	122	6162

Figure 3-6: ISFSI Loading and Respective Fitting Functions for Each Section



4.0 SOFTWARE

Microsoft Excel was used for various calculations and to fit the data to the functions given in Section 5.0. The file has been uploaded to AREVA's COLD system. The files ending in .mht are archives of Excel documents.

Table 4-1: COLD File Description

File Name	File Date	File Size	Description
BB_ISFSI-Rev001.mht	9-8-08	171,133 bytes	Calculation Spreadsheet

5.0 CALCULATIONS

5.1 Dose Rate from Distance Function

TLD location was estimated with input from Figure 3-3, Figure 3-4 and Figure 3-5. The positions in Table 3-1 were used as inputs to the equation below to determine the distances for each TLD.

$$d = \sqrt{\left(N - N_{ref}\right)^2 + \left(E - E_{ref}\right)^2} \text{ (ft)}$$

The distance from the center of the North ISFSI section (the only one loaded at the time of TLD measurements) at SSES is contained in Table 5-1.

Table 5-1: TLD Distance (ft) from ISFSI Center

TLD ID	Distance from ISFSI (ft)
13S2	428
13S5	593
13S6	694
14S5	935

The dose rate data from Reference [1] was converted to mrem from the given units of mR and additionally increased by 10% to account for the neutron dose not measured by the TLDs. It was then plotted and a function of the form given by Equation 1-3 was generated for varying distances to evaluate the fit across the range of 100 ft to 10,000 ft. The parameter 'k' was adjusted to normalize the quotient of calculated to measured dose to unity. R corresponds to the effective radius of each section, 100 ft. The data and fitting function is seen in Figure 5-1, with the fitting parameters listed in Table 5-3.

Table 5-2: TLD Measurements in Vicinity of SSES ISFSI (mrem [γ+n])

TLD location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Total Gross (per year)	Total Net (γ+n) (per year)
13S2	30.4 ± 2.3	26.3 ± 1.2	31.2 ± 1.9	26.4 ± 1.9	118.5 ± 3.9	25.3 ± 7.8
13S5	29.8 ± 1.6	26.2 ± 2.9	29.8 ± 2.1	26.7 ± 3.2	116.7 ± 5.3	23.5 ± 8.5
13S6	28.2 ± 1.2	23.0 ± 1.5	26.6 ± 1.4	22.7 ± 1.1	104.1 ± 2.7	11.4 ± 7.3
14S5	28.5 ± 2.3	21.8 ± 1.5	25.2 ± 1.6	22.7 ± 0.7	101.7 ± 3.4	9.1 ± 7.6
Control	24.4 ± 3.3	19.3 ± 2.8	24.8 ± 4.1	20.5 ± 3.3	92.3 ± 7.1	NA

Figure 5-1: Dose Equation Model with TLD Measurements at Varying Distances

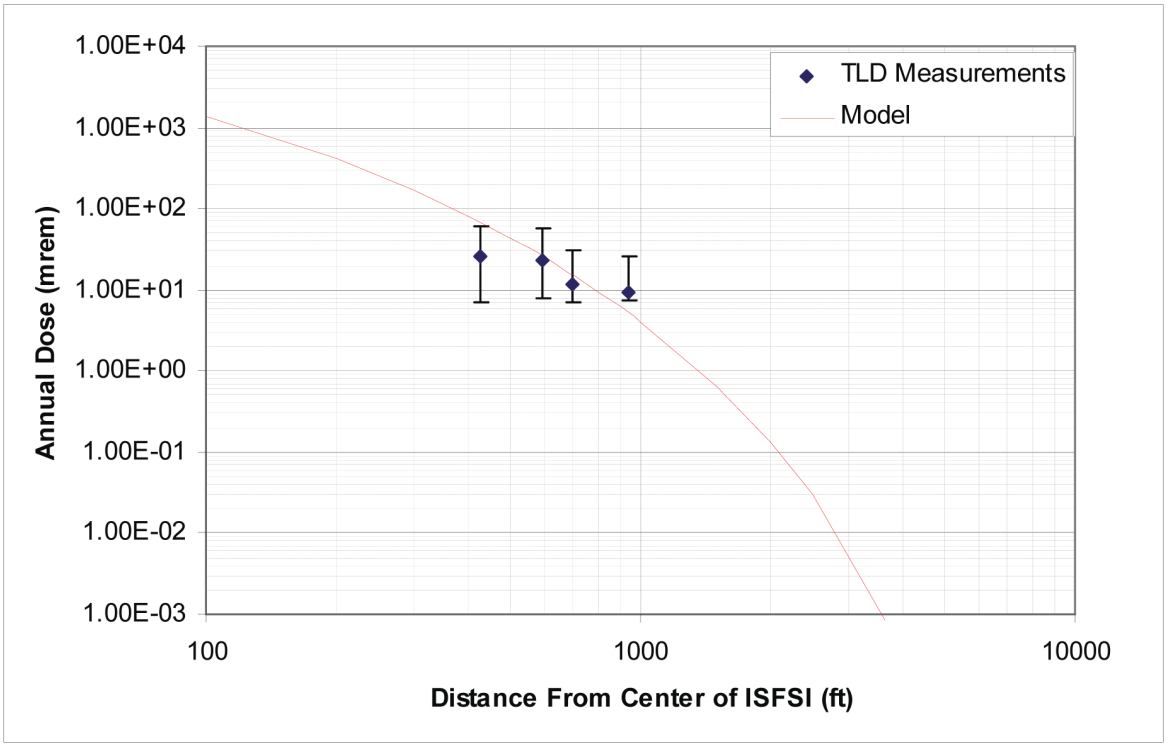


Table 5-3: Fitting Parameter for Distance Relationship to Dose Rate

Parameter	Value
k	1500 ft^{-1}

5.2 Time Correction

With the information on the predicted loading of the ISFSI into the future given in Section 3.3, a relationship between a given year and the total ISFSI loading, referenced by the load in 2007 was generated using linear curve fitting. The ISFSI was divided into 2 sections, one that is currently partially loaded and one that will start loading in 2010. The resulting equations are below.

Equation 5-1

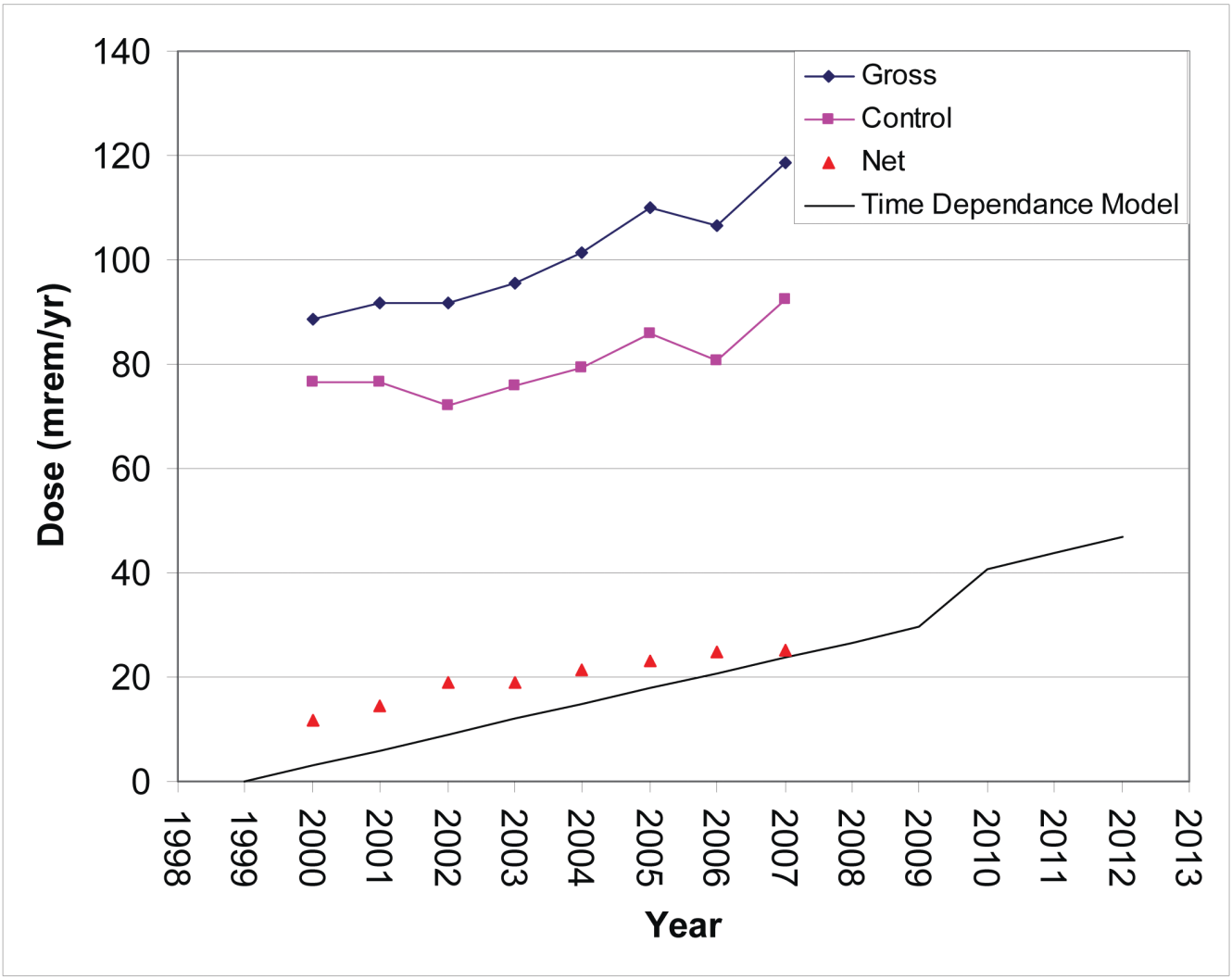
$$f_N(t) = 0.117t - 233.88, t \le 2009$$
$$f_N(t) = 1.33, t > 2009$$

Equation 5-2

$$f_S(t) = 0.1264t - 253.79, t \geq 2010$$
$$f_S(t) = 0, t < 2010$$

The functions above were compared with historical data obtained from the Annual Radiological Environmental Operating Report for SSES Units 1 and 2 (Reference [5]). Using the 2007 TLD data for TLD 13S2 as a reference dose, the product of the reference dose and time correction functions above was plotted as the time dependence model. This was compared with the recorded historical net dose and is seen in Figure 5-2.

Figure 5-2: TLD (ID 13S2) Data Verifying Time Correlation Function



6.0 RESULTS

The dose rate due at a distance, r, and time, t, is given by the following function:

$$D(r_N, r_S, t) = k\left[f_N(t)\varpi_N e^{-\mu r_N} + f_S(t)\varpi_S e^{-\mu r_S}\right]_{\text{mrem/yr}}$$

All variables are defined in Table 6-1 below.

Table 6-1: Dose Rate Function Variables and Constants

Parameter	ISFSI Section	
	North (i=1)	South (i=2)
a_i	-233.88	-253.79
b_i (yr^{-1})	0.117	0.126
r_i (ft)	$\sqrt{(N-N_i)^2+(E-E_i)^2}$	
ϖ_i (sr)	$\varpi_i = \pi\left(1-\frac{r_i}{\sqrt{r_i^2+R^2}}\right)$	
μ (ft^{-1})	0.002056	
R (ft)	116.52	
k (mrem/sr)	1500	
N_i (ft)	341,550	341,450
E_i (ft)	2,409,100	2,409,100

7.0 OPEN ITEMS

Open Item Number	Description	Resolution
1	The method for calculating the dose rate from a source using the solid angle is documented in AREVA Document Number 51-9085104-000. This is currently in a draft form. This method is used in Section 1.4	32-9089377-000 has been prepared and released by records management. This calculation has been updated based on the method documented. 92-9085094-000 has been closed

8.0 REFERENCES

1. PPL Susquehanna LLC, "Susquehanna Steam Electric Station Units 1 and 2 Annual Radiological Environmental Operating Report 2007," ML081680546.

2. AREVA Document Number 32-9089377-000, "Equation for Dose vs Distance from ISFSI".

3. Transnuclear, Inc., "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel", Revision 9, 2/3/06.

4. AREVA Document Number 38-9079793-001, "BBNPP Site Utilization Plot Plan, Rev. 6, Sheet 1".

5. AREVA Document Number 38-9085096-000, "Response to EPR 08-394"