UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION I
475 ALLENDALE ROAD
KING OF PRUSSIA, PENNSYLVANIA 19406-1415

August 8, 1995

Docket No. 030-20934 License No. 37-23341-01

MEMORANDUM FOR: Charles W. Hehl, Director
Division of Radiation Safety and Safeguards, RI

FROM: Mohamed M. Shanbaky, Chief MS 7/13/95
Research and Development Section
Nuclear Materials Safety and Safeguards Branch, RI

SUBJECT: 1995 UPDATE TO MEMORANDUM DATED NOVEMBER 7, 1988 "INTERSTATE NUCLEAR SERVICES (INS) CORPORATION ROYERSFORD, PENNSYLVANIA"

The Interstate Nuclear Services (INS) Corporation nuclear laundry in the Borough of Royersford, Pennsylvania releases effluent containing radioactive material to the Royersford Wastewater Treatment Facility (RWTF), also in Royersford. Although the INS releases are made in compliance with the allowable concentration which may be released to the sanitary sewerage system as described in 10 CFR 20.303 and 10 CFR 20.2003, much of the radioactive material is reconcentrated in the sludge produced by the RWTF. The RWTF is an unusually small capacity wastewater treatment facility, resulting in INS providing a relatively high percentage of influent. The RWTF handles less than 500,000 gallons of influent per day, of which 15,000 gallons may come from INS. The reconcentration of radioactive material in the sludge was identified in 1985. At that time, the RWTF sludge was disposed of by spray application to local farmlands (the sludge from the secondary digester is a liquid containing approximately 4 to 6% solids), and the NRC requested that Oak Ridge Associated Universities (ORAU) perform a study of the RWTF sludge and a pathway analysis of doses to potential persons exposed. The study began in April 1986, and included measurements of: effluents released by INS; influent and effluent samples from the RWTF; sludge samples from the RWTF; and soil samples from the farms. Reports of the study issued in 1987, 1988, and 1989 concluded that only small doses would be received by the hypothetical maximally exposed person, and that no dose is received by real individuals as a result of this practice. Alternate methods of disposal have been developed for this sludge since 1987, and ORAU continues to analyze samples from the RWTF for Region I.

In March 1988, the Pennsylvania Department of Environmental Resources (PADER) prevented the RWTF from further land application of the sludge due to concerns about concentration of the non-radioactive copper. After exploring a number of alternate disposal methods for the sludge, the RWTF had the sludge mechanically dewatered, and disposed of the dewatered sludge (approximately 40% solids and the consistency of damp potting soil) into a local landfill. This option was approved by PADER in July 1988, then was rescinded in August, 1988 due to the radioactive materials in the sludge. The problem of the disposal of the sludge has been discussed between the Borough of Royersford, PADER, INS, and the NRC since that time, because the RWTF secondary digester has limited storage capacity, requiring periodic (approximately once per year) removal of material from the secondary digester in order to operate the facility. Since 1988, PADER has allowed disposals of the dewatered sludge to a landfill on a case-by-case basis, but does not consider this method of disposal to be appropriate on a routine basis due to the radioactive material content of the sludge.

In an effort to find a more economic and continuous method of dewatering the sludge for disposal, reed beds were built at the RWTF in 1990. The sludge from the secondary digester is pumped into the beds where growing reeds remove the water and some nutrients from the sludge. The beds are designed to accumulate 5 to 10 years' quantity of sludge, after which removal of the dried sludge would be required. Because this method will result in the accumulation of radioactive material in one location (as opposed to dispersal on farmland or in a landfill), Region I began monitoring the RWTF with thermoluminescent dosimeters (TLDs) sensitive to environmental radiation levels in July 1990, prior to the first application of sludge to the reed beds. Calculations of the maximum expected dose were also performed using the computer code MICROSHIELD. The predictions of the calculations have been confirmed by the TLD monitoring: the maximum radiation levels are less than two millirem per hour, and the radiation levels have become reasonably constant. This is expected to remain for the useful lifetime of the reed bed, assuming the quantities of radioactive material released by INS do not change.

It appears from the studies performed by ORAU that the amount of radioactive material found in the sludge is comparable to the quantity released from the INS laundry, and is independent of the concentration of radioactive material in the INS effluent. Since the identification of the radioactive material concentrating in the sludge at the RWTF, INS has worked to improve its effluent treatment to reduce the quantity of radioactive material released to the sewer. In April, 1987, INS installed a new filtration system to reduce the amount of radioactive materials in their effluent. The total activity released each year decreased from approximately 250 millicuries in 1988 to 70 millicuries by 1991. Since that time, the total activity released by INS has increased, and the cause of this increase is under review. INS continues to perform studies of effluent treatments, and performed pilot tests of new processes including ultrafiltration and reverse osmosis treatment of effluents at their Royersford facility in the fall of 1991.

In 1988, INS informed the NRC of their hope to eliminate releases to the RWTF by releasing effluent water directly to the river in accordance with 10 CFR 20.106. They committed to having concentrations of materials in effluent water be 10% of the NRC limit, and to provide the NRC with quarterly reports of discharges to the sewer and to the river. In 1994, INS received a National Pollutant Discharge Elimination System (NPDES) permit from PADER discharge effluent water directly to the river. INS is in the process of negotiating access across private property which lies between the laundry and the Schuykill River.

INS also agreed to perform a pathway analysis for radioactive material released in effluent from their Royersford facility, including potential exposures at the RWTF. INS submitted a sample pathway analysis to the NRC for approval of the method. The "Radiological Impacts of Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services, Royersford, Pennsylvania" was issued in August 1993. The maximally exposed member of the general public is calculated to receive an annual dose of 0.286 millirem in a year and a 50-year committed dose of 0.298 millirem. The maximally exposed wastewater treatment plant work is calculated to receive 18.6 millirem in a year and a 50-year committed dose of 7.83 E-5 millirem.

At this time, there are no health and safety concerns due to the presence of radioactive material in the reed bed, although radiation levels in the reed bed are higher than normally expected in unrestricted areas. However, at the end of the useful life of the reed bed (expected between 1995 and 2000), an estimated 200 to 700 millicuries total radioactive material may accumulate in the dried sludge, which may require radiological safety precautions to be taken during its removal. For this reason, we intend to continue monitoring the RWTF with TLDs, and to have ORAU perform analyses of samples from the RWTF. In addition, appropriate disposal of the reed bed sludge must be identified.

Attachments:
1. INS and RWTF Chronology of Events
2. RWTF Reed Bed Dose Assessment with Appendixes
   Appendix 1. "INS Quarterly Discharges to the RWTF"
   Appendix 2. Reed Bed Samples
   Appendix 3. Calculations of Dose from Reed Bed
   Appendix 4. TLD Monitoring Results
   Appendix 5. Diagram: Location of TLDs at RWTF
   Appendix 6. Graph: RWTF Standard Quarter TLD Results

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Attachment 1

INS and RWTF: Chronology of Events Associated with the Accumulation of Contaminated Sludge at the RWTF

DATE	EVENT
April 1983	License issued to Tri-State to operate a nuclear laundry in Royersford, Pennsylvania.
September 1984	License issued to Interstate Nuclear Services (INS) to operate the nuclear laundry previously owned by Tri-State.
November 1985	Measurements by NRC determine that, although sewer discharges are within regulatory limits, treatment in the Royersford wastewater treatment Facility (RWTF) results in the reconcentration of the radioactivity in the sludge, which is being sent for land application to local farms as fertilization.
April 1986	Oak Ridge Associated Universities (ORAU) begin study of discharges from INS, sludge treatment plant, and impact of land application of sludge. INS begins to provide NRC with results of analyses of discharges each quarter.
April 1987	New filtration system installed at INS to reduce discharges to the sewer.
September 1987	Phase I of the ORAU study indicates that only small doses are being caused by the land application of the Royersford sludge.
March 29, 1988	Pennsylvania Department of Environmental Resources (PADER) prevents further land application of sludge because of concerns about (nonradioactive) copper concentration.
4/22 to 7/11/88	14 truckloads of sludge transferred by RWTF to the Pottstown sewage plant for mixing and dewatering.
July 5, 1988	PADER gives permission to the Pottstown Landfill to receive RWTF dewatered sludge.
August 5, 1988	PADER rescinds permission for the disposal of Royersford sludge in the Pottstown landfill.

August 16, 1988	INS, PADER, Borough of Royersford, and NRC met in Region I to discuss disposal options, including land application, burial in the local landfill, and burial in one of the low level radioactive waste burial sites. NRC agrees to have ORAU study landfill disposal. The report of Phase II of ORAU study given to PADER. This study confirmed the results of the Phase I study.
August 22, 1988	PADER requests NRC guidance on disposal of sludge by land application and dewatering/landfill disposal.
August 31, 1988	NRC informs PADER that it has no objection to land application of the sludge.
August 1988	INS informs NRC in amendment request letter that they plan eventually to discharge effluent water to the river.
September 1988	9 truckloads of sludge to farms for land application.
November 7, 1988	Memo Joyner (NMSB Branch Chief) to Ebneter (Acting DRSS Director): Summary of INS/RWTF reconcentration problem.
January 27, 1989	Memo H. Thompson (NMSS) to Russell (Region I Administrator): Regulation of Radioactive Material Subsequent to Discharge from a Licensed Facility" responds to legal questions from RI regarding NRC jurisdiction over material after its release to the sewer.
June 1989	ORAU Phase III (final report) issued.
August 1989	PADER informs RWTF that their dewatered sludge containing RAM cannot be taken to a landfill but must be disposed of as radioactive waste.
September 1989	Amendment No. 08 issued to INS, requiring INS river discharges not to exceed 10% of 20.106 limits, and quarterly reports of all discharges to sewer and/or river.
April 1990	RWTF plans for building reed beds for dewatering of sludge on their facility have been approved. Mechanical dewatering must be done beginning no later than May in order to prevent overflow of the secondary digester.
July 1990	Quarterly environmental TLDs placed around the RWTF prior to first application of sludge to Reed Bed #1. Inspection report (dated March 1991) issued for pre-placement survey.
May 1, 1991	Meeting between M. Miller (RI State Liaison Officer) and PADER at PADER office in Harrisburg included discussion of NRC position to allow RWTF sludge to land application or to landfill.
September 1991	INS begins pilot test of ultrafiltration and reverse osmosis treatments of wastewater to be released to the sewer.

September 1991	RWTF discontinues work on Reed Bed #2 until the issue of radioactive material in sludge is settled. They do not want any chance of this new reed bed becoming contaminated and are still considering shutting INS out of system.
October 31, 1991	Memo Bellamy (NMSB Branch Chief) to Knapp (DRSS Director) responds with comments to Region II's Confirmatory Action Letter to INS resulting from the detection of radioactive material in sewer lines after release from the INS Virginia facility.
February 19, 1992	ORAU RFTA 92-006 approved to continue sample analysis from RWTF.
February 25, 1992	Meeting with INS at NRC to explain results of research for methods of reducing releases of radioactive material in laundry wastewater to sewer. INS agrees to perform a pathway analysis for exposure from their Royersford releases, and agrees to provide RI with similar analysis (performed for another INS facility) for comment prior to beginning their analysis. Sample pathway analysis received in May 1992. Approval of method given June 4, 1993.
May 1993	INS submits the current collection and analysis procedures for the monthly samples which are reported to the NRC.
August 1993	INS issues "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services, Royersford, Pennsylvania".
December 1993	Routine Inspection - Clear
Spring 1994	INS receives NPDES permit from PADER to release to the river. However, INS must receive permission from railroad and private property owners to cross their properties to get to the river.
April 12, 1994	ORISE RFTA 94-017 issued for sample analyses from INS/RWTF; open-ended.
January 1995	RWTF informs INS that they must discontinue releases of effluent water from the nuclear laundry to the RWTF system by June 1995. (Note: the shut-off date has been extended by the RWTF, due to the efforts of INS to develop other disposal methods.)

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Attachment 2

ROYERSFORD WASTEWATER TREATMENT FACILITY REED BED DOSE ASSESSMENT

Introduction

The Royersford Wastewater Treatment Facility (RWTF) in the Borough of Royersford, Pennsylvania receives effluent from the Interstate Nuclear Service Corporation (INS) nuclear laundry, also in Royersford. INS began operating the laundry in September 1984, after purchasing the facility from Tri-State which had opened it in 1983. INS releases quantities of licensed material annually which have ranged from 70 millicuries to 450 millicuries total. Approximately one-third of the activity is cobalt-60, one third is cesium-137, and the remainder is composed of other isotopes in very small quantities. INS releases are made in compliance with the allowable concentrations released to a sanitary sewerage system (as described in 10 CFR 20.303 prior to January 1, 1994, and as described in 10 CFR 20.2003 currently). INS provides a quarterly report to Region I of analyses of composite samples for each month. Appendix 1 lists the annual activity of isotopes released by INS for the period of First Quarter 1986 through Fourth Quarter 1994.

The RWTF is an unusually small capacity wastewater treatment facility, to which INS provides a relatively high percentage of influent. The RWTF handles less than 500,000 gallons of influent per day, of which 15,000 gallons may come from INS. Water flows into the treatment facility into settling tanks where large solids are removed. Liquid from the settling tanks go to the biofilter and are processed for release to the river. Solid sludge is pumped to the primary digester for initial treatment. Excess water from the primary digester is recirculated through the RWTF, and the treated sludge is pumped to the secondary digester for final treatment and storage. This sludge is currently applied to a double-celled reed bed on site. Reeds take up the water, drying the sludge. The root system of the reeds contains bacteria which further break down the solids. The reed bed is expected to be used for 5 to 10 years before removal of the sludge is required. Reeds are harvested annually, and currently composted on site.

Much of the radioactivity from the INS effluent is reconcentrated in the sludge produced by the RWTF. The reconcentration of radioactive material in the sludge was identified by the NRC in 1985, who initiated a study to determine dose from the sludge to the general public. INS continues to investigate methods to further reduce the amount of radioactive materials in their releases.

Sludge Characteristics

Results of analyses of releases from INS and sludge from the secondary digester released to farmlands in 1986, 1987 and 1988 indicate that nearly all of the cobalt-60 released by INS stays in the RWTF sludge. Analyses of dried sludge from the reed beds performed by Oak Ridge Associated Universities (ORAU) indicate that the cobalt-60 comprises 50% of the activity in the sludge, while cesium-137 makes up less than 10% of the radioactive material in the sludge bed. A summary of results of analyses of sludge from the reed beds and the uptake in the reeds is included as Appendix 2. Because the RWTF has implemented the use of on-site reed beds as the method for dewatering the sludge, cobalt-60 and other radioactive material will accumulate on the RWTF site in the next 5 to 10 years.

Sludge spread on the farmlands was pumped directly from the secondary digester to a tank truck. This sludge is approximately 4 to 6% solids, and has the appearance and consistency of water or similar liquids. It was applied to farmlands by spraying. Dewatered sludge is produced when liquid sludge from the secondary digester is processed mechanically to remove the water. It is approximately 30-40% solids, and has an appearance and consistency similar to potting soil or compost. Reed bed sludge has a higher solids content than dewatered sludge when dry. However, in the reed bed, the solids content varies according to how recently liquid sludge from the secondary digester has been applied to the reed bed. The reed bed sludge typically has an appearance and consistency similar to swamp mud.

Predicted Doses from Sludge from the RWTF

Calculations were performed using the MICROSHIELD computer code to determine the quantity of radioactive material which could accumulate at the RWTF without creating radiation levels in excess of those permitted in unrestricted areas. A summary of the calculations is included as Appendix 3 of this attachment. Based on these calculations, 354 millicuries of cobalt-60 remaining (after accumulating at 60 millicuries per year for ten years, minus decay) in sludge having a density of 1.0 to 1.6 grams per milliliter in the reed bed over a ten year period would result in a dose rate between 1.2 millirem per hour to 1.8 millirem per hour. The dose rate after accumulation of 60 millicuries is expected to range from 1.1 millirem per hour to 1.6 millirem per hour. This would meet the regulatory limits of 10 CFR 20.105(b)(1) and the new 10 CFR 20.1301(a)(2) of 2 millirem in any one hour of continuous occupancy. However, the limit of 10 CFR 20.105(b)(2) of 100 millirem in any seven consecutive days continuous occupancy (0.6 millirem per hour) as well as the limit of 20.1301(a)(1) of 100 millirem in any one year (0.011 millirem per hour) were predicted to be exceeded with as little as 60 millicuries accumulation in the surface layer. (Note: The actual dose, as measured with thermoluminescent dosimeters by the NRC, detected radiation levels lower than predicted.)

10 CFR 20.105(a) [in effect prior to January 1, 1994] and 10 CFR 20.1301(c) [effective as of January 1, 1994] also allow licensees to request Commission approval for areas to be considered unrestricted if a total dose of 500 millirem in one calendar year would be received by individuals in these areas, based on anticipated average radiation levels and anticipated occupancy times.

The RWTF employs two workers whose duties only occasionally require them to work in or around the reed bed. Sludge application occurs only once every two weeks during the growing season (assumed to be 9 months), and requires one person less than one hour working outside the reed bed, above the retaining wall. Once each year, the reeds are harvested in the winter when the bed is frozen. This activity requires one person to spend eight hours inside the reed bed cutting and retrieving the reeds. Assuming a total of 26 hours spent in or around the reed bed at 2 millirem per hour, the RWTF employees would not exceed the 100 millirem annual limit to members of the general public.

After a period of 5 to 10 years, enough sludge is expected to accumulate in the reed beds to require disposal of the sludge. An estimate that this activity will require 3 persons working in or around the bed for 20 hours at 2 millirem per hour would result in a dose of 40 millirem to each worker. The internal dose to these workers is not considered here, although this activity is likely to produce airborne dust which may be of radiological concern.

INS completed the "Radiological Impacts of Effluent Releases to the Atmosphere and Sanitary Sewer from Interstate Nuclear Services, Royersford, Pennsylvania" in August 1993, which calculated doses from a variety of pathways to persons likely to be affected. INS used the NRC 1992 TLD measurements in the assessment of doses from direct exposure to contaminated sludge, determining an average dose rate factor of 7.85 E-2 millirem per hour. Assuming RWTF workers spent 20 hours working in the reed bed during the year, INS calculated an annual dose of 1.57 millirem. The INS pathway analysis of dose from direct exposure and inhalation of contaminated dust during removal of sludge from the reed bed after 5 years accumulation of sludge, estimates an annual dose of 0.304 millirem to a worker and assuming a total of 80 hours work time required to perform that activity.

TLD Monitoring at the RWTF

A TLD monitoring system was placed around the RWTF in July of 1990 to measure actual accumulated dose. A summary of the data collected from Third Quarter 1990 (the first quarter that sludge application began) through Fourth Quarter 1994 is listed in Appendix 4 of this memorandum. Doses to the TLDs consistently drop during the fourth quarter of one year and the first quarter of the next year, probably due to: 1) no application of sludge during the dormant winter season; and 2) shielding by snow cover (see especially winter 1993-94). The graph in Appendix 4 of doses measured at the reed bed also show doses increase to a constant level (as predicted) due to shielding of radioactive material by successive layers of sludge; a noticeable increase in this plateau level is seen in late 1994, probably due to the application of sludge containing the higher quantities of licensed material released by INS in 1993 and 1994 (see Appendix 1).

The average dose rates to the TLDs at the edge of the reed bed are below the calculated value. This is due to the following factors: 1) Currently, the reed bed accounts for disposal of about one-fourth to one-half of the sludge from the secondary digester. When the secondary digester gets too full, the remainder is disposed of by mechanical dewatering. This occurs because the capacity of the reed bed is not large enough to handle all the sludge, and sludge application can only occur during the growing season, not during the winter when the reeds are dormant. 2) The calculated dose rate was performed for dose at the center of the bed. When a dose was calculated for the edge of the bed, it was about half the value of the dose at the center. 3) Calculations were performed assuming an average release from INS of 120 millicuries in a year, resulting in an activity concentration of 400 to 700 picocuries per gram in the reed bed sludge.

However, the total releases in 1990 and 1991 were each less than 70 millicuries, and the measured activity concentration was 60 to 100 picocuries per gram of reed bed sludge. 4) Limited application of sludge occurred during the third quarter of 1990 when the reeds were newly planted, and in the fourth quarter of 1990 and first quarter of 1991 due to winter dormancy.

Overall, measured doses from the reed bed are lower than expected, and no immediate health and safety concerns exist due to the presence of radioactive material in the reed bed sludge at this time. However, some consideration may be required of possible radiological safety precautions to be taken by workers during removal of the dried sludge at the end of the useful life of the reed bed, expected after 5 to 10 years accumulation of material. In addition, appropriate disposal method and location must be determined for the dried reed bed sludge and the composted reeds.

Region I will continue to provide monitoring with the TLDs at the RWTF. Also, samples of sludge from the secondary digester will be collected at the time of the mechanical dewatering, and samples of reed bed sludge and harvested reeds will be collected over the winter for analysis.

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APPENDIX 1

INS QUARTERLY DISCHARGES TO THE RWTF

QUARTER	* TOTAL ACTIVITY (mCi)	TOTAL VOLUME (gallons)	per cent Cobalt-60	per cent Cesium-137
1Q86	67.0	753,350	isotopic information not available	isotopic information not available
2Q86	63.8	1,049,400		
3Q86	48.8	1,133,970		
4Q86	62.5	1,021,680		
	total 242.1			
1Q87	66.1	1,168,200	isotopic information not available	isotopic information not available
2Q87	48.4	1,236,225		
3Q87	30.8	1,228,275		
4Q87	32.9	1,371,375		
	total 178.2			
1Q88	38.9	1,609,762	isotopic information not available	isotopic information not available
2Q88	41.8	1,479,954		
3Q88	90.9	1,359,971		
4Q88	99.7	1,419,535		
	total 271.3			
1Q89	44.3	839,593	21 %	40 %
2Q89	37.0	520,593	18	52
3Q89	30.2	848,495	37	39
4Q89	63.2	not found	30	28
	total 174.9			
1Q90	33.5	not found	28 %	35 %
2Q90	15.8	not found	27	38
3Q90	11.0	not found	41	28
4Q90	10.0	not found	45	31
	total 69.3			
1Q91	26.2	not found	28%	17 %
2Q91	27.9	not found	43	29
3Q91	4.7	not found	40	29
4Q91	6.8	937,294	25	49
	total 65.6			

QUARTER	* TOTAL ACTIVITY (mCi)	TOTAL VOLUME (gallons)	per cent Cobalt-60	per cent Cesium-137
1Q92	6.8	1,162,842	35 %	42 %
2Q92	11.2	1,741,801	15	74
3Q92	71.9	867,115	18	55
4Q92	56.8	1,343,820	28	32
	total 146.7			
1Q93	85.8	1,227,842	21 %	34 %
2Q93	219.9	1,267,934	27	36
3Q93	55.7	726,682	21	34
4Q93	79.5	1,834,245	27	31
	total 440.9			
1Q94	197.0	1,899,536	24 %	32 %
2Q94	83.5	1,954,667	25	33
3Q94	59.4	1,137,717	40	28
4Q94	15.3	2,160,158	31	36
	total 355.2			

* Activities from 1986, 1987, and 1988 based on gross beta activity; no isotopic analysis available.

Note: The total activity listed here does not include tritium, most of which stays in the liquid at the RWTF, and is released to the river with treated water. Also, strontium-90 analysis was performed of composite samples at a different frequency, and is not reported here.

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APPENDIX 2

TABLE 1. SUMMARY OF RADIOACTIVE MATERIALS IN RWTF REED BED SLUDGE

Date/Location	Co-60		Cs-137		Sr-90		Other	
	pCi/g	%	pCi/g	%	pCi/g	%	pCi/g	%
12/12/90 Cell B	60.6	43	10.5	7.4	2.2	1.6	68.1	48
12/12/90 Cell B	87	43	15.1	7.5	2.1	1.0	98.3	48
12/12/90 Cell B	427.7	50	61.9	7.2	7.2	0.8	357.9	42
6/4/92 Cell A	178	59	29.6	10	3.4	1.1	90	20
6/4/92 Cell B	295	60	46.3	9.4	3.9	0.8	147	30

TABLE 2. SUMMARY OF RADIOACTIVE MATERIALS TAKEN UP BY REEDS

Date	Co-60		Cs-137		Sr-90		Other	
	pCi/g	%	pCi/g	%	pCi/g	%	pCi/g	%
12/12/91	3.1	4.3	2.6	3.6	0.2	0.3	66.8	92
12/12/91	1.0	2.1	1.2	2.4	0.3	0.6	46.2	96
12/12/91	1.5	2.7	2.0	3.6	0.3	0.5	51.3	93
6/4/92	29.1	35	6.8	8	0.1	0.1	47	57

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APPENDIX 3

CALCULATIONS OF DOSE FROM REED BED

MICROSHIELD 3.13 parameters selected:

source configuration: rectangular solid, no shielding except air gap

X = thickness of source (sludge) layer plus shielding layers plus 100 centimeters (distance from surface of reed bed to point of interest)

T1 = thickness of the source (sludge) layer = 30 centimeters

T2 = thickness of sludge shielding the source layer

L = length of reed bed = 85 feet = 2700 centimeters

W = width of reed bed = 35 feet = 1100 centimeters

source material = sludge deposited in reed bed.

Case 1 assumes the material to be concrete-type composition with a density of 1.6 grams per milliliter (typical soil density).

Case 2 assumes the sludge to be water with a density of 1.0 grams per milliliter.

buildup factor: Taylor/MICROSHIELD

segment integration: MICROSHIELD default of 11 segments, point kernel method

Situation A: Radioactive material in the sludge is assumed to be cobalt-60 only, deposited at a rate of 60 millicuries per year. All MICROSHIELD default parameters used for photon energy selection etc.

Table A1: Total Dose Rate from Each Layer, Each Year, with a Sludge Density of 1.6 g/ml, concrete material

	Dose Rate in Millirem per Hour for Layer:										Total
YEAR	1	2	3	4	5	6	7	8	9	10	
1	1.08										1.08
2	0.11	1.08									1.19
3	1E-2	0.11	1.08								1.20
4	2E-3	1E-2	0.11	1.08							1.21
5	2E-4	2E-3	1E-2	0.11	1.08						1.21
6	3E-5	2E-4	2E-3	1E-2	0.11	1.08					1.21
7	5E-6	3E-5	2E-4	2E-3	1E-2	0.11	1.08				1.21
8	7E-7	5E-6	3E-5	2E-4	2E-3	1E-2	0.11	1.08			1.21
9	1E-7	7E-7	5E-6	3E-5	2E-4	2E-3	1E-2	0.11	1.08		1.21
10	2E-7	1E-7	7E-7	5E-6	3E-5	2E-4	2E-3	1E-2	0.11	1.08	1.21

Table A2: Total Dose Rate from Each Layer, Each Year with a Sludge Density of 1.0 g/ml, water

	Dose Rate in Millirem per Hour for Layer:										Total
YEAR	1	2	3	4	5	6	7	8	9	10	
1	1.56										1.56
2	0.16	1.56									1.72
3	2E-2	0.16	1.56								1.74
4	3E-3	2E-2	0.16	1.56							1.74
5	4E-4	3E-3	2E-2	0.16	1.56						1.74
6	5E-5	4E-4	3E-3	2E-2	0.16	1.56					1.74
7	7E-6	5E-5	4E-4	3E-3	2E-2	0.16	1.56				1.74
8	1E-8	7E-6	5E-5	4E-4	3E-3	2E-2	0.16	1.56			1.74
9	1E-7	1E-8	7E-6	5E-5	4E-4	3E-3	2E-2	0.16	1.56		1.74
10	2E-8	1E-7	1E-8	7E-6	5E-5	4E-4	3E-3	2E-2	0.16	1.56	1.74

Table A3: Dose Rates from a One-Year Application of Sludge, with Decay Correction for Ten Years, and Added Sludge Shielding

YEAR	X (cm)	T1 (cm)	T2 (cm)	ACTIVITY (mCi)	DOSE RATE AT X (mrem / hour) [d=1.6]	[d=1.0]
1	130	30	0	60.0	1.08	1.56
2	160	30	30	52.5	0.11	0.16
3	190	30	60	46.0	1.3E-2	1.9E-2
4	220	30	90	40.2	1.7E-3	2.5E-3
5	250	30	120	35.2	2.4E-4	3.5E-4
6	280	30	150	30.8	3.4E-5	4.9E-5
7	310	30	180	27.0	4.8E-6	6.9E-6
8	340	30	210	23.6	6.9E-7	9.8E-7
9	370	30	240	20.7	1.0E-7	1.4E-7
10	400	30	270	18.1	1.5E-8	2.1E-8

X = thickness of source (sludge) layer plus shielding layers plus 100 centimeters (distance from surface of reed bed to point of interest)

T1 = thickness of the source (sludge) layer = 30 centimeters

T2 = thickness of sludge shielding the source layer

Table A4: Total Activity from Each Layer, Each Year

YEAR	Activity in Millicuries for Layer: 1	2	3	4	5	6	7	8	9	10	Total
1	60.0										60.0
2	52.5	60.0									112.5
3	46.0	52.5	60.0								158.5
4	40.2	46.0	52.5	60.0							198.7
5	35.2	40.2	46.0	52.5	60.0						233.9
6	30.8	35.2	40.2	46.0	52.5	60.0					264.7
7	27.0	30.8	35.2	40.2	46.0	52.5	60.0				291.7
8	23.6	27.0	30.8	35.2	40.2	46.0	52.5	60.0			315.3
9	20.7	23.6	27.0	30.8	35.2	40.2	46.0	52.5	60.0		336.0
10	18.1	20.7	23.6	27.0	30.8	35.2	40.2	46.0	52.5	60.0	354.1

Situation B: Radioactive material in the sludge is assumed to be comprised of 36 millicuries cobalt-60, 6 millicuries of cesium-137, 9 millicuries of manganese-54, and 9 millicuries of zinc-65 for a total of 60 millicuries deposited per year. All MICROSHIELD default parameters used for photon energy selection etc.

Table B1: Total Dose Rate from Each Layer, Each Year, with a Sludge Density of 1.6 g/ml, concrete material

	Dose Rate in Millirem per Hour for Layer:										Total
YEAR	1	2	3	4	5	6	7	8	9	10	
1	0.74										0.74
2	3E-2	0.74									0.76
3	1 E-3	3 E-2	0.74								0.76
4	8 E-5	1 E-3	3 E-2	0.74							0.76
5	5 E-6	8 E-5	1 E-3	3 E-2	0.74						0.76
6	3E-5	5 E-6	8 E-5	1 E-3	3 E-2	0.74					0.76
7	2E-8	3E-7	5 E-6	8 E-5	1 E-3	3 E-2	0.74				0.76
8	1E-9	2E-8	3E-7	5 E-6	8 E-5	1 E-3	3 E-2	0.74			0.76
9	1E-10	1E-9	2E-8	3E-7	5 E-6	8 E-5	1 E-3	3 E-2	0.74		0.76
10	7E-12	1E-10	1E-9	2E-8	3E-7	5 E-6	8 E-5	1 E-3	3 E-2	0.74	0.76

Table B2: Total Dose Rate from Each Layer, Each Year with a Sludge Density of 1.0 g/ml, water

	Dose Rate in Millirem per Hour for Layer:										Total
YEAR	1	2	3	4	5	6	7	8	9	10	
1	1.08										1.08
2	1E-1	1.08									1.18
3	1E-2	1E-1	1.08								1.19
4	2E-3	1E-2	1E-1	1.08							1.19
5	2E-4	2E-3	1E-2	1E-1	1.08						1.19
6	3E-7	2E-4	2E-3	1E-2	1E-1	1.08					1.19
7	4E-6	3E-7	2E-4	2E-3	1E-2	1E-1	1.08				1.19
8	6E-7	4E-61	3E-7	2E-4	2E-3	1E-2	1E-1	1.08			1.19
9	8E-8	6E-7	4E-61	3E-7	2E-4	2E-3	1E-2	1E-1	1.08		1.19
10	1E-8	8E-8	6E-7	4E-61	3E-7	2E-4	2E-3	1E-2	1E-1	1.08	1.19

Table B3: Dose Rates from a One-Year Application of Sludge, with Decay Correction for Ten Years, and Added Sludge Shielding

YEAR	X (cm)	T1 (cm)	T2 (cm)	TOTAL ACTIVITY (mCi)	DOSE RATE AT X (mrem / hour) [d=1.6]	[d=1.0]
1	130	30	0	60.0	7.4E-1	1.08
2	160	30	30	48.2	2.7E-2	9.8E-2
3	190	30	60	36.1	1.4E-3	1.2E-2
4	220	30	90	30.9	8.4E-5	1.5E-3
5	250	30	120	27.1	5.2E-6	2.1E-4
6	280	30	150	23.9	2.9E-5	3.3E-7
7	310	30	180	21.5	2.2E-8	4.1E-6
8	340	30	210	19.3	1.4E-9	5.9E-7
9	370	30	240	17.4	9.7E-11	8.5E-8
10	400	30	270	15.7	6.6E-12	1.2E-8

X = thickness of source (sludge) layer plus shielding layers plus 100 centimeters (distance from surface of reed bed to point of interest)

T1 = thickness of the source (sludge) layer = 30 centimeters

T2 = thickness of sludge shielding the source layer

Table B4: Total Activity from Each Layer, Each Year with Mixed Radionuclides

YEAR	Cobalt-60		Cesium-137		Manganese-54		Zinc-65		Total
	mCi	%all	mCi	%all	mCi	%all	mCi	%all	mCi
1	36.0	60%	6	10%	9	15%	9	15%	60.0
2	31.5	71%	5.9	13%	3.9	9%	3.2	7%	44.5
3	27.6	76%	5.7	16%	1.7	5%	1.1	3%	36.1
4	24.1	78%	5.6	18%	0.74	2%	0.41	1%	30.9
5	21.1	78%	5.5	20%	0.32	1%	0.14	1%	27.1
6	18.5	77%	5.3	22%	0.14	1%	0.05	<1%	24.0
7	16.2	75%	5.2	24%	0.06	<1%	0.02	<1%	21.5
8	14.2	73%	5.1	26%	0.03	<1%	0.01	<1%	19.3
9	12.4	71%	5.0	29%	0.01	---	---	---	17.4
10	10.8	69%	4.9	31%	0.01	---	---	---	15.7

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APPENDIX 4

TLD MONITORING, JULY 1990 THROUGH DECEMBER 1994

Net Dose in Millirem to TLDs for Standard Calendar Quarters

Location		3Q90	4Q90	1Q91	2Q91	3Q91	4Q91
1	Reed Bed 1, Cell A	37	90	119	142	190	151
2	Reed Bed 1, Cell B	40	103	129	170	213	193
3	East Fence	16	20	18	25	19	22
4	Rail by Cell B	20	32	31	39	38	39
5	Rail by Sec Digester	14	19	15	20	16	17
6	North Fence	17	20	17	21	18	19
7	West Fence	16	22	17	34	18	22
8	Lamp Post by Reed Bed 2	17	22	18	27	20	25
9	West side, Sec digester	24	22	17	21	16	19
10	Flag Pole	17	19	17	20	18	19
11	South Fence	17	23	18	--	18	23
12	Contact Building	26	29	27	30	26	27
13	Top of Ladder	28	29	25	53	41	31
13	East Side, Sec digester	23	27	28	33	31	29
14	Rail, walkway to office	14	16	17	20	15	17
15	Inside Office	20	23	17	24	19	21

Location		1Q92	2Q92	3Q92	4Q92	1Q93	2Q93	3Q93	4Q93
1	Reed Bed 1, Cell A	122	136	160	163	137	168	172	145
2	Reed Bed 1, Cell B	141	163	191	181	166	193	190	174
3	East Fence	20	21	19	22	17	23	20	20
4	Rail by Cell B	33	34	33	38	32	38	37	38
5	Rail by Sec Digester	17	--	16	19	15	19	17	18
6	North Fence	19	20	18	20	16	21	18	--
7	West Fence	22	23	19	23	16	24	18	21
8	Lamp Post by Reed Bed 2	21	26	20	25	19	28	**	**
9	West side, Sec digester	20	21	--	22	18	23	21	21
10	Flag Pole	18	20	19	20	16	20	17	18
11	South Fence	20	23	18	24	16	24	19	20
12	Contact Building	28	29	27	30	25	30	27	28
13	Top of Ladder	35	30	36	18	17	18	22	48
14	East Side, Sec digester	29	27	27	28	25	29	30	28
15	Rail, walkway to office	16	16	16	18	14	16	--	17
16	Inside Office	21	24	21	22	29	22	21	21

-- TLD damaged; no data available
** lamp post removed; new location needed

Location		1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95	4Q95
1	Reed Bed 1, Cell A	90	188	251	259	231			
2	Reed Bed 1, Cell B	115	219	279	273	296			
3	East Fence	14	23	21	24	21			
4	Rail by Cell B	26	44	49	48	50			
5	Rail by Sec Digester	--	21	19	21	20			
6	North Fence	16	22	17	20	17			
7	West Fence	15	23	18	22	17			
8	Light Switch, Back Shed	**	**	14	16	14			
9	West side, Sec digester	16	23	19	21	18			
10	Flag Pole	--	20	18	20	22			
11	South Fence	15	23	17	22	19			
12	Contact Building	16	31	28	29	28			
13	Top of Ladder	36	44	55	35	40			
14	East Side, Sec digester	21	33	34	35	34			
15	Rail, walkway to office	15	18	19	17	17			
16	Inside Office	17	20	18	21	19			

-- TLD damaged; no data available
** lamp post removed; new location needed

See Appendix 5 for a diagram showing the approximate locations of the TLDs and the Reed Bed at the Royersford Wastewater Treatment Facility.

See Appendix 6 for graphs of the standard quarter TLD results for Locations 1 through 8.

Average Dose Rates in Millirem Per Hour to TLDs in Reed Bed 1, Cell A and Cell B

Location		3Q90	4Q90	1Q91	2Q91	3Q91	4Q91
1	Reed Bed 1, Cell A	0.017	0.042	0.055	0.066	0.088	0.067
2	Reed Bed 1, Cell B	0.019	0.048	0.060	0.079	0.100	0.088

Location		1Q92	2Q92	3Q92	4Q92	1Q93	2Q93	3Q93	4Q93
1	Reed Bed 1, Cell A	0.056	0.062	0.074	0.075	0.063	0.077	0.079	0.067
2	Reed Bed 1, Cell B	0.064	0.074	0.088	0.083	0.076	0.089	0.087	0.080

Location		1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95	4Q95
1	Reed Bed 1, Cell A	0.041	0.086	0.115	0.119	0.098			
2	Reed Bed 1, Cell B	0.053	0.100	0.128	0.125	0.125			

These average dose rate readings are much lower than the dose rates calculated in Appendix 3, Tables A1 (plateau at 1.08 millirem per hour) and B1 (plateau at 0.76 millirem per hour). The RWTF applied less than half of the sludge processed during each of these years, and calculations of the dose rate at the edge of the reed bed results in approximately half the dose calculated for the center of the reed bed. Given this, the measured dose rates are in reasonable agreement with those calculated.

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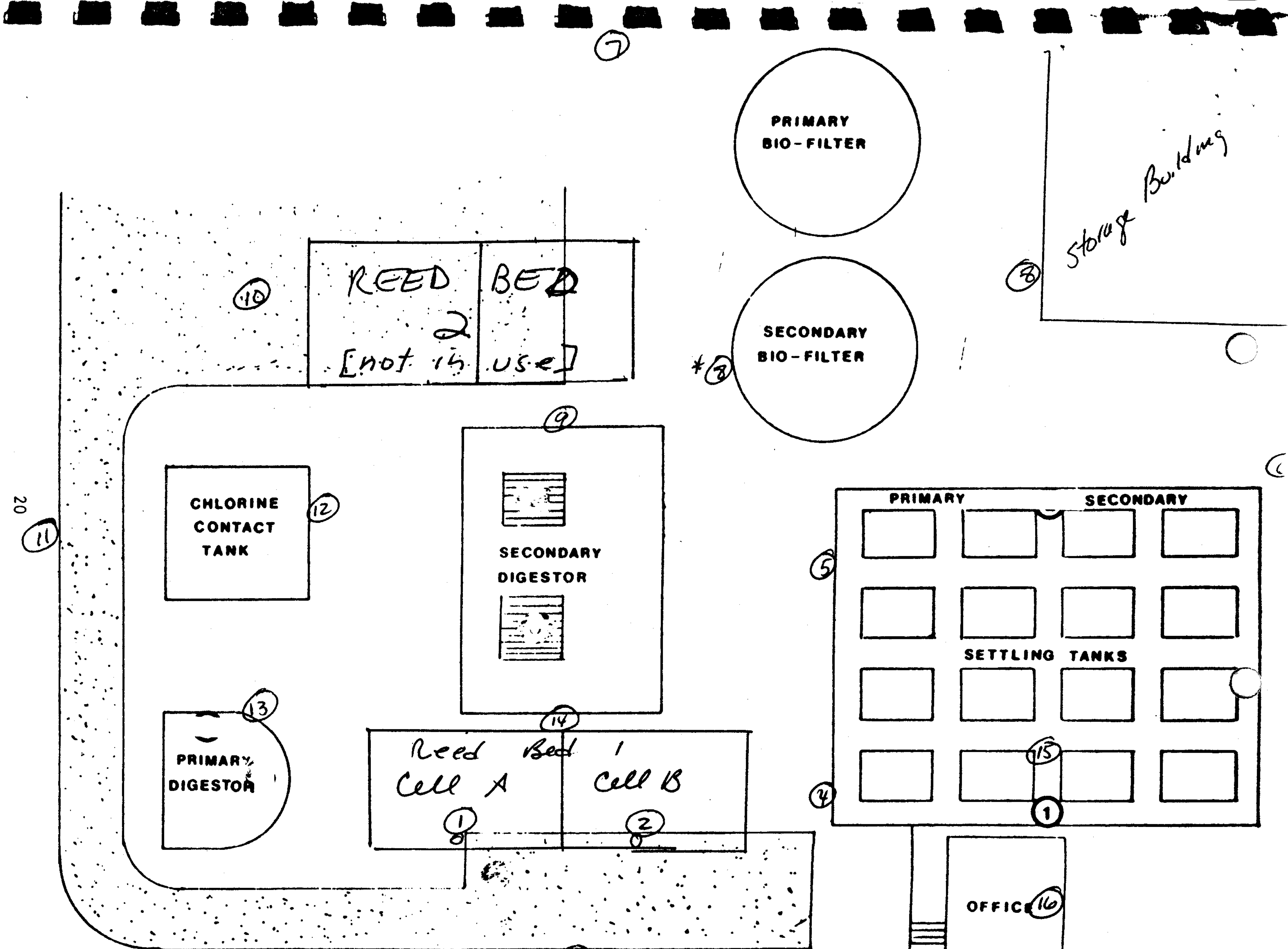
APPENDIX 5

DIAGRAM: LOCATION OF TLDS AT RWTF



Map of the Royersford Wastewater Treatment Facility
Indicating Locations of TLD MONITORS

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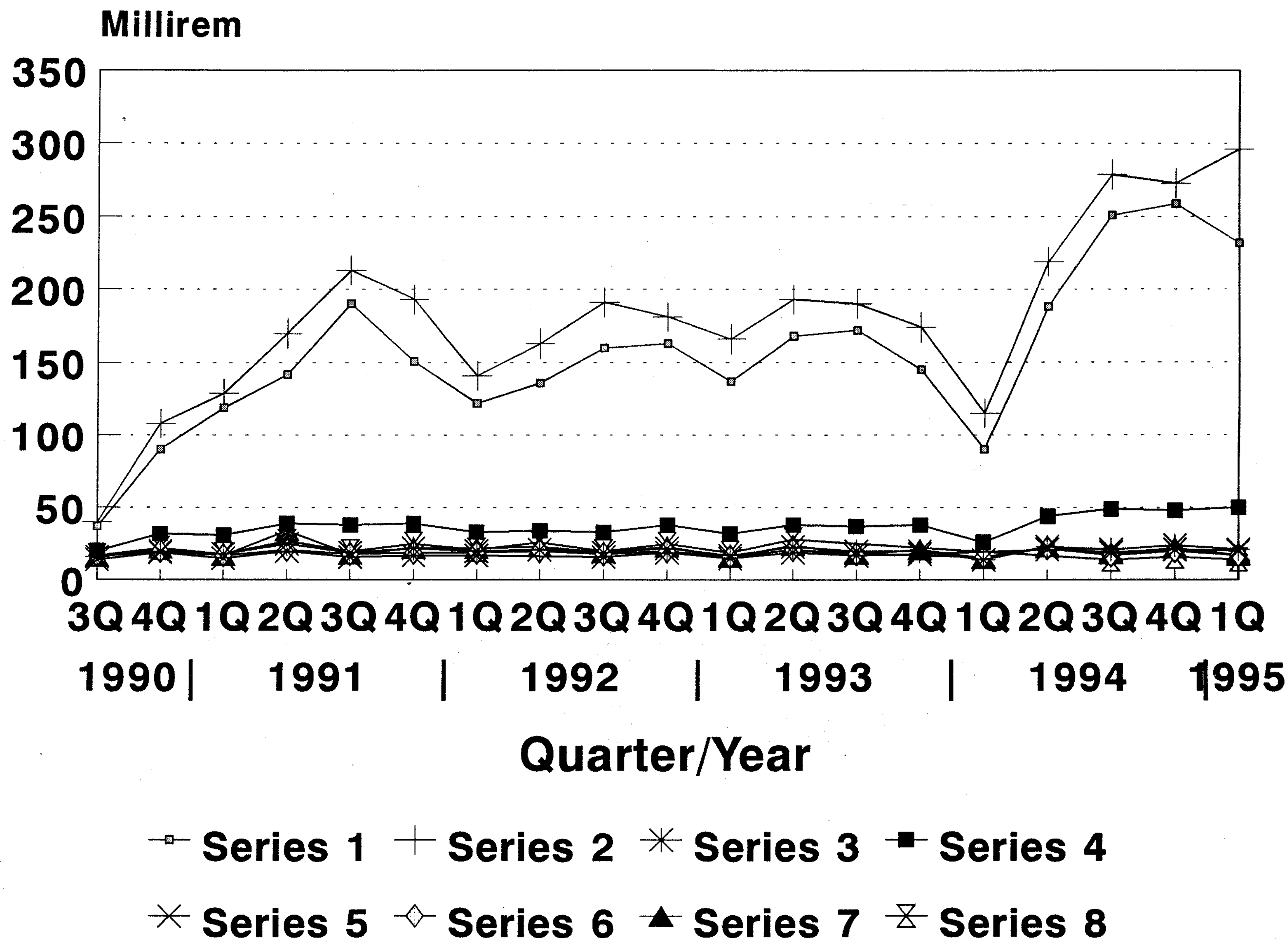
APPENDIX 6

GRAPH: RWTF STANDARD QUARTER TLD RESULTS

RWTF Standard Quarter TLD Results



RWTF Standard Quarter TLD Results

Locations 9 through 16