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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
04/26/2007	00	Approved new document to provide information to perform dose reconstructions for Extrusion Plant claims. Incorporates formal internal review comments. Added additional references and Table A-1. Modified to address formal NIOSH review comments and typographical errors. Adds a Glossary, and Attributions and Annotations section. There is no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Robert Hysong.

TABLE OF CONTENTS

LIST OF TABLES

TABLE **TITLE** **PAGE**

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	anterior-posterior (X-ray)
AWE	Atomic Weapons Employer
BZ	breathing zone
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ES & H	Environment, Safety and Health
FEMP	Fernald Environmental Management Project
FMPC	Feed Material Production Center
HEPA	High Efficiency Particulate Air
hr	hour
IREP	Interactive RadioEpidemiological Program
keV	kilovolt-electron, 1,000 electron-volts
L	liter
lb	pound
mg	milligram
min	minute
mL	milliliter
mrad	millirad
mrem	millirem
MT	metric ton
MTU	metric tons uranium
NAD	nuclear accident dosimeter
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NLO	National Lead of Ohio, Inc.
NRC	U.S. Nuclear Regulatory Commission
NVLAP	National Voluntary Laboratory Accreditation Program
ODH	Ohio Department of Health
PA	posterior-anterior (X-ray)
pCi	picocurie
RCRA	Resource Conservation and Recovery Act
RMI	Reactive Metals, Inc.

TBD	technical basis document
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
yr	year
µCi	microcurie
µg	microgram
°F	degree Fahrenheit
§	section or sections

1.0 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions for particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry monitoring results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived:

- Radiation from naturally occurring radon present in conventional structures

[1] The U.S. Department of Labor is ultimately responsible under the EEOICPA for determining the POC.

- Radiation from diagnostic X-rays received in the treatment of work-related injuries

1.1 PURPOSE

The purpose of this summary document is to help provide consistency in dose reconstructions for the Extrusion Plant (also known as Reactive Metals Inc., or RMI) and to help ensure that all components of dose are adequately addressed. The document provides information on the radiological processes and source terms and on the radiological controls and monitoring practices. While not meant to substitute for a complete site profile, it represents the best understanding of the covered site at this time and provides assumptions for estimating doses when specific dose-related information is not available in individual records.

1.2 SCOPE

Section 2.0 of this document describes the Extrusion Plant and its history, including information about the radiological processes and source terms as well as the radiological controls and monitoring practices. Sections 3.0 and 4.0 discuss internal and external dose, respectively.

2.0 SITE INFORMATION

The DOE Office of Worker Advocacy defines the following information for the Extrusion Plant (DOE 2006):

Site	Extrusion Plant (Reactive Metals, Inc.)
Alternative names	Reactive Metals, Inc. RMI
Location	Ashtabula, Ohio
Covered Period	1962 to present
Facility Type	Department of Energy

The Extrusion Plant received uranium from the Feed Material Production Center (FMPC) and the Weldon Spring Plant as well as lesser quantities from other sites for extrusion and/or closed-die forging (DOE 2000). Most of the uranium arrived in the form of billets, which were extruded into feed stocks for fabrication of fuel and target elements for use in nuclear production reactors. In addition, smaller quantities of thorium were processed at the Plant.

The Extrusion Plant was the corporate successor of Bridgeport Brass facilities of Adrian, Michigan, and Bridgeport, Connecticut. The work at Adrian, Michigan, was very similar to the work at the Extrusion Plant, and the same extrusion press was used at both facilities. The press, a 3,850-ton Loewy horizontal extrusion press owned by AEC, was moved from Adrian to Ashtabula in November or December 1961 (Haywood 1982; Jeffererson 1961; 1962a) following the cessation of work in Adrian and uranium extrusion at Ashtabula began in January 1962 (Koh 1995). The majority of material processed at the facility was for AEC and DOE, but non-radioactive metals such as copper, zirconium, titanium, and molybdenum for commercial firms were also extruded (ORAU 1985).

The Extrusion Plant conducted its radiological operations under Section 110, Exclusions, of the Atomic Energy Act (Koh 1995, p. 2-4) and as an AEC/Nuclear Regulatory Commission (NRC) licensee (DOE 2000). The Atomic Energy Act, Section 110 (NRC 2002) states,

> *Nothing in this chapter shall be deemed*

a. to require a license for (1) the processing, fabricating, or refining of special nuclear material, or the separation of special nuclear material, or the separation of special nuclear material from other substances, under contract with and for the account of the Commission; or (2) the construction or operation of facilities under contract with and for the account of the Commission; or

b. to require a license for the manufacture, production, or acquisition by the Department of Defense of any utilization facility authorized pursuant to section 91, or for the use of such facility by the Department of Defense or a contractor thereof.

Extrusion Plant's DOE (and predecessor) operations were conducted under a prime contract from 1962 through August 1987, a subcontract with the Fernald Environmental Management Program (FEMP) from September 1987 through November 1992, a prime contract with DOE Oak Ridge Operations from December 1992 through March 1993, a prime contract with DOE Chicago Operations Office (apparently) from April 1993 through March 1995 and then a prime contract with DOE Ohio Field Office (DOE 2000). On December 22, 2003, the Ohio Department of Health (ODH) received notification that the DOE prime contract DE-AC24-93-CH1055 was terminated (ODH 1999-2004). DOE contracts with Extrusion Plant included DE-AC05-760R 01405, administered by the Oak Ridge Operations Office (ORAU 1985) and DE-AC24-93CH10555 (DOE 2000).

Extrusion Plant's NRC-regulated work was conducted under source material License Number SMB-602, first issued in June 1962, which initially allowed the use of 500,000 lbs (230 MT) of uranium and thorium; this was changed to 400,000 lbs (180 MT) of uranium and 100,000 lbs (45 MT) of thorium on October 31, 1973 (NRC 1962-1999) and to 10,000 lbs (4.5 MT) of natural uranium, 600,000 lbs (270 MT) of depleted uranium and 10,000 lbs (4.5 MT) of thorium in 1979 (NRC 1979-1980). On June 7, 1985, the NRC license allowed possession, use, and storage of 5000 kg (5 MT) natural uranium and 300,000 kg (300 MT) of depleted uranium; thorium was no longer listed. On October 15, 1991, the NRC license amounts remained the same, but the condition of use was changed to *possession incidental to site characterization and decommissioning plan preparation* until September 11, 1997, when the condition of use was changed to *possession incident to decommissioning, remediation, restoration, and waste disposal*. On May 26, 1999, the quantities were removed from the license, and the materials were listed as natural uranium, depleted uranium, enriched uranium, and ^{99}Tc; and the amount was described as "contaminated materials present at the site as of July 1, 1998" (NRC 1962-1999). The authority for licensing was later transferred to ODH and on August 31, 1999, and ODH issued License Number 11900040004, which was similar to SMB-602 (DOE 2000; ODH 1999-2004). RMI also held NRC license 34-10618-01 (Van Loocke 1979), which was reportedly for a 1-millicurie sealed ^{137}Cs source used to calibrate a gamma alarm system (RMI 1995a). As of 1995, RMI possessed 171 sealed sources for use in instrument calibrations including ^{60}Co, ^{90}Sr/Y, ^{99}Tc, ^{137}Cs, ^{210}Pb, ^{226}Ra, ^{230}Th, natural uranium, ^{239}Pu, ^{241}Am, and ^{242}Am; the quantities were not noted, but it was stated that some of the sources to be disposed would be characterized as Class C waste under 10 C.F.R. § 61.55 (RMI 1995a). On March 6, 2004, ODH issued approval for RMI to use sealed sources, ^{55}Fe, ^{109}Cd, and ^{241}Am sealed sources in an X-ray fluorescence analyzer, ^{133}Ba in a liquid scintillation counter, and ^{63}Ni in a gas chromatography instrument.

DOE work included the extrusion of primarily depleted and enriched uranium for N-Reactor and Savannah River. License SMB-602 allowed extrusion of uranium and thorium (NRC 1962-1999); it was also RMI's authorization for use of source material for Department of Defense (DOD) armor-piercing penetrator work from 1974 through 1985 for DOD contractors (DOE 2000).

Westinghouse Materials Company of Ohio (1989) noted in their June 1989 review of the RMI program the most recent DOE extrusion campaign had been completed in September 1988 and that commercial extrusion work was occurring during the June 1989 review. Westinghouse also stated that no uranium was being extruded during the June 1989 review (Westinghouse Materials Company of Ohio 1989, p. 15). Other references (DOE 2000; RMI 1995a) report that RMI uranium extrusion for DOE ceased in September 1988, and all other extrusion operations ceased on October 31, 1990. However, in Section 2.2 of this document, it is shown that uranium was received in 1989, 1990, and 1993, albeit in quantities much less than during the pre-1989 years. NRC License SMB-602 authorized uranium extrusion until the issuance of Amendment 4 on October 15, 1991.

This site profile refers to the radiological production period as January 1, 1962, through October 14, 1991, the period during which uranium was being extruded or during which uranium could have been extruded under RMI's NRC license. The postproduction period is defined in this document as October 15, 1991, to the present, the period during which extrusion of radioactive metals ceased and predecommissioning and decommissioning activities were underway. Although there appears to be receipts for 0.05 MTU in 1993, there is currently no evidence that the material was processed.

2.1 PROCESS DESCRIPTION AND FACILITIES

The Extrusion Plant is in Ashtabula County, Ohio, slightly east of the city of Ashtabula. The facility consisted of 25 buildings occupying 7 acres of a 32-acre site. A floor plan of the buildings is shown in Figure 2-1; Table 2-1 lists buildings where uranium was processed or process equipment was stored. Attachment A contains detailed site figures by year that show changes to the site over time.

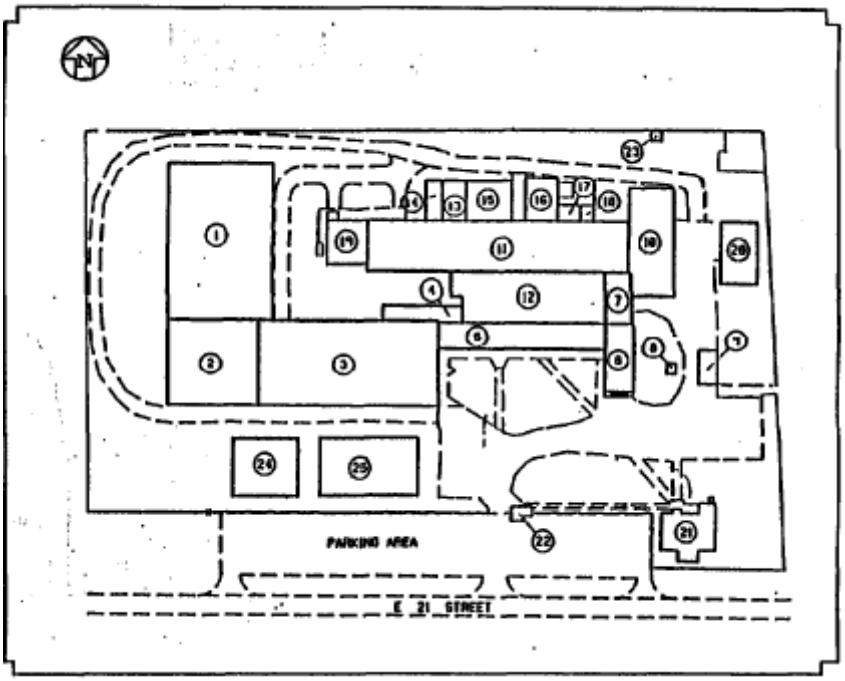

Figure 2-1. Extrusion Plant site map (DOE 1993).

Table 2-1. Primary processing and storage buildings.

Bldg. no.	Building name[a]	Description/comments[b]
1	Northwest storage building	Storage of contaminated process equipment
2	RF-6 Butler Building addition	Acid neutralization tanks
3	RF-6 Butler Building	Storage of contaminated process equipment, lathes, drill press, small

Bldg. no.	Building name[a]	Description/comments[b]
		extrusion press, warehouse, laboratory, and offices; pickling, inspection, machining, and packaging of uranium
4	Enclosed ramp	
5	Locker rooms/foreman's office	
6	Enclosed truck ramp	
7	Dock area	
8	Emergency equipment storage building	
9	RCRA storage building	
10	Billet storage warehouse	Storage of incoming and outgoing uranium
11 12	Main plant high bay Main plant low bay	Uranium processing, 3850 ton extrusion press, transfer table, pickling tanks, furnaces, abrasive saw.
13	Runout table filter building	
14	Saw filter building	
15	Tool crib	Extrusion tooling storage
16	Die head filter building	
17	Switchgear room	
18	Compressor room	
19	Wastewater treatment plant	
20	RF-3 Butler Building	Uranium incinerator (oxidizer) and volume reduction equipment
21	ES & H Building	
22	Guard house	
23	Sewage disposal plant	
24	Modular laboratory	
25	Modular office	

a. DOE (1993).
b. RMI (1995a).

The normal operations of extrusion and of forging performed at RMI can be generally described as a metals fabrication process. RMI's primary function was to change the shape or configuration of the received materials and then to ship these reconfigured metals to the receiving sites.

RMI's primary equipment for handling the uranium and thorium metals included the Loewy extrusion press, a runout table, a cooling table, and a cut-off saw. The process components also included a straightener, a degreaser, an oil bath, and a cleaning hood. Three gas-fired incinerators were in an auxiliary building (RF-3 Butler Building). Two of the incinerators were used to oxidize uranium sludges and residues while the third was used to incinerate contaminated combustible materials.

The process steps varied with different materials but they generally consisted of heating the metal in a salt bath for 1.5 hours, followed by extruding and quenching. This was followed by a degreasing step and packaging and weighing.

A portion of the extruded uranium metal was pickled in a nitric acid solution for the purpose of cleaning the material.

RMI's DOE work was done in support of the N-Reactor at the Hanford Site and for the reactors at the Savannah River Site (SRS). RMI also supported the armor-piercing penetrator programs for DOD contractors. RMI produced N-Reactor fuel and targets from 1962 to 1988. From 1962 until 1970, the uranium processing for N-Reactor consisted of receiving uranium primarily from the FMPC, extruding the metal, and returning the extrusions and scrap primarily to FMPC. In 1971, RMI began using a forge process for N-Reactor fuel, which involved further processing of the extrusions before sending them directly to Hanford (DOE 2000). The detailed steps involved in this process are described in Attachment B. SRS production was done at RMI from 1962 to 1988. The general steps consisted of receiving uranium, followed by extrusion and sectioning, and then returning the extrusions and scrap. Some minor changes were made to the process over time. These changes, as well as a detailed

description of production for SRS, are included in Attachment C. Work was done on armor-piercing penetrators for DOD contractors under RMI's AEC/NRC license. This was done from 1974 until 1985. This process was similar to that for SRS except for three process changes:

- The extrusions were hydraulically sheared and air-cooled before water quenching.
- The extrusions were not generally cut on the abrasive saw and were not run through the roll straightener.
- The extrusions were pickled with nitric acid and then rinsed before shipment.

A detailed description of the process is included in Attachment D.

In addition to uranium, thorium metal (with no cladding) was extruded for DOE at RMI from 1962 through 1971 (RMI 1995b). A small number of NPR clad beryllium ingots were also extruded. This involved a process step described as hand rolling (Breslin and Glauberman1964). Because the ingots were identified as beryllium, they would not have been a source of exposure.

2.2 PRODUCTION QUANTITIES

The quantities of uranium (listed in MTU) sent to RMI for the N-Reactor and SRS production are listed in Table 2-2.

Table 2-2. Uranium receipts for N-Reactor and SRS work (MTU)[a].

Uranium type	1962-1970	1971-1990
Enriched	13,442	11,829
Normal	4,904	330
Depleted	5,094	30,778
All	23,440	42,937

a. DOE (2000).

RMI production for the DOD penetrator program was reported as approximately MT of depleted uranium from 1974 to 1985 (DOE 2000). According to this inventory information, the total uranium sent to RMI was therefore, 75,757 MTU. This amount is in basic agreement with the 76,721.78 MTU of uranium compiled from annual receipts of recycled uranium at RMI shown in Table 2-3 below (DOE 2000).

Table 2-3. Annual recycled uranium receipts at RMI.[a]

Year	MTU	Year	MTU	Year	MTU	Year	MTU
1962	526.85	**1970**	1,731.69	**1978**	2,314.72	**1986**	4,322.51
1963	2,977.63	**1971**	1,920.31	**1979**	2,355.17	**1987**	800.76
1964	4,518.48	**1972**	1,898.09	**1980**	3,175.80	**1988**	496.52
1965	2,213.02	**1973**	3,083.36	**1981**	3,794.46	**1989**	9.67
1966	2,694.82	**1974**	2,226.30	**1982**	5,873.91	**1990**	0.17
1967	3,249.29	**1975**	1,547.26	**1983**	6,619.13	**1991**	0
1968	2,875.46	**1976**	2,076.36	**1984**	4,832.58	**1992**	0
1969	2,657.32	**1977**	2,232.35	**1985**	3,697.74	**1993**	0.05
						Total	76,721.78

a. The information comes from reference DOE 2000, and it is not clear if this is only a listing of DOE-contract processed uranium or if it also includes NRC licensed materials.

According to the current (2006) RMI Environmental, Safety and Health Director, site documentation indicates that the amount of uranium (and presumably thorium) processed and handled at the Extrusion Plant was larger than the amount shipped because some of the material was processed more than one time at the Plant (Vogel 2006). The total amount of uranium processed, reported as 121,224 MT (Saito 1993; RMI 1995a) and as 130,712 MT (Koh 1995), provides an upper amount of uranium handled at the Extrusion Plant. The difference between the latter two numbers is additional DOD work of 9,488 MTU (Koh 1995). Tables 2-4 and 2-5 indicate the enrichment of the uranium handled and received at RMI. On average, the enrichment of uranium received and handled at the Extrusion Plant was much lower than the highest enrichment ever handled at the Extrusion Plant (2.1%).

Table 2-4. Uranium-235 weight percentage of uranium handled.[a]

U-235 % by weight	0.14 & 0.2	0.71	0.86	0.95	1.25	2.1	Total MTU
MTU	64,438	25,178	3,932	28,115	8,108	941	130,712
Percentage of total uranium processed	49.3	19.3	3	21.5	6.2	0.72	100

a. Koh (1995).

Table 2-5. Annual receipts of enriched uranium.[a]

Year	**MTU**	**U-235 MTU**	**Average % Enrichment**
1962	244.7	2.3	0.947
1963	1,027.3	9.7	0.947
1964	2,503.1	24.2	0.965
1965	1,931.1	18.8	0.972
1966	2,357.3	25.6	1.083
1967	3,102.2	35.3	1.139
1968	1,068.5	18.5	1.732
1969	761.4	7.6	0.995
1970	448.4	4.2	0.946
1971	343.4	3.7	1.064
1972	554.2	5.6	1.005
1973	398.5	3.8	0.962
1974	918.2	9.2	0.999
1975	663.1	6.5	0.986
1976	321.9	3.4	1.046
1977	297.7	2.9	0.980
1978	535.0	5.4	1.009
1979	426.8	4.1	0.970
1980	266.3	2.8	1.048
1981	607.6	6.0	0.982
1982	670.5	6.5	0.970
1983	1,372.3	14.1	1.026
1984	1,324.0	13.1	0.987
1985	1,242.4	12.2	0.982
1986	1,262.3	12.5	0.991
1987	421.6	4.4	1.053
1988	257.7	2.4	0.947
1993	.002084	.000025	1.199
Total	25,327.5	264.8	

a. DOE (2000).

A search of Extrusion Plant records conducted by RMI indicated that thorium was only processed at the plant between 1962 and 1971 (RMI 1995a). The amounts of uranium processed for DOE and the amounts of thorium processed for SRS, Hanford, the Y-12 Plant, and Davison Chemical (also known as W. R. Grace) between 1962 and 1971 are listed by year in Table 2-6 (Britcher 1992). Consideration of RMI's total uranium process inventory would reduce the Table 2-6 ratios if the thorium inventories are complete.

Table 2-6. Masses of DOE uranium and thorium processed and mass ratio of thorium to uranium.

Year	U (MT)[a]	Th (lb)[b]	Th (MT)	Th:U
1962	526.9	7,674	3.5	6.64E-03
1963	2,977.6	47,320	21.5	7.22E-03
1964[c]	4,518.5	4,200	1.9	4.20E-04
1965	2,213.0	0	0	0.00E+00
1966	2,694.8	1,170	0.5	1.86E-04
1967	3,249.3	883	0.4	1.23E-04
1968	2,875.5	0	0	0.00E+00
1969	2,657.3	3,200	1.5	5.64E-04
1970	1,731.7	1,300	0.6	3.46E-04
1971	1,920.3	1,925	0.9	4.69E-04

a. DOE (2000).
b. Britcher (1992).
c. An additional amount of thorium was processed for Hanford's Project A-801-38 (Britcher 1992), but the amount is currently unavailable. It consisted of only one extrusion.

2.3 SOURCE TERM

Uranium was assumed to be extruded from January 1, 1962, through October 14, 1991, and thorium was extruded intermittently from May 1, 1962, through December 31, 1971. Depleted, normal, and enriched uranium were processed. Most of the uranium was probably recycled uranium. Uranium factors that might be of use are listed in Table 2-7 below. As listed in Tables 2-4 and 2-5, the enrichment of uranium handled at the Extrusion Plant was typically well below 2.1%. For dose reconstruction, the default assumption is that the uranium was 2% enriched.

Table 2-7. Uranium mixtures, specific activity, and isotopic fractions.

Slightly enriched (2%)[a]	Activity fraction	Mass fraction	Activity ratio to U-235	Mass ratio to U-235
U-234	0.7694	0.0002	28.76	0.01
U-235	0.0268	0.02	1	1
U-238	0.2038	0.9798	7.618	48.99
U (2%) pCi/µg	1.616			
U (pCi): U-235 (µg)	80.8			
Useful factors				
U (2.0%) pCi/µg	1.616			
U (2.0%) U-235 (µg)	80.8			
Natural uranium	**Activity fraction**	**Mass fraction**	**Activity ratio to U-235**	**Mass ratio to U-235**
U-234	0.4886	5.37E-05	21.4	0.00745
U-235	0.0228	7.20E-03	1	1
U-238	0.4886	9.93E-01	21.4	138
Useful factors				
U-natural pCi/µg	0.683			
U (pCi): U-235 (µg)	94.9			

Depleted	Activity fraction	Mass fraction	Activity ratio to U-235	Mass ratio to U-235
U-234	0.1546	1.00E-05	14.45	0.00502
U-235	0.0107	1.99E-03	1	1
U-236	0.0005	3.11E-06	0.0467	0.00156
U-238	0.8342	9.98E-01	78	501
Useful factors				
Depleted uranium pCi/µg	0.4021			
Depleted uranium (pCi): U-235 (µg)	202			

a. Although listed as a recycle uranium component, U-236 represents <1% of the dose resulting from exposure to uranium (ORAUT 2004a).

Extrusion Plant was licensed by NRC to use thorium from mid 1962 to mid 1985 (NRC 1962-1999) and might also have processed thorium under an Atomic Energy Act exception (Koh1995). A review of site records (Britcher 1992) indicated that thorium was not processed by RMI after 1971. Table 2-6 shows Th:U mass ratios of less than 1%, and the NRC (1962-1999) licensing documents indicate that for most periods, authorized mass ratio of thorium to U (natural and depleted) was no more than 25% prior to 1979 and was less than 2% by 1979, and these ratios would be lower if consideration was given to the mass of enriched uranium. The low ratios of Th:U are also supported by later environmental sampling and characterization surveys that only identified uranium and technetium contamination at the site (RMI 1995a, 1995b). Thorium-232 (which is the most significant isotope by mass in natural thorium) contamination was not detected on site. Th-230, a long-lived uranium progeny, was found on site but was characterized as consistent with background levels (NRC 1962-1999).

2.3.1 Industrial X-Ray Sources

No Extrusion Plant site documentation indicates that radiography sources were used at the Ashtabula facility. Furthermore, the 1965 RMI application for renewal of license SMB-602 specifically stated that no provision for metallographic laboratory handling activities would be included in the application like those previously carried out at the Bridgeport Brass facilities in Seymour, Connecticut (Bean 1965a).

2.4 RADIOLOGICAL SAFETY PROGRAM

Information regarding Extrusion Plant's early radiological safety program was described in licensing documentation. Other information sources included the RMI (1973) *Health Protection Manual*; Health and Safety Laboratory reports; and health protection, nuclear safety, and environmental inspections and appraisals that were conducted periodically throughout the history of the Extrusion Plant. In 1985, an independent health, safety, and environmental review conducted at RMI resulted in a recommendation that the entire area of industrial hygiene and health physics be upgraded starting with a thorough health protection program evaluation and fundamental assistance on establishing written procedures, sampling, documentation, and recordkeeping, followed by a quality assurance evaluation (ORNL 1985). Consequently, between July 1985 and 1988, Battelle, Pacific Northwest Laboratory conducted an in-depth review of the RMI radiation protection program that included air sample particle size and solubility studies and recommendations for internal and external dose control, contamination control, training, respiratory protection, and associated procedures (Munson 1985). RMI established an As Low as Reasonably Achievable (ALARA) Committee, which had its first organizational meeting on April 2, 1985. A Health Physics Appraisal in May 1987 indicated that a draft health physics procedure manual was completed on September 25, 1986, and was formally adopted in July 1989 (RMI 1989a) after DOE uranium extrusion had ceased.

After passing through the guardhouse, hourly production and maintenance workers entered and exited the main plant building through the locker room door and performed a complete clothing and shoe change (Jefferson 1962a). By 1973 caps were also required by for hourly and production personnel (AEC 1973). A storage bin containing clean coveralls and gloves was located in the locker room (Jefferson 1962a). Lockers were used to store uncontaminated street shoes and personal clothing; contaminated shoes were stored below benches adjacent to the clothing lockers and a drum for disposal of contaminated work coveralls and gloves was located just outside the door leading from the locker room into the plant production area (Jefferson 1962b). At the end of a work shift, workers sat down at a bench in front of their lockers and removed contaminated coveralls and shoes. They then put on their shower clogs and deposited their contaminated clothing in the disposal drum as they proceeded to the shower area. After showering, a worker would return to his locker, put on personal clothing, and exit the Plant through the locker room door (Jefferson 1962b).

Salaried workers and visitors were allowed through the main Plant office area entrance door, which originally required an immediate change into smocks and shoes for use in contaminated areas or the use of rubber shoe covers (Jefferson 1962a). The location of the rack containing re-usable smocks was moved a short time later from the shoe change area just inside the main Plant office area entrance door to just outside the door leading from the main Plant office into the main Plant production area next to a drum for contaminated smocks (Jefferson 1962b). Entrance to the Plant production area from the office area required the use of reusable smocks and rubber shoe covers. The entire floor area of the Plant office area was treated as a radiologically controlled area. Spot check surveys of desktops and other spots above the floor were used as a means of controlling the spread of contamination to desks (Jefferson 1962b).

Contamination monitoring of personnel exiting the Plant operating area was not performed in the early years of operation because it was believed that good housekeeping, use of protective clothing, and washing of hands before leaving would afford adequate protection against inhalation or ingestion of contamination (Jefferson 1962a). Daily surveys of the locker room, Plant office area, and production area access points was practiced “rigidly,” and hourly production employees were encouraged to take showers at the end of their shifts (Jefferson 1962a). Site documentation implies that contamination monitoring was performed routinely in later years; however, the findings of an independent review of the RMI radiation protection program in July 1985 indicated that contamination control boundaries and frisking were lax, but the nature of material available to be spread along with existing controls were such that the accidental transport of significant quantities of material offsite was “unlikely” (Munson 1985). Correspondence dated November 7, 1985, indicates that RMI had procured some “needed personnel friskers” based on a recommendation from Battelle and that the radiation worker training planned for January 1986 would correspond with the implementation of an improved contamination control program (Munson 1985). Westinghouse Materials Company of Ohio (1989) observed that contamination control and monitoring practices were being implemented in their June 1989 review of the RMI program. By 1991, personnel contamination monitoring, when workers exited a contamination control zone, was being performed with alarming beta-gamma frisker instrumentation. Protective clothing and personal clothing contamination limits were 15,000 and 3,700 dpm/100 cm^2 beta-gamma (or alpha), respectively (RMI 1991), while the skin contamination limit was 3,700 dpm/100 cm^2 beta-gamma (RMI 1994).

Before the construction of a new Butler Building sometime around the first quarter of 1965, the Plant change facility (locker room) was also used as a lunchroom (Ruch 1965). The dining table in the locker room was used at lunch breaks and coffee breaks (three per shift), where Plant personnel were required to wear blue smocks over contaminated coveralls to prevent the spread of contamination to the table. In addition, the washing of hands was supposed to be “strictly enforced” at the time the blue smocks were used during breaks (Jefferson 1962a). The lunchroom and offices were relocated

to the new Butler Building by March 1965 (Ruch 1965); however, alpha contamination survey records from 1977 and 1978 indicate removable contamination levels up to 1,500 dpm/100 cm^2 in the hourly employee lunch room as well as elevated fixed contamination (Featsent 1977a). Similar results were recorded on 1975 and 1977 alpha contamination survey records from the hourly employee locker room (Featsent 1975, 1977b). Contamination surveys of the lunchroom and change room in September 1989 indicated total beta-gamma levels of 29,526 dpm/100 cm^2 and 76,798, respectively (RMI 1989b).

Early site documentation indicates that there were designated eating and smoking areas, but in May 1985, an independent health, safety, and environmental review conducted at RMI resulted in RMI instituting a no-smoking policy in the production and incineration areas of the Plant because "employees were smoking throughout the plant" (ORNL 1985).

Written standard operating procedures that incorporated criticality controls were used for extrusion and handling of slightly enriched uranium (Puterbaugh and Van Loocke 1964), and nuclear accident dosimeters (NADs) had been placed inside access doors to plant areas shortly before the 1.95%-enriched uranium (clad with beryllium) New Production Reactor campaign in September 1964 (Bean 1964). A fourth NAD was installed in the warehouse area of the RF-6 Building in June 1965. By April 1965, a criticality alarm system had been installed (Bean 1965b).

Ventilation was the primary means used to limit radioactivity in the air at the Extrusion Plant, but respirators were provided to personnel for certain operations that caused excessive airborne contamination (Jefferson 1962c). The Health and Safety Laboratory conducted dust and ventilation surveys at RMI in June 1962 and March 1964 that resulted in ventilation system modifications and procedural changes to reduce dust levels. Four ventilation systems with hoods were used for the early extrusion process. The Loewy extrusion press, die head and runout table, extrusion cooling table, and cut-off saw were each serviced by a separate ventilation system. There was also a small hood adjacent to the extrusion press, used to clean die parts, with its own fan and exhaust system. Another ventilation system serviced three gas-fired incinerators in an auxiliary building (Scrap Building). Two of the incinerators were used to oxidize uranium sludges and residues while the third was used for contaminated combustible materials (Breslin and Glauberman 1964). The gas fired incinerators were equipped with a Type N Rotoclone dust collector (Breslin and Glauberman 1964 ORAU 1985). Additional processes that were served at one time or another by a ventilation or exhaust system included the resistance heater-roll straightener, vapor degreaser, acid pickle tanks, lathes, forge booths, hand filing/forge area, and the ingot acid etch booth and grinding booths in the warehouse portion of the RF-6 Building (Bean 1973). Site documentation (Ruch 1964; Smith 1973; Hibbitts and Wing 1980; Wing 1982) indicates that during most of the production period of the Extrusion Plant, the primary source of stack emissions was the abrasive saw followed by the scrap incinerator. The abrasive saw exhaust stack was not equipped with an emission control system until 1984 when a precipitator was installed (ORAU 1985).

Isokinetic sampling probes equipped with filter paper discs were periodically used to obtain representative airborne particulate samples from each plant stack for alpha counting. One stack sample a week was collected by the Plant Safety Officer on a rotating basis so that each exhaust system was sampled at least every seven weeks (AEC 1973). Continuous monitoring of all seven Plant stacks, along with emission control improvements for the stacks, serving the abrasive saw, forge area, and uranium scrap incinerators was recommended in 1985 (ORNL 1985). Installation and testing of a new abrasive saw ventilation system, which utilized High Efficiency Particulate Air (HEPA) filters and a bag house filter system, were completed in August 1985, and RMI established a new policy of performing continuous stack sampling when the saw was in use. In addition, a ventilation and filter (non HEPA type) system was installed on the scrap incinerator at some time between June

1985 and June 1987, but isokinetic exhaust sampling was only performed when the ventilation equipment for the incinerator facility was operating (Davis 1987). Westinghouse Materials Company of Ohio (1989) noted in their June 1989 review of the RMI program that Permit to Install applications had been submitted for the extrusion press, runout table, cooling table, abrasive saw, scrap incinerator, forge area, pickling tanks, tool coating dip tank, and lathe emission sources, and that ventilation systems with HEPA filtering and stack emission monitoring were in place for each of the sources.

2.4.1 Area Surveys

According to the Extrusion Plant 1962 license application, floor contamination surveys in the locker and Plant office areas were to be performed daily, and weekly floor surveys were to be performed in the production areas associated with the highest contamination levels (including the Scrap Building and warehouse portion of the RF-6 Building). Surveys of the surfaces of equipment above floor level were to be made based on the judgment of the Safety Officer or whenever equipment was shipped or removed from a contaminated area. The routine in-plant cleanup cycles were expected to keep the surface contamination limits below the levels listed in Table 2-8. Available portable instruments at the start of operations included alpha detectors and Geiger-Müller counters. Decontamination procedures generally involved the use of simple detergents, solvents, or steam cleaning. Broom sweeping was prohibited; dry vacuuming could be performed using an electrically operated industrial vacuum (Jefferson 1962b, 1962c). According to the independent health, safety, and environmental review in May 1985, there was no delineation of contaminated zones in areas of the Plant where uranium was received, handled, processed, machined, and prepared for delivery (ORNL 1985). By June 1985, establishment of contamination control levels were consistent with DOE policy, but the total area of the facility was considered a contamination zone. By May 1987, progress had been made in reducing the area of contaminated zones to approximately two-thirds of the facility (Davis 1987).

Table 2-8. Recommended surface contamination limits in 1962[a].

Location	Alpha (dpm/100 cm^2)		Beta-gamma (mrad/hr)	
	Removable	Fixed	Removable	Fixed
Hot working areas	3,000	6,000	5	10
Other production plant areas	1,500	3,000	2	5
Locker room floor	250	500	0.2	2.5
Eating table	100	200	-	-
Plant office	500	1,000	0.3	2.5
Shipping-receiving floor	500	1,000	0.4	2.5
Truck beds (after use)	No detectable	500	No detectable	0.4
Process equipment above floor level				
Equipment-in-place (accessible areas)	10,000	20,000	5	10
Before removal (to other Plant property sites)	2,000	4,000	0.4	2.5

a. Jefferson (1962a, 1962b, 1962c).

2.4.2 Personnel Monitoring

Based on a review of the claim files and available site documentation, it appears that nearly 50% of the RMI employees were monitored for external and internal radiation. External monitoring for most years of RMI operations consisted of the use of a film or thermoluminescent dosimeter (TLD) badge worn on the chest to monitor radiation from photons and electrons. Neutron monitoring and extremity monitoring studies occurred in later years, and extremity monitoring was routine for some employees in later years. Determination of uranium levels in urine began in 1962 for workers believed to have the larger potential for internal exposures. Beginning in 1968, *in vivo* chest counts were also being

used to monitor internal exposure from uranium. Beginning in 1979, *in vivo* chest count results sometimes included monitoring for other radionuclides such as thorium and technetium.

2.4.3 Air Monitoring

Early site documentation (Jefferson 1962c) indicates that the Plant Safety Officer periodically performed breathing-zone (BZ) air sampling at each production worker's operating position such that each position was sampled routinely every 2 months for comparison to the maximum allowable concentration of 6×10^{-11} µCi/mL, but it is not clear that specific actions were taken if this level was exceeded . BZ sampling appears to have continued throughout the history of the Plant. Later documentation (Brewer 1990) indicates that workers were required to wear respiratory protection and BZ monitoring samplers when air concentrations reached 2×10^{-11} µCi/mL. In addition, at least one general area high-volume air sample was collected weekly at different locations at the Plant chosen by the Plant Safety Officer based on the activities being conducted (Jefferson 1962c). General area air sampling appears to have continued throughout the history of the Plant. Between 1962 and 1965, the AEC's Health and Safety Laboratory conducted stack, environmental, general area, cyclone, and BZ air sampling at the Extrusion Plant. The most comprehensive and complete data report available (Breslin and Glauberman 1964) has been used as a basis for comparison to airborne exposure at the Bridgeport Brass Adrian, Michigan, plant. The conclusion that can be reached from this comparison is that, in general, exposures at the Extrusion Plant were less than those at the Bridgeport Brass Adrian plant. In addition, two-stage air-sampling studies that were conducted in the 1963 – 1964 timeframe at the Extrusion Plant indicated that 90% of the air contamination was in a nonrespirable particle size range (Ruch 1964). Later studies conducted in the 1985 – 1986 time frame indicated that over 90% of the aerosol in the Scrap Building was nonrespirable (Munson 1986a) while 66% of the aerosol in the extrusion press area was nonrespirable (Munson 1986b).

2.5 RADIOLOGICAL INCIDENTS

There are two notes written beside urine bioassay results that refer to fires in the Scrap Building in late June 1965 and in November 1965. No additional information on the 1965 fires has been found. A 1995 uranium fire incident involving a drum containing slightly enriched uranium oxide waste (the folder that contained the report was labeled, "1% Oxide Issue") occurred inside a glovebox (probably in October) (DOE 1995). The initial report indicated a small pie-shaped area (one-sixth the area of the drum and a few inches deep) in the bottom of the drum was smoldering like burning embers (DOE 1995). A later review (DOE 1995) indicated that the smoldering had changed to flames inside the enclosure, that the ventilation remained on during the fire, and that at least one worker in the area was not wearing the required gloves.

2.6 PHYSICAL EXAMINATIONS INCLUDING OCCUPATIONALLY REQUIRED MEDICAL X-RAY INFORMATION

The Extrusion Plant shared medical facilities with a nearby RMI plant (Hibbitts and Pryor 1970), and a dispensary was collocated with the main guardhouse. The medical program, described in 1970 and 1976 health and nuclear safety appraisals (Hibbitts and Pryor 1970; Johnson 1976), consisted of preemployment, annual, and termination physicals including blood tests, audiograms, (medical) urinalyses, and chest X-ray examinations for everyone except female clerical employees. In addition, hourly employees had a preemployment lower back ("normal spine") X-ray examination (Johnson 1976) because they were more "prone" to back injuries (Hibbitts and Pryor 1970). In 1976, it was noted that the back X-ray exam was only for laborers (Johnson 1976). The 1970 appraisal specifically stated that X-ray examinations were made off the site at Ashtabula General Hospital. The current (2006) RMI Environmental, Safety and Health Director, stated that RMI obtained their own X-ray

equipment for chest X-ray examinations in later years, although the specific date of equipment acquisition is unknown (Hysong 2006a). Specific X-ray techniques used to perform RMI X-ray examinations are not available. X-ray examinations were performed at the RMI dispensary at some point after 1976 until 1996. In addition, the practice of taking preemployment back (spinal) X-rays was phased out sometime before 1986 (Hysong 2006a). Beginning sometime in 1997, chest X-rays were only taken at the physician's discretion.

The claim files do not appear to contain any specific information on spinal X-ray examinations. Few records noting occupationally required X-ray examinations have been found in the claim files.

2.7 WORK PERIODS

For much of the operational period at RMI, there were at least two shifts – day and night. The 1964 Health and Safety Laboratory air concentration study (Breslin and Glauberman 1964) used 480 minutes for the total exposure time per day on the site, but assigned 40 minutes for lunch with a morning break and 10 minutes in the locker room, which would reduce the time engaged in work to 430 min/day. In general, bioassay and external dosimeters will be used to determine doses, and in those cases, the period of exposure will be irrelevant. To account for exposures that were not monitored by bioassay or dosimeters, this summary assumes a default exposure of 2,000 hr/yr.

2.8 PERIOD AFTER RADIOLOGICAL PRODUCTION

This summary refers to the radiological production period as January 1, 1962, through October 14, 1991, during which uranium was being extruded or might have been extruded based on uranium receipts. The postproduction period is that period during which extrusion of radioactive metals ceased and predecommissioning and decommissioning activities were underway (from October 15, 1991, to the present). On October 15, 1991, license amendment 4 converted SMB-602 from an Operating license to a Possession Only license for possession incident to site characterization and decommissioning plan preparation. On May 14, 1993, License Amendment 5 was approved to designate a new Radiation Safety Officer and contact person for RMI. License amendment 6 was approved on November 9, 1993, enabling predecommissioning activities that included surveys, equipment removal, waste handling, shipment, and disposal. On September 11, 1997, the decommissioning plan was approved and incorporated into the license as amendment 8. Internal and external monitoring continued throughout the postproduction period until 2004 when internal monitoring practices changed. According to the current RMI Environmental, Safety and Health Director, starting in January 2004, the only urine bioassay samples submitted by workers were preemployment, termination, and "for cause" whenever an intake was suspected (Hysong 2006a). By January 2004, building decontamination was completed and work at the site consisted primarily of soil and ground-water remediation (Hysong 2006a). In March 2004, decontamination and decommissioning activities at the site temporarily ceased until November 2005 when a remediation services contractor (LATA-SHARP Remediation Services LLC) was hired to complete decontamination and decommissioning of the site (Hysong 2006b). By March 2004, less than 20 RMI management and compliance personnel remained at the Extrusion Plant site to provide oversight of the remaining decontamination and decommissioning field activities which were likely to be completed by December 2006 (Hysong 2006b).

Uranium extrusion for DOE at RMI ceased in September 1988, and all other extrusion operations reportedly ceased on October 31, 1990 (DOE 2000), although the inventory receipt information compiled in Table 2-2 shows receipt of 0.1 MTU in 1993. The following information is from the licensing documents (NRC 1962-1999). On October 15, 1991, license amendment 4 converted SMB-602 from an operating license to a Possession Only license for possession incident to site

characterization and decommissioning plan preparation. License amendment 6 was approved on November 9, 1993, allowing for pre-decommissioning activities including surveys, equipment removal, waste handling, shipment, and disposal (amendment 5 named a new radiation safety officer). On September 11, 1997, the decommissioning plan was approved and incorporated into the license as amendment 8. This site profile refers to the radiological "production period" as January 1, 1962, through October 14, 1991, the period during which uranium was being extruded or could have been extruded and the "post production period" as the period during which extrusion of radioactive metals is believed to have ceased (despite the later receipt of uranium in 1993, which appears to not have been extruded based on the license change in 1991).

3.0 INTERNAL DOSE

The source term at RMI consisted of depleted uranium, normal uranium, slightly enriched uranium, recycled uranium contaminants and thorium. Uranium urinalyses were performed, but it appears that urinalysis for thorium was never performed at the Extrusion Plant. Some *in vivo* chest counts are available beginning in 1968. Uranium intakes shall be assessed based on bioassay data. Thorium and recycled uranium contaminant intakes are derived from the uranium intakes. Because of the tendency of technetium to become airborne more readily than uranium (DOE 2004), ^{99}Tc intakes may be higher than the intake derived using Table 3-4 below. Consequently, if *in vivo* monitoring records indicate ^{99}Tc lung count results greater than the *in vivo* counter MDA of 0.5 uCi, then *in vivo* monitoring records are used to assess ^{99}Tc intakes.

3.1 URANIUM BIOASSAY DATA

Uranium urinalyses for workers whom RMI judged to be exposed were performed quarterly at the Extrusion Plant beginning in 1962. By 1963, urine sampling was performed quarterly for production and maintenance workers and semiannually for salaried personnel. Special studies involving urine sampling were performed when new processes were started. The RMI site investigation level for uranium in urine was 50 µg/L until 1985, when it was changed to 15 µg/L; work restrictions were implemented if urinalysis results exceeded 30 µg/L and continued until repeated analysis indicated levels less than 15 µg/L. By 1997, the investigation level was decreased to 1 µg/L (Henderson 1997).

From 1962 through 1964, bioassay consisted of uranium photofluorimetry urinalyses conducted by AEC's Health and Safety Laboratory. From 1965 to the early 1970s, uranium urinalyses were conducted by Tracerlab, Inc. of Waltham, Massachusetts, also using photofluorimetry methods. For most of the 1960s, three spot urine samples (the first submitted on a Monday morning before work, the second on the following Friday morning before work, and the third on the following Monday morning before work) were obtained every 3 months from personnel judged by RMI to have significant exposure potential. Starting sometime in the mid-1970s until 1988, total uranium urinalysis was conducted by the United States Testing Company, Inc. (USTC) of Richland, Washington, using a mass-based uranium measurement technique. Site documentation suggests that single urine voidings were obtained at an onsite restroom on two consecutive Mondays every 3 months until 1986 (Manninen 1986). Beginning in 1986, workers were provided sample containers to take home during the weekend instead of providing urine samples in the potentially contaminated restroom on return to work on Monday morning. Also beginning in 1986, workers provided a "simulated 12 hour [sic] sample" that consisted of all urine passed by the employee between 2 hours before bedtime and 0.5 hours after waking the next morning (Manninen 1986). From 1988 to the present, uranium urinalysis has been performed by several vendors including Controls for Environmental Pollution of Santa Fe, New Mexico, Quanterra and Severn Trent Laboratories in Richland, Washington, and General Engineering Laboratories in Charleston, South Carolina. Based on available information in claim files, all urinalysis vendors used a mass-based uranium measurement technique, and results are presented

in either milligrams or micrograms of uranium per liter. Table 3-1 lists the Extrusion Plant uranium urinalysis vendors and detection levels based on a review of claimant records and site documentation.

Table 3-1. Uranium urinalysis vendors and detection levels.

Analyst[a]	Year(s)	Detection threshold concentration (µg/L)	Reference
Health and Safety Laboratory	1962–1964	2.0	AEC 1964
Tracerlab and National Lead of Ohio	1965–1972	1.0	RMI 1967
USTC	Early 1973–1983	3.0	RMI 1974
USTC	1985	5.0	Manninen1988
USTC	1986	0.1	Manninen1988
USTC	1987	0.5	Manninen1988
USTC, Controls for Environmental Pollution (CEP), Quanterra, Severn Trent and General Engineering Laboratories	1988–2003	0.5 or less	CEP 1991 and claim file records

a. CEP was the RMI vendor from 1989 through 1993. In April 1994, Sandia National Laboratory stopped using CEP's bioassay services because quality control testing had raised questions about the reliability of CEP urinalysis results (NRC 1994). Although this information exists, nothing has been identified directly related to the Extrusion Plant.

According to the RMI 1990 license renewal application, RMI employees were required to submit weekly, monthly, or quarterly urine samples depending on their work assignment (Marsh 1990). According to the 1992 RMI urine bioassay program description, bargaining unit personnel were sampled monthly and salaried personnel were sampled quarterly (Gammon 1992). According to the current RMI Environmental, Safety and Health Director, starting in January 2004, the only urine bioassay samples submitted by workers were preemployment, termination, and "for cause" whenever an intake was suspected. By January 2004, work at the site consisted primarily of soil and ground-water remediation. Intakes for personnel who may not have been monitored after 2003 are presented in section 5.0.

3.2 *IN VIVO* MONITORING

Beginning in 1968, RMI began using the results of either *in vivo* lung counting or uranium urinalysis to determine worker's internal exposures, although site documentation indicates a much greater reliance on lung counts for demonstrating regulatory compliance. Annual *in vivo* chest counts for total uranium and enriched uranium were performed by an unidentified vendor (probably the AEC/DOE *in vivo* mobile counter provided by the Y-12 Plant) in 1968, 1969, and 1971 through 1985. From 1968 through 1978, lung count results are reported in micrograms of ^{235}U, milligrams of total uranium, grams of potassium, and nanocuries of ^{137}Cs on an "INVIVIO [sic] RADIATION MONITORING REPORT" for individual workers at the Plant. There is no evidence of occupational intakes of ^{137}Cs at the Extrusion Plant, so no dose of record should be associated with these measurement results in any year. Table 3-2 lists general information about the detection capabilities of *in vivo* lung counting at the Extrusion Plant for various time periods. Table 3-3 lists codes with their interpretations. A review of available records indicates that from 1979 through 1985, some *in vivo* lung-counting records also contain results for thorium activity inferred from the ^{228}Ac and/or ^{212}Pb lung activity; however, the Y-12 mobile counter did not provide adequate detection sensitivity for either transuranics or thorium until 1986 (ORAUT 2004a) by which time the Y-12 mobile counter was no longer used at the Extrusion Plant. According to correspondence related to the RMI radiation protection program review conducted by Battelle Pacific Northwest Laboratory, when previous whole-body counting data were evaluated, they revealed "mostly problems and questions" (Munson 1985).

Beginning in 1986, Helgeson Scientific was contracted to perform annual *in vivo* lung counts for natural uranium and ^{235}U because of their greatly improved sensitivity (2.5 nCi) compared to the DOE

Mobile Counter (Manninen 1988). March 1990 site correspondence indicates that the lung count results from Helgeson indicate system bias and that a background level would need to be established to test the data for significance at a 95% confidence level (Aldridge 1990). Correspondence containing corrected lung count data (dated October 14, 1997) from Helgeson Scientific to RMI indicated that Helgeson reports from 1986 to September 1996 have headings that are incorrectly labeled milligrams of uranium rather than nanocuries of uranium and that the percent of the annual limit on intake calculation is low by a factor of 1.4 (Helgeson 1997). A review of several claim files indicates that these corrections were made to records in the available claim files. From a review of claim files, it appears that annual lung counting was discontinued around 2002 when Helgeson ceased operation.

Table 3-2. *In vivo* measurement types and detection levels for various time periods[a].

Period	Equipment	Measurement type	Radionuclide	MDA[b,c]	Action level for recount	Action level for work restriction
1968-1985	Y-12 Mobile Counter	Lung	Total uranium	4 mg	Unknown	Unknown
1968-1985	Y-12 Mobile Counter	Lung	Enriched uranium (2% ^{235}U)	0.1mg	Unknown	Unknown
1968-1985	Y-12 Mobile Counter	Lung	Depleted Uranium	4 mg	Unknown	Unknown
1968-1985	Y-12 Mobile Counter	Lung	Np-237	200 pCi	Unknown	Unknown
1968-1985	Y-12 Mobile Counter	Lung	Tc-99	0.5 uCi	Unknown	Unknown
1968-1985	Y-12 Mobile Counter	Lung	Th-232	6 mg	Unknown	Unknown
1986-1995	Helgeson Counter	Lung	Total uranium	2 – 4 mg	Unknown	Unknown
1986-1995	Helgeson Counter	Lung	Enriched uranium	0.04 – 0.07 mg	Unknown	Unknown

a. Adapted from ORAUT (2006a).
b. The Tc-99 MDA is based on McDougal (1980).
c. The Th-232 MDA is based on Scott et. al. (1969) and ORAUT (2006a).

Table 3-3. *In vivo* record codes.

Form identification	Measurement type	Code	Interpretation
In Vivo Radiation Monitoring Report	Lung	F/B Ratio	This is a measure of how close to the front or back the internal contamination is. A ratio of greater than 1 may indicate external contamination.
In Vivo Radiation Monitoring Report	Lung	A. Enriched Uranium	The maximum U-235 enrichment at the Extrusion Plant was 2.1%.
In Vivo Radiation Monitoring Report	Lung	J. NLO Uranium	Refers to the special spectrum region of interest for National Lead of Ohio, early operator of the Fernald facility.
Helgeson	Lung	n-u handwritten on forms with a spectral print out	Natural uranium result usually with corresponding handwritten result in nanocuries with the two sigma uncertainty.
Helgeson	Lung	U-235 handwritten on forms with a spectral print out	U-235 (enriched uranium) result usually with corresponding handwritten result in micrograms with the two sigma uncertainty.

3.3 INTAKE ASSUMPTIONS

3.3.1 Uranium

Uranium intakes are assumed to be type M or S. For calculating annual organ doses, the intake (in disintegrations per minute) can be assumed to be entirely ^{234}U. Table 3-4 shows an estimate of recycled uranium contaminants that might have contributed significantly to internal doses beginning in 1962. The numbers are based on a review of recycled uranium contaminants at Hanford and FMPC. (The relative internal dose contributions from ^{99}Tc, ^{228}Th, and ^{232}Th were low enough to be excluded). In addition, the activity fractions assume that the uranium specific activity is based on depleted uranium, which increases the proportion of the contaminants by activity. The contaminant levels for depleted uranium overestimate the contaminants in uranium of normal enrichment by about 40%. Plutonium is assumed to behave as absorption type M or type S material and neptunium as absorption type M. If *in vivo* monitoring records indicate ^{99}Tc lung count results greater than 0.5 uCi, the ^{99}Tc intake should be assessed assuming a type M intake.

Table 3-4. Estimated recycled uranium activity fractions for internal dose reconstruction.[a]

Uranium	Pu-239	Np-237
1	0.00246	0.00182

a. ORAUT (2005a).

3.3.2 Thorium

In vitro analyses to estimate RMI thorium exposures are unavailable, and thorium activity determined from chest counts was not reported until 1979, which is after the reported thorium processing period. Table 2-6 indicates that the thorium received at RMI in any year was less than 1% of the uranium received by mass. Because there are no specific process and monitoring records for thorium use, this document assigns a U:Th mass intake ratio as 0.01 during the thorium production period, which is assumed to be from January 1, 1962, through December 31, 1971.

The specific activity of normal uranium is a factor of 1.7 larger than that of depleted uranium, but on the order of a factor of 2.4 smaller than that of 2%-enriched uranium. As a consequence, it appears to be favorable to claimants to assume natural uranium when determining the relative activity of thorium based on the relative mass comparisons. To determine the relative activities of uranium to thorium, the specific activity of ^{232}Th is divided by the specific activity of natural uranium and multiplied by a Th:U mass ratio of 1%. This results in a relative ^{232}Th-to-uranium intake fraction by activity of 0.00161. Further, it is assumed that ^{232}Th is in equilibrium with ^{228}Th, so the ^{228}Th-to-uranium activity fraction is also 0.00161. Exposure from ^{228}Ra (half-life of 5.75 years) is assumed to be insignificant because the thorium was likely to have been recently produced and because the dose conversion factor is small compared to thorium.

It is further assumed that thoron levels were not significant in the ventilated metal-handling workplace.

3.4 INTERNAL DOSE ASSIGNMENT SUMMARY

Depleted, natural, and slightly enriched uranium were all source terms at RMI, and the type is assumed to be M or S. For results measured in mass units, it is favorable to claimants to assume exposures to slightly enriched uranium (2.0% ^{235}U by mass) if no better information is available. If uranium urinalysis measurements were made in both mass and activity units, the activity units should be used to calculate intakes and ^{234}U can be assumed for uranium dose calculations.

Uranium urinalysis, when available, should be used to estimate uranium intakes; the default detection thresholds are 3 µg/L for samples analyzed between 1962 and 1984, 5 µg/L in 1985, and 0.5 µg/L from 1986 to 2003. It should be noted that the forms used to record uranium urinalysis results at the Extrusion Plant had a column labeled "Mg/L" (which meant mg/L or milligrams per liter and not megagram per liter); nevertheless, the results were sometimes recorded in µg/L (micrograms per liter).

The assumptions in Table 3-5 can be used to estimate intakes from recycled uranium contaminants and thorium once the uranium intake has been calculated from bioassay.

Table 3-5. Assumptions for intake determinations from uranium bioassay.

Radionuclide	Type	Intake activity ratio compared to uranium	Applicable period	Note
U	M, S	1	January 1, 1962–present	Can assume U-234 for dose calculations
Pu-239	M, S	0.00246	January 1, 1962–present	
Np-237	M	0.00182	January 1, 1962–present	
Th-228	M, S	0.00161	January 1, 1962–December 31, 1971	
Th-232	M, S	0.00161	January 1, 1962–December 31, 1971	

Thorium was not processed in 1965, 1968, and after 1971 (Britcher 1992); site documentation indicates that RMI cleaned up after thorium extrusions to prevent commingling of thorium and recyclable uranium (Jefferson 1962a), but it is uncertain whether the clean up included all areas of the plant. Even though the thorium was cleaned up prior to uranium extrusions, it appears favorable to the claimant to assume that residual contamination resulted in thorium intakes in 1965 and 1968 when no thorium (^{232}Th and ^{228}Th) processing was recorded.

4.0 EXTERNAL DOSE

RMI employees were exposed to radiations from uranium, thorium, and their short-lived progeny. This document assumes that photon energies were in the 30- to 250-keV range, which is favorable to claimants when considering both organ dose conversion factors and radiation effectiveness factors. Shallow or open-window dose is assumed to be from electrons with energies greater than 15 keV.

From 1962 to the mid-1980s, claim files contain a handwritten Film Badge Assignment Sheet containing Name, Badge Number (typically between 1 and 80 assigned by RMI), and notes or comments such as lost film, damaged film, inverted film, quit, terminated, retired, vacation, wore two badges in monitoring period, and issue date if not on the first day of the month or quarter. The next page(s) contain the dosimeter vendor report with the badge number corresponding to the Film Badge Assignment Sheet handwritten next to the appropriate results. Beginning in 1986, RMI personnel names are specifically provided in the vendor reports, and there is no Film Badge Assignment Sheet or there is a database printout (1987 through 1996) that contains personnel names and external dosimetry data. Some claim files contain a Terminated Employee Radiation Exposure Report containing skin and whole-body dose for the employment period. In addition, some claim files contain Form AEC-5 (beginning in the early 1960s) and later Form NRC 5.

4.1 PENETRATING DOSES

Table 4-1 lists available information on badges used from 1962 to 2004; whole-body external dosimetry results appear to be present in claimant files. There are also some extremity badge results beginning in 1974.

Routine film badge results included whole-body beta and gamma monitoring results. Table 4-1 provides some of the available information on the monitoring methods, detection limits, and reporting. Neutron doses appear to have been monitored for most RMI employees in 1986, 1987, and 1988.

Table 4-1. External dosimetry

Period	External dosimetry vendor	Exchange frequency/ monitoring method	Detection threshold reported in records
1962–1966	Controls for Radiation, Cambridge, MA	Monthly/ Film	A zero indicates less than minimum detectable dose of 5 mrem for X-ray and gamma <175 keV or 10 mrem for hard X-ray and gamma and beta.
1967–1987	USTC, Richland, WA	Quarterly/ Film until TLDs in 1986	1972 and 1976 film badge reports indicate film detection limits of 10 mrem for X-ray, 20 mrem for gamma ray, and 20 mrem for beta. According to a 1977 film badge report calibrations for gamma performed with Cs-137, beta performed with Sr-90, and X-ray performed with 16- to 117-keV photons. A 1983 film badge report indicates film detection limits of 10 mrem for photons and 20 mrem for beta. 1986 and 1987 TLD badge reports indicate detection limits of 10 mrem for X-ray, gamma, beta, and neutron radiation.
1988–1991	USTC, Richland, WA, and Westinghouse Materials Company of Ohio at FEMP	Monthly/ TLD	1988 and 1989 TLD badge reports from USTC indicate detection limits of 10 mrem for X-ray, gamma ray, beta, and neutron radiation. The minimum detection limit for FEMP TLDs was 30 mrad beta and gamma from 1989 to 1992.
1992– 2004	Westinghouse Materials Company of Ohio at FEMP, TMA Eberline, ThermoNUtech, Landauer, ICN, and Global Dosimetry Solutions	Probably quarterly/ TLD	The minimum detectable level for FEMP TLDs was 30 mrad beta and gamma from 1989 to 1992. Other TLD badge reports typically indicate detection limits of 10 mrem for X-ray, gamma ray, and beta, but information was not found for every vendor's badge type. Site documentation implies that all TLD vendors were DOE Laboratory Accreditation Program or National Voluntary Laboratory Accreditation Program certified by 1992.

Table 4-2 summarizes RMI-reported external penetrating doses for 1962 through 1999 and provides a general sense of the program size, although the number of persons monitored appears to include visitors and/or temporary workers beginning in the 1980s. The doses in Table 4-2 do not include nonpenetrating and extremity doses and Table 4-2 only includes NCRP 38 (1971) neutron doses measured on TLD badges in 1986, 1987 and 1988. Attachment E contains a more detailed breakdown of doses for years in which they are available beginning in 1974.

Table 4-2. Penetrating whole-body external doses, 1962–1999

Year	Number not monitored	Number monitored	Dose (rem)		Reference
			0–1	1–2	
1999	Unknown	1,202	1,202		Eberline 2000
1998	Unknown	–[a]	–	–	
1997	Unknown	290	290		TN 1997
1996	Unknown	285	285		TN 1996
1995	Unknown	255	255		TMA 1995
1994	Unknown	332	332		TMA 1994
1993	Unknown	–	–	–	
1992	Unknown	–	–	–	
1991	Unknown	–	–	–	
1990	Unknown	282	282		Rizzi 1991

Year	Number not monitored	Number monitored	Dose (rem)		Reference
			0–1	1–2	
1989	Unknown	–	–	–	
1988	Unknown	920	920		Author unknown
1987	Unknown	822	822		Brewer 1988
1986	Unknown	134	130	4	Manninen 1988
1985	Unknown	124	124		Manninen 1988
1984	Unknown	117	117		Schaeffer 1985
1983	Unknown	118	118		Schaeffer 1984
1982	Unknown	116	116		Schaeffer 1983
1981	Unknown	89	89		Van Looke 1982
1980	Unknown	80	80		Schaeffer 1981
1979	Unknown	80	80		Van Looke 1980
1978	Unknown	68	68		Schaeffer 1979
1977	Unknown	62	62		Schaeffer 1978
1976	Unknown	58	58		Schaeffer 1977
1975	Unknown	62	62		Heiser 1976
1974	Unknown	69	69		Heiser 1975
1973	27	53	53		Travis 1974
1972	20	46	46		Travis 1973
1971	24	46	46		Lenhard 1972
1970	25	47	47		Lenhard 1971
1969	33	41	41		Smith 1970
1968	31	62	62		Hibbits 1969
1967	28	65	65		Lenhard 1968
1966	27	57	57		Sapirie 1967
1965	8	66	66		Sapirie 1966
1964	14	81	81		Sapirie 1965
1963	9	71	70	1	Sapirie 1964
1962	7	52	51	1	Sapirie 1963

a. – = No data available.

Dosimeters consisted of film badges for beta, X-ray, and gamma radiation from 1962 through 1985. TLDs replaced film in 1986. In the early period of Plant operation, a strip of indium metal foil was placed in badges for criticality monitoring. In 1986, 1987, and 1988, neutron monitoring was performed in addition to beta, X-ray, and gamma monitoring based on a recommendation from the Battelle Pacific Northwest Laboratory RMI Radiation Protection Program Review. Dosimetry badges were exchanged monthly from 1962 through 1966 and quarterly or monthly thereafter.

Film badge detection thresholds are assumed to be 40 mrem for beta and gamma (ORAUT 2004b). The least sensitive beta-gamma TLD badge vendor appears to be from the FEMP with a detection threshold of 30 mrad beta and gamma (ORAUT 2004c). The sensitivity of the USTC neutron TLD badges was reported as 10 mrem in 1986, 1987, and 1988.

The overall uncertainty in recorded dose is dependent upon: 1) administrative practices, 2) dosimetry technology, 3) calibration and 4) workplace radiation fields. The Extrusion Plant used a variety of dosimetry vendors from 1962 to 2004 and the precise details of dosimeter type and calibrations are not available; consequently, uncertainty estimates are based on ORAUT (2005d). The uncertainty associated with beta-gamma, film badge results from 1962 through 1985 are estimated to be $\pm$ 60%, and the uncertainty associated with beta-gamma, TLD badge results from 1986 through 2004 doses are estimated to be $\pm$ 30%. The uncertainty associated with neutron TLD badge results from 1986, 1987 and 1988 are estimated to be $\pm$100%.

4.2 NONPENETRATING DOSE

The nonpenetrating dose has not been tabulated for this site. At RMI's predecessor operation, the Bridgeport Brass Adrian Plant, the ratio of nonpenetrating to penetrating dose, 7.87, can be determined from the information in ORAUT (2005b). This ratio can be used to estimate nonpenetrating dose when no monitoring is available for workers in the plant area and workers whose locations are unknown.

4.3 NEUTRON DOSE

No records have been located to indicate the source of neutron exposure. According to the current RMI Health Physics Manager, neutron monitoring was performed based on a recommendation during the 1985 Battelle Pacific Northwest Laboratory review of RMI's radiation protection program. Therefore, the neutron dose must be attributable to spontaneous fission neutrons and, to a much lesser extent, from alpha-neutron reactions. Of the 379 available quarterly TLD badge results from 1986 and 1987, 38 were reported at or above the recording level of 10 mrem with the highest quarterly neutron dose reported as 90 mrem and the highest annual dose reported as 140 mrem (no missed dose was considered). A maximum quarterly dose of 90 mrem can be used to account for individuals with just some unmonitored quarters, and a maximum annual dose of 230 mrem (140 mrem, the maximum dose for three quarters, plus 90 mrem to account for the unmonitored quarter) can be used to account for unmonitored neutron dose in areas such as the Billet Storage Warehouse, Main Plant extrusion area and the RF-6 and RF-3 Butler Buildings, where large amounts of source material were handled or stored from 1962 through 1991. For neutrons generated by spontaneous fission neutrons and alpha-neutron reactions, all of the neutron doses should be assumed to result from the 0.1 – 2 MeV energy group. It is not known for certain how the TLDs for neutron dose were calibrated in 1986 to 1988. For dose reconstruction purposes it is assumed that the badges measured the NCRP 38 (1971) dose which must be converted to ICRP 60 (1990) neutron dose using a factor of 1.91 (ORAUT 2006b).

4.4 EXTREMITY MONITORING

The earliest extremity badge results were for wrist badge assignments to 12 personnel from July to September 1, 1974. Quarterly wrist badge results were also noted in December 1983 in two claim files. Finger rings appear to have replaced wrist badges in 1986. Monthly finger ring results (left and right) were present for 1986. Extremity doses were also noted in database output forms in the claim files beginning in 1987 and on some AEC-5 Forms in claim files.

According to the 1974 annual health protection appraisal, RMI was advised to begin immediate monitoring of extremity radiation exposures to workers who closely handled or inspected uranium billets to determine if continuous extremity monitoring would be required. This was in anticipation that the AEC would soon revise the radiation standard for forearm exposures to conform to a National Council on Radiation Protection and Measurements recommendation to decrease allowable exposures from 75 to 30 rem annually. Several employees were expected to exceed 10% of the anticipated 30-rem limit that would require monitoring (Jelinek 1974). The use of wrist film badges was initiated in July 1974. The annualized results of a 6-month study of skin doses to the forearm and chest performed from July 1 to December 31, 1974, are listed in Table 4-3. According to correspondence from RMI to the Energy Research and Development Administration (a DOE predecessor agency) in January 1977, ring badge dosimeters had not yet been used at RMI to assess hand doses, but RMI estimated that hand exposures would run as high as 10 to 15 rem/yr for four to six workers at the Extrusion Plant (Van Loocke 1977).

Table 4-3. Forearm and chest skin dose monitoring results for personnel who closely handled or inspected uranium billets in 1974.[a]

Job/task	Wrist badge (mrem/year)	Chest badge (mrem/year)
Lathe Operator	100	1,120
Billet Inspector	2,460	3,860
Lathe Operator	680	1,120
Forge Helper	5,120	5,420
Forge Helper	2,080	2,600
Roll Operator	360	2,500
Runout Table	820	1,900
Salt-Bath Operator	1,320	460
Forge Inspector	8,900	4,660
Saw Operator	820	1,960
Extrusion Inspector	3,020	4,580
Forge Inspector	3,640	5,580

a. Fletcher (1976).

A study was performed in the November 1985 timeframe to determine the ratio between the fingertip dose and the TLD ring dose on workers whose inspection tasks required them to run their bare fingers across the surface of uranium metal. Calibrated tissue-equivalent dosimeters were exposed on a hand phantom on a uranium billet at the Plant. The results indicated that a properly worn finger ring would respond a maximum of 60% low compared to a fingertip in contact with a billet. The study showed that a finger ring dosimeter worn on the inside of the little finger was as accurate as one worn on the inside of the finger ring. Finger rings worn on the outside of the hand significantly under-responded (Munson and Stacy 1985).

Even though early documentation from the Extrusion Plant indicates that whole-body film badges were to be displayed in the open and not obscured (RMI 1973), the results of a May 1985 independent health, safety, and environmental review at the Extrusion Plant indicated that film badges were inappropriately being placed into oversized plastic wrap to prevent them from becoming contaminated; however, by June 4, 1985, this was corrected by placing the badges into a properly sized heat-sealed plastic holders (ORNL 1985).

For most work categories, if extremity monitoring is not available, it is reasonable to estimate extremity entrance dose as being equal to the shallow dose measured by the chest badge result. For workers whose job category was inspector, the factor of 3 (derived from the ratio of the 1974 Salt Bath Operator's annual chest badge exposure to his annual wrist badge exposure), which is more favorable to the claimant, should be applied. Based on the Munson and Stacy (1985) study, finger doses could be a factor of 1.67 larger or more, which would be about a factor of 5. The ORAUT (2005a) methodology can be used to estimate a maximum extremity dose.

4.5 OCCUPATIONALLY REQUIRED MEDICAL X-RAYS

The medical program described in 1969 and 1976 health and nuclear safety appraisals consisted of preemployment, annual, and termination physicals including a chest X-ray for everyone except female clerical employees. In addition, hourly employees (laborers) are assumed to have received one single preemployment back lumbar spine X-ray from 1962 through 1975 and laborers are assumed to have received pre-employment lumbar spine X-rays prior to 1986 (Hibbitts and Pryor 1970; Johnson 1976).

No information is currently available regarding the type of X-ray equipment and the techniques used for RMI exams. With the exception of female clerical personnel, this document assumes that preemployment, annual, and termination posterior-anterior (PA) chest X-ray examinations were performed on all personnel from 1962 to the present and that one preemployment lumbar-spine X-ray series, assumed to consist of two anterior-posterior (AP) and two lateral views in accordance with OCAS 2005c, was performed on hourly personnel before 1986. ORAUT-OTIB-0006 (ORAUT 2005c or current version) can be used to determine the dose from occupationally required medical X-ray procedures. There is no Extrusion Plant documentation that indicates that photofluorography was performed.

4.6 MISCELLANEOUS INFORMATION CONCERNING EXTERNAL EXPOSURE

Personal contamination surveys were nonexistent or lax until 1986.

No Extrusion Plant site documentation was found that indicates industrial radiography sources were used at the RMI Ashtabula facility. Consideration should be given to assigning the other industrial radiation dose found in ORAUT (2005a) to unmonitored workers whose claims indicate analytical laboratory work.

4.7 EXTERNAL DOSE ASSIGNMENT SUMMARY

Many RMI employees were monitored for beta, X-ray, and gamma external exposures. The data in Table 4-2 indicates that the annual 95th percentile dose falls into the 0 to 1 rem dose range. For periods when no gamma monitoring results are available for an individual, it is favorable to the claimant to assign an annual penetrating exposure of 1 rem.

ORAUT (2005b) external dose methodology can be used to reconstruct dose for unmonitored workers or unmonitored periods when another method is not specified.

Table 4-4. External dose assumptions.

Radiation type	Assumed energy and exposure assumptions	Monitoring method	Assumed detection threshold	Notes
Photons	30 to 250 keV, acute, 100% AP	Film badge (1962–1985) TLD (1986–present)	40 mrem 30 mrem	Default dose for the unmonitored worker is either the 95th percentile dose in Attachment E or 1 rem/y. Interactive RadioEpidemiological Program (IREP) distribution is constant for default assumption.
Electrons	>15 keV, acute	Film badge (1962–1985) TLD (1986–Present)	40 mrem 30 mrem	Default dose is 7.87 times the photon dose.
Extremities		Film (1974–1985) TLD (1986–2006)	40 mrem 30 mrem	Multiply chest badge dose by 3.
Fingers				Multiply extremity dose by 1.7 or chest badge dose by 5.
PA chest X-ray	Use assumptions in ORAUT 2005c or current version			Initial plus one examination per year plus a termination examination is the default assumption. Female clerical employees are assumed to have had an initial and termination chest X-ray.
2 AP and 2 lateral lumbar spinal X-rays	Use assumptions in ORAUT 2005c or current version			One initial exam for hourly laborers from January 1, 1962, through 1985.

Radiation type	Assumed energy and exposure assumptions	Monitoring method	Assumed detection threshold	Notes
Neutron	0.1 – 2 MeV	TLD (1986–1988)	10 mrem	Default neutron dose is 90 mrem per quarter, but no more than 230 mrem per year (439 mrem per year ICRP 60 dose) for unmonitored periods from January 1, 1962, through October 14, 1991. IREP distribution is constant for default assumption.

5.0 INTERNAL DOSE DURING THE POSTPRODUCTION PERIOD

During the postproduction period at the Extrusion Plant (after October 14, 1991), uranium extrusion activities ceased along with the handling of bulk uranium metal for extrusion. Worker exposures and intakes occurred from residual uranium contamination on site structures and components and on site soil during characterization surveys and sampling, equipment dismantlement and removal, decontamination, demolition, and waste packaging and shipping activities. Section 2.8 contains a summary of worker monitoring changes that occurred during the postproduction period at the Extrusion Plant (after October 14, 1991), but based on a review of available site documentation such as personnel dosimetry files and claim files, it is not evident that site personnel from the remediation contractor (LATA-SHARP Remediation Services LLC), or even RMI, participated in an internal or external monitoring program after 2003. As stated in section 2.8, by January 2004, building decontamination was completed and work at the site consisted primarily of soil and ground-water remediation.

To calculate the intakes from soil to unmonitored site personnel during soil remediation activities starting in 2004, this analysis assumed that uranium exposure was to the average soil concentration from locations within the main plant area and the property located to the east of the main plant at a level of 350 pCi/g total uranium and to the maximum ^{99}Tc concentration of 49 pCi/g within the main plant area (RMI 1995b). Using a mass loading factor of 2×10^{-4} g/m^3 and a breathing rate of 2,400 m^3/yr, the calculated annual uranium inhalation intake was 168 pCi and the annual ^{99}Tc intake was 24 pCi. The daily inhalation intakes for total uranium and ^{99}Tc are 0.460 pCi and 0.065 pCi. It is assumed that other recycle uranium contaminants would be an inconsequential component. The mass loading factor of 2×10^{-4} g/m^3 takes into account short periods of high mass loading and sustained periods of normal activity on a typical farm (Yu et al. 2001).

According to NIOSH (2004), the daily ingestion rate in picocuries can be estimated by multiplying the daily air concentration in picocuries per cubic meter by a factor of 0.2 resulting in the daily ingestion of 0.014 pCi of uranium and 1.96×10^{-3} pCi ^{99}Tc.

An estimate of the uncertainty associated with soil resuspension intakes has been made by assuming that the soil concentrations are lognormally distributed and that the average uranium soil concentration (350 pCi/g) can be used to underestimate the 50th percentile concentration and that the maximum uranium soil concentration ever measured at the plant (2,600 pCi/g) represents the upper 95th percentile (RMI 1995b). The resulting geometric standard deviation is 3.4.

6.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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GLOSSARY

accreditation
Recognition that a dosimeter system has passed the performance criteria of the DOE Laboratory Accreditation Program (DOELAP) standard in specified irradiation categories.

background radiation
Radiation from cosmic sources, naturally occurring radioactive materials including naturally occurring radon, and global fallout from the testing of nuclear explosives. Background radiation does not include radiation from source, byproduct, or Special Nuclear Materials regulated by the U.S. Nuclear Regulatory Commission. The average individual exposure from background radiation is about 360 millirem per year.

beta radiation
Charged particle emitted from some radioactive elements with a mass equal to 1/1,837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is a positron. Most of the direct fission products are (negative) beta emitters. Exposure to large amounts of beta radiation from external sources can cause skin burns (erythema), and beta emitters can be harmful inside the body. Thin sheets of metal or plastic can stop beta particles.

contamination, radioactive
Radioactive material in an undesired location including air, soil, buildings and persons.

curie (Ci)
Traditional unit of radioactivity equal to 37 billion (3.7×10^{10}) becquerels, which is approximately equal to the activity of 1 gram of pure ^{226}Ra.

decontamination
Reduction or removal of radioactive material from a structure, area, object, or person. Decontamination can occur through (1) treating the surface to remove or decrease the contamination or (2) allowing natural radioactive decay to occur over a period of time.

depleted uranium (DU)
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium. As examples, spent (used) fuel elements, byproduct tails, residues from uranium isotope separation, and some weapons materials contain DU. DU can be blended with highly enriched uranium to make reactor fuel or used as a raw material to produce plutonium.

deep dose equivalent
The dose equivalent at the respective depth of 1.0 cm in tissue.

DOELAP
The DOE Laboratory Accreditation Program accredits DOE site dosimetry programs based on performance testing and onsite reviews on a 2-year cycle.

dose

In general, the effects of ionizing radiation in terms of the specific amount of energy absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of roentgens, rads, reps, or grays.

dosimeter

Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual. See *thermoluminescent dosimeter*.

dosimetry

Measurement and calculation of internal and external radiation doses.

enriched uranium

Uranium in which processing has increased the proportion of ^{235}U to ^{238}U to above the natural level of 0.7%. Reactor-grade uranium is usually about 3.5% ^{235}U; weapons-grade uranium contains greater than 90% ^{235}U.

exposure

(1) In general, the act of being exposed to ionizing radiation. (2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

film

Radiation-sensitive photographic film in a light-tight wrapping.

fission

Splitting of the nucleus of an atom (usually of a heavy element) into at least two other nuclei and the release of a relatively large amount of energy. This transformation usually releases two or three neutrons.

gamma radiation

Electromagnetic radiation (photons) of short wavelength and high energy (10 kiloelectron-volts to 9 megaelectron-volts) that originates in atomic nuclei and accompanies many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Gamma rays are very penetrating, but dense materials such as lead or uranium or thick structures can stop them. Gamma photons are identical to X-ray photons of high energy; the difference is that X-rays do not originate in the nucleus.

half-life

Time in which half of a given quantity of a particular radionuclide disintegrates (decays) into another nuclear form. During one half-life, the number of atoms of a particular radionuclide decreases by one half. Each radionuclide has a unique half-life ranging from trillionths of a second to billions of years.

In vitro

In glass. Outside the living body and in an artificial environment. Typically used for bioassay of a contaminant in excreta, such as fecal or urine samples.

In vivo

In the living. In the living body of a plant or animal. Bioassay counting analysis of radionuclides in the human body.

ionizing radiation

Radiation of high enough energy to remove an electron from a struck atom and leave behind a positively charged ion. High enough doses of ionizing radiation can cause cellular damage. Ionizing particles include alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, photoelectrons, Compton electrons, positron/negatron pairs from photon radiation, and scattered nuclei from fast neutrons.

isotope

One of two or more atoms of a particular element that have the same number of protons (atomic number) but different numbers of neutrons in their nuclei (e.g., ^{234}U, ^{235}U, and ^{238}U). Isotopes have very nearly the same chemical properties but often have different physical properties.

natural uranium

Uranium as found in nature, approximately 99.27% ^{238}U, 0.72% ^{235}U, and 0.0054% ^{234}U by weight. The specific activity of this mixture is 2.6×10^7 becquerel per kilogram (0.7 microcuries per gram).

neutron

Basic nucleic particle that is electrically neutral with mass slightly greater than that of a proton. There are neutrons in the nuclei of every atom heavier than normal hydrogen.

nucleus

Central core of an atom, which consists of positively charged protons and, with the exception of ordinary hydrogen, electrically neutral neutrons. The number of protons (atomic number) uniquely defines a chemical element, and the number of protons and neutrons is the mass number of a nuclide. The plural is nuclei.

nuclide

Stable or unstable isotope of any element. Nuclide relates to the atomic mass, which is the sum of the number of protons and neutrons in the nucleus of an atom. A radionuclide is an unstable nuclide.

photon

Basic unit of electromagnetic radiation. Photons are massless “packages” of light energy that range from low-energy microwave photons to high-energy gamma rays. Photons have energies between 10 and 100 kiloelectron-volts.

proton

Basic nucleic particle with a positive electrical charge and mass slightly less than that of a neutron. There are protons in the nuclei of every atom, and the number of protons is the atomic number, which determines the chemical element.

quality factor

Historical value assigned to reflect the average effectiveness of a particular kind of radiation in producing biological effects in humans, now called radiation weighting factor. The quality factor multiplied by the absorbed dose yields the dose equivalent.

rad

Traditional unit for expressing absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium. A dose of 1 rad is equivalent to the

absorption of 100 ergs per gram (0.01 joules per kilogram) of absorbing tissue. The rad has been replaced by the gray in the International System of Units (100 rads = 1 gray). The word derives from radiation absorbed dose.

radiation

Subatomic particles (alpha, beta, neutron) and electromagnetic rays (photons) that travel from one point to another, some of which can pass through or partly through solid materials including the human body.

radioactive

Giving off ionizing radiation such as alpha particles or X-rays.

radioactivity

Disintegration of certain elements (e.g., radium, actinium, uranium, and thorium) accompanied by the emission of alpha, beta, gamma, and/or neutron radiation from unstable nuclei. See *radionuclide*.

radioactive waste

Radioactive solid, liquid, and gaseous materials for which there is no further use. Wastes are generally classified as high-level (with radioactivity as high as hundreds of thousands of curies per gallon or cubic foot), low-level (in the range of 1 microcurie per gallon or cubic foot), intermediate level (between these extremes), mixed (also contains hazardous waste), and transuranic.

radionuclide

Radioactive nuclide. See *radioactive* and *nuclide*.

rem

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The average American receives 360 millirem a year from background radiation. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

roentgen

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive and negative charge equal to 2.58×10^{-4} coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0° Celsius and standard atmospheric pressure. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

thermoluminescent dosimeter (TLD)

A device containing solid chips of material that when heated release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

transuranic

Radioisotopes of nuclides having an atomic number greater than 92.

U.S. Atomic Energy Commission (AEC)

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy

for military and civilian applications. The Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from the AEC in 1974. The U.S. Department of Energy succeeded the Energy Research and Development Administration in 1979.

whole-body dose

Commonly defined as the absorbed dose at a tissue depth of 1.0 centimeters; also used to refer to the dose recorded.

X-ray radiation

Penetrating electromagnetic radiation (photons) of short wavelength (0.001 to 10 nanometers) and energy less than 250 kiloelectron-volts. X-rays usually come from excitation of the electron field around certain nuclei. Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 1 of 20

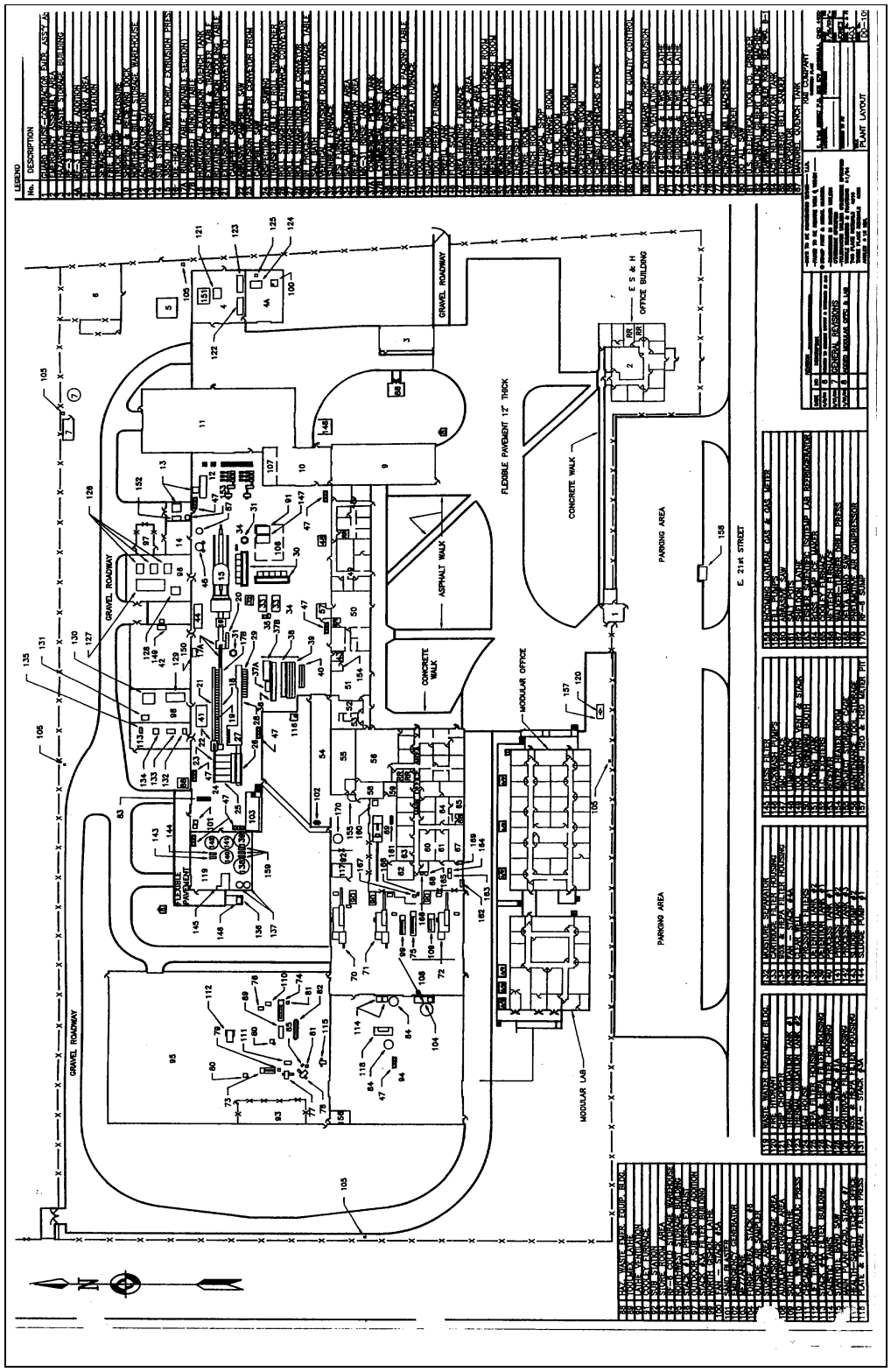

Figure A-1. Plant Layout.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 2 of 20

Table A-1. Key for Figure A-1.

No.	Description
1	Guard House - Contractor Emergency Assembly Area
2	Emergency Assembly Area
3	Hazardous Waste Storage Building
4	RF-3 Building
4A	RF-3 Building Addition
5	Equipment Cleaning Area
6	Electrical Substation
7	Sewage Disposal
8	Firehouse
9	Truck Ramp Enclosure
10	Shipping and Receiving Back
11	Northeast Billet Storage Warehouse
12	Accumulator Station
13	Air Compressor
14	Substation
15	3850 Ton Loewy Horizontal Extrusion Press
16	Die Head
17A	Runout Table (Movable Section)
17B	Powered Runout Table
18	Horizontal Extrusion Quench Tank
19	Extrusion Cooling and Transfer Table
20	Rotating NPR Extrusion Cooling Table
21	Extrusion Transfer Conveyor To Campbell Saw
22	Abrasive Campbell Saw
23	Extrusion Transfer Conveyor From Campbell Saw
24	Inspection After Sawing
25	Transfer Table To Roll Straightener
26	Roll Straightener Entrance Conveyor
27	Roll Straightener
28	Roll Straightener Exit Conveyor
29	In Process Transfer and Storage Cable
30	Salt Bath
31	Vertical Extrusion Quench Tank
32	Sunbeam Furnace
33	FSI Furnace
34	Salt Bath Loading Area
35	Receipt Inspection Area
36	MK-31 Rinse Tank
37A	Commercial Pickle Tank
37B	Commercial Rinse Tank
38	Extrusion Wash Tank
39	Extrusion Pickle Tank
40	Inspection Weighing and Packing Table
41	Container Preheat Furnace
42	Toll Crib
43	Gauge Room
44	Tool Preheat Furnace
45	Prefill Tank
46	Floor Scale
47	Area Heating Furnace
48	Engineering Office Area
49	Foremen's Office Area
50	Men's Hourly Dirty Locker Room
51	Men's Hourly Clean Locker Room
52	Women's Dirty Locker Room
53	Women's Clean Locker Room
54	Enclosed Rampway
55	Storeroom
56	Lunchroom
57	Electrical Shop
58	Salary Change Room
59	Lab Tool Room
60	Wet Chemical Room
61	Metalographical Room
62	Conference Room
63	Computer Room
64	Chemist/Technicians Office
65	Print Room
66	Dark Room
67	Analytical Room
68	Development Lab and Quality Control Area
69	350 Ton Lombard Horizontal Extrusion Press and Ventilation
70	#1 Giddings and Lewis CNC Lathe
71	#2 Giddings and Lewis CNC Lathe
72	#3 Giddings and Lewis CNC Lathe
73	Small Monarch Lathe
74	Lodge and Shipley Lathe
75	Large Monarch Lathe
76	Rockwell Drill Press
77	Racine Saw
78	Cincinnati Mill Machine
79	Stanley Grinder
80	Do All Saw
81	U.S. Electrical Tool Co. Grinder
82	Cincinnati Gilbert Drilling Machine
83	Stairway Down To Boiler Room
84	Acid Neutralization Tank
85	Engleberg Belt Sander
86	Evaporator
87	Mandrel Quench Tank
88	Hazardous Waste Emergency Equipment Building
89	Toolmex Lathe
90	Lathe Ventilation
91	Cooley Furnace
92	Substation
93	Storeroom Area
94	RF -- 6 Cold Storage Warehouse
95	Northwest Storage Building
96	Stack #1A Press Exhaust
97	Outdoor Substation Addition
98	Stack #3A Filter Building
99	North Gisholt Lathe
100	Fan -- Stack #5A
101	Sandblaster
102	Emergency Generator
103	Mezzanine
104	Forge Area Stack #8
105	Outside Air Sampler
106	Storage Area
107	Extrusion Storage Area

No.	Description
108	Auxiliary Storage Area
109	South Gisholt Lathe
110	K. R. Wilson Hydraulic Press
111	Chicago Shear
112	Lift Truck Hoist
113	Stack #4Afilter Building
114	Caustic Tanks
115	Startrite Band Saw
116	Main Plant Acid, Stack #7
117	Health-Safety Technician's Office
118	Plate and Frame Filter Press
119	Wastewater Treatment Building
120	Fire Hydrant
109	South Gisholt Lathe
110	K. R. Wilson Hydraulic Press
111	Chicago Shear
112	Lift Truck Hoist
113	Stack #4Afilter Building
114	Caustic Tanks
115	Startrite Band Saw
116	Main Plant Acid, Stack #7
117	Health-Safety Technician's Office
118	Plate and Frame Filter Press
119	Wastewater Treatment Building
120	Fire Hydrant
121	Chip Chopper
122	Thermal Oxidation Tank #1
123	Thermal Oxidation Tank #2
124	Baghouse
125	HEPA Filter Housing
126	95% and HEPA Filter Housing
127	Cartridge Filter Housing
128	Fan -- Stack #1A
129	Cartridge Filter Housing
130	95% and HEPA Filter Housing
131	Fan -- Stack #3A
132	Moisture Separator
133	Cartridge Filter Housing
134	95% and HEPA Filter Housing
135	Fan -- Stack #4A
136	Clear Well
137	Pressure Filters
138	Detention Tank #2
139	Detention Tank #1
140	Processed Tank #1
141	Processed Tank #2
142	Processed Tank #3
143	Sludge Pump #2
144	Sludge Pump #1
145	Pressure Filter
146	Backwash Pumps
147	H. M. C. Furnace
148	Lumber Rack
149	Tool Coating Vent and Stack
150	Tool Grinding Booth
151	Holding Tank
152	D. C. Exciters
153	Receiver
154	Water Heater Room
155	Project Storage Cage
156	Maintenance Tool Storage
157	Incoming Water and Water Meter Pit
158	Incoming Natural Gas and Gas Meter
159	Still Pumps
160	Abrasive Saw
161	Salt Pots
162	Sheldon Lathe
163	Fisher Scientific Iso-Temp Lab Refrigerator
164	Ross Temp Icemaker
165	Cooley Furnace
166	Neytech Furnace
167	Walker-Turner Drill Press
168	Delta Band Saw
169	Pneumotive Air Compressor
170	RF -- 6 Sump

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 3 of 20

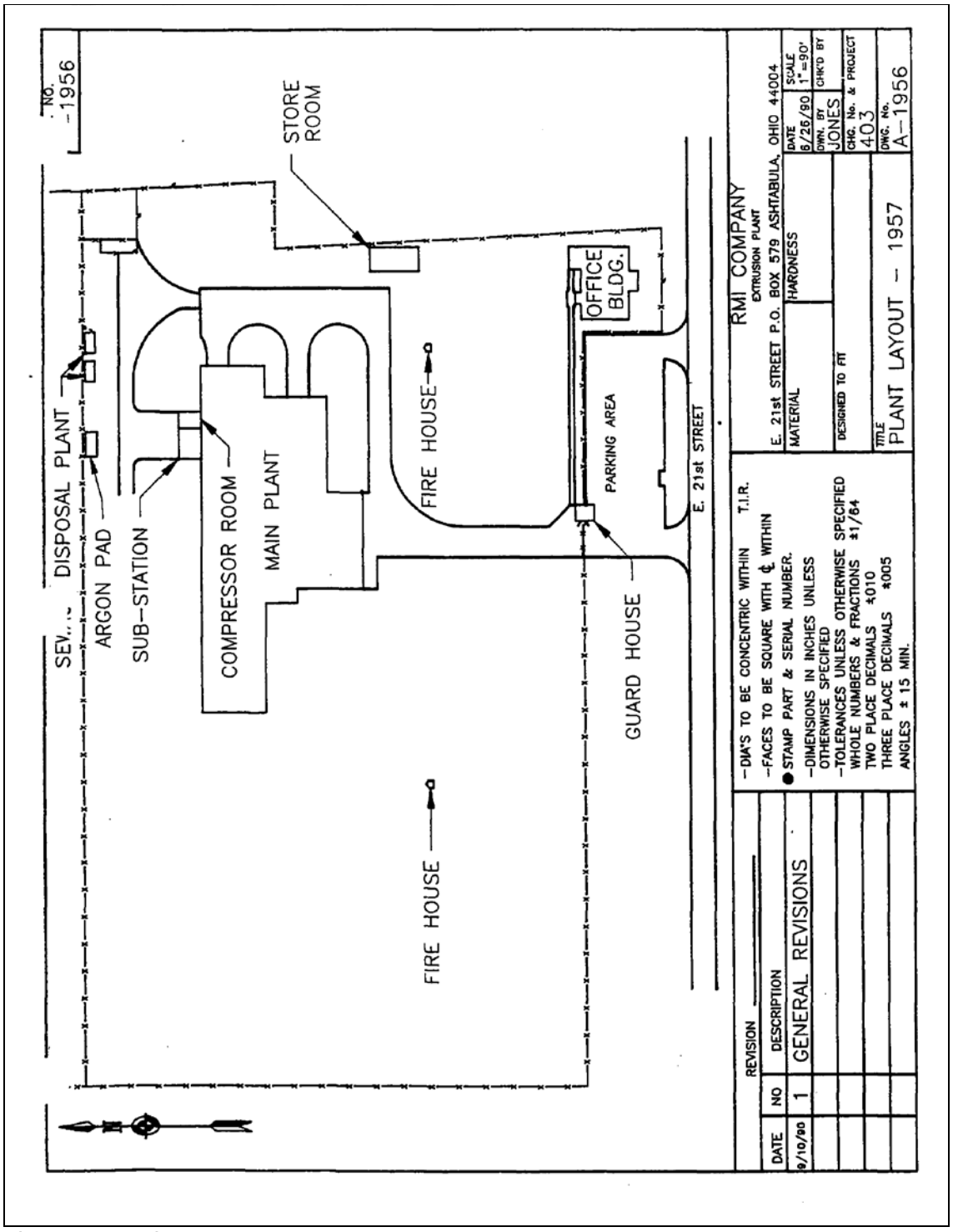

Figure A-2. Plant Layout – 1957.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 4 of 20

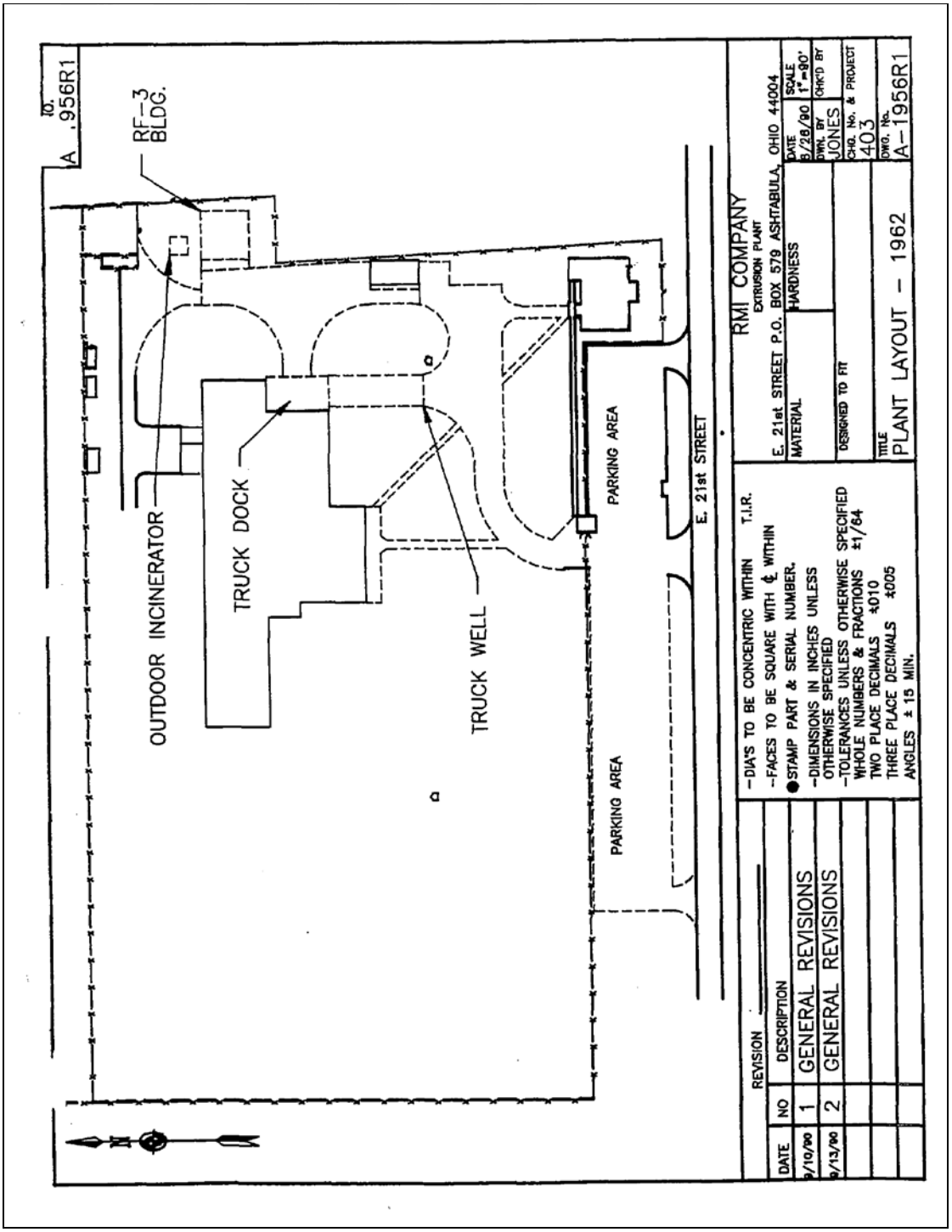

Figure A-3. Plant Layout – 1962.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 5 of 20

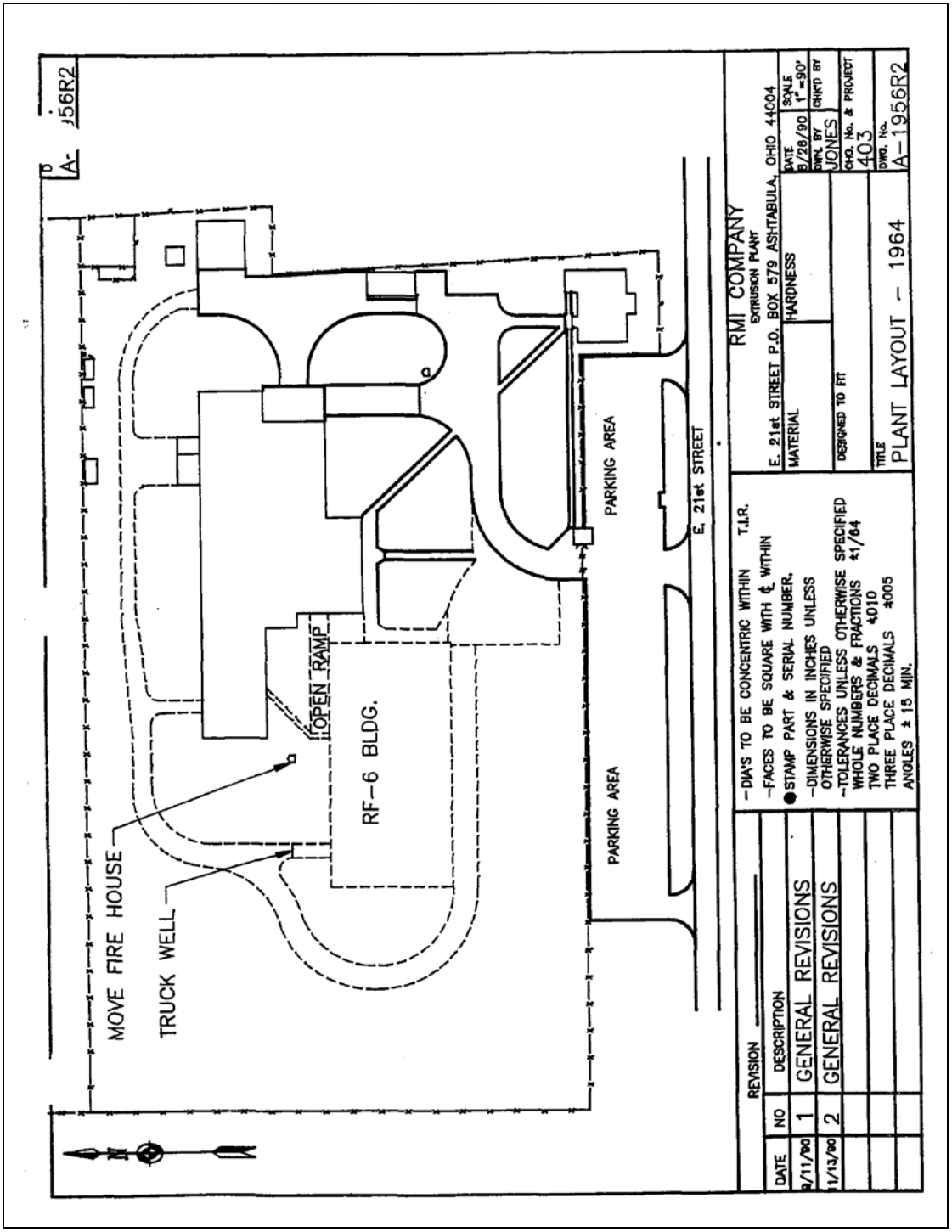

Figure A-4. Plant Layout – 1964.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 6 of 20

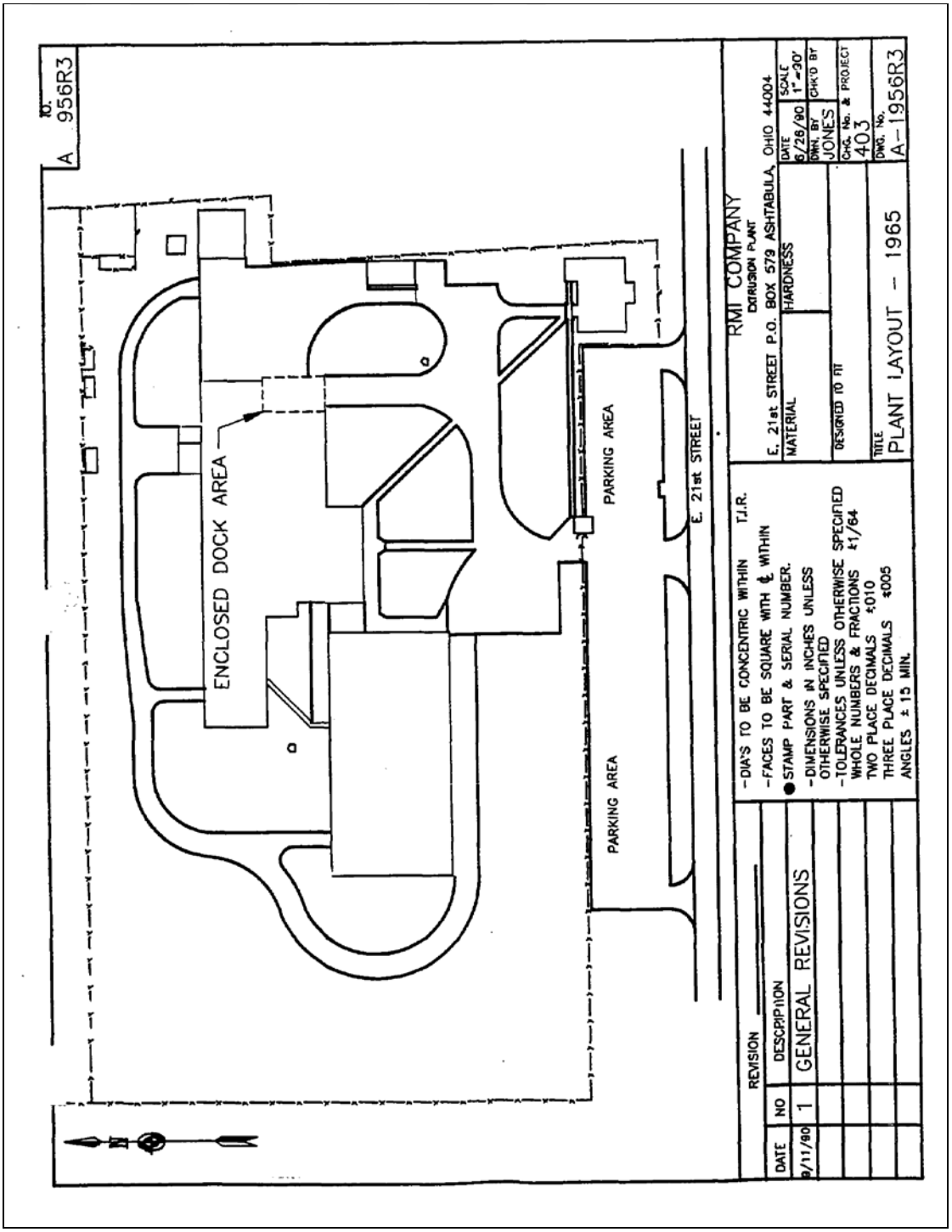

Figure A-5. Plant Layout – 1965.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 7 of 20

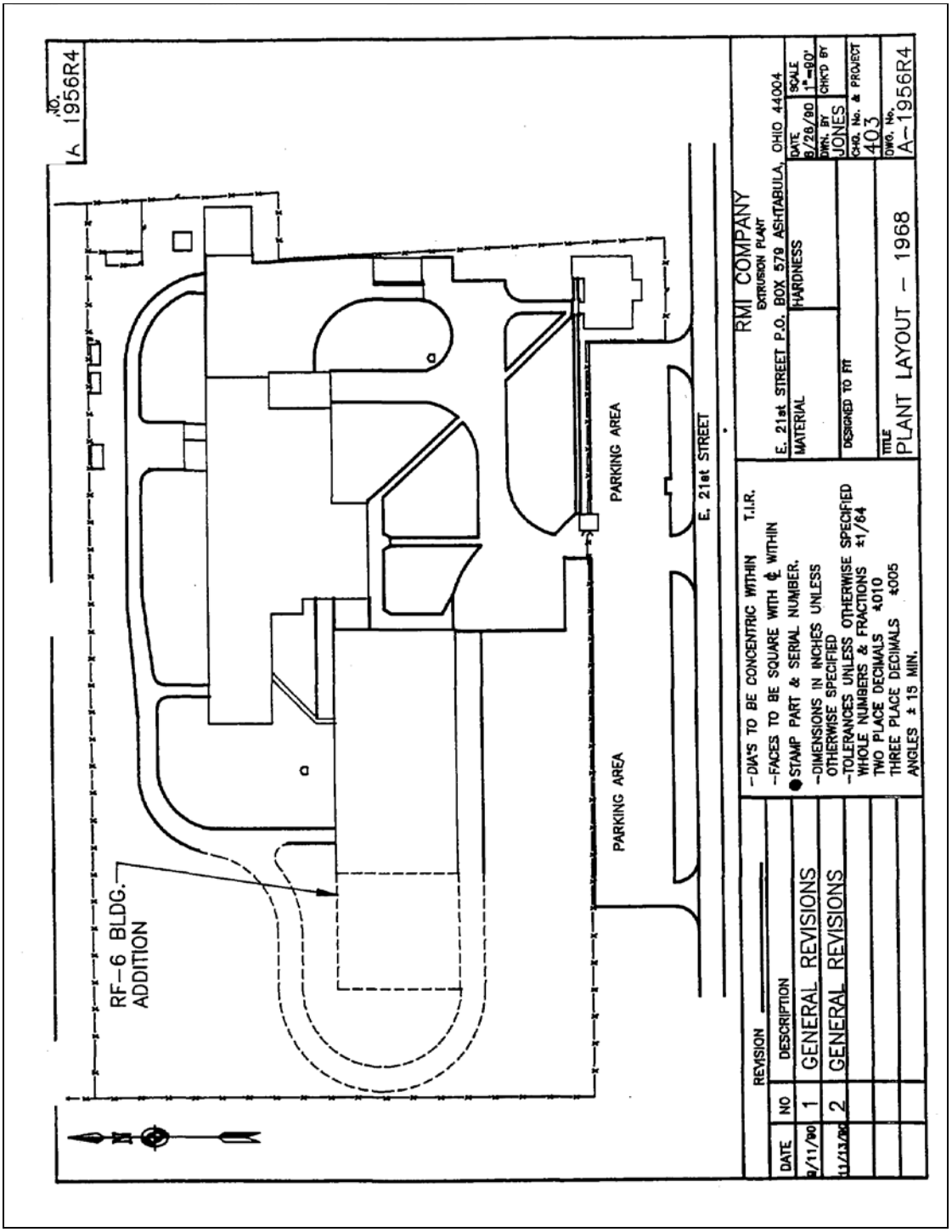

Figure A-6. Plant Layout – 1968.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 8 of 20

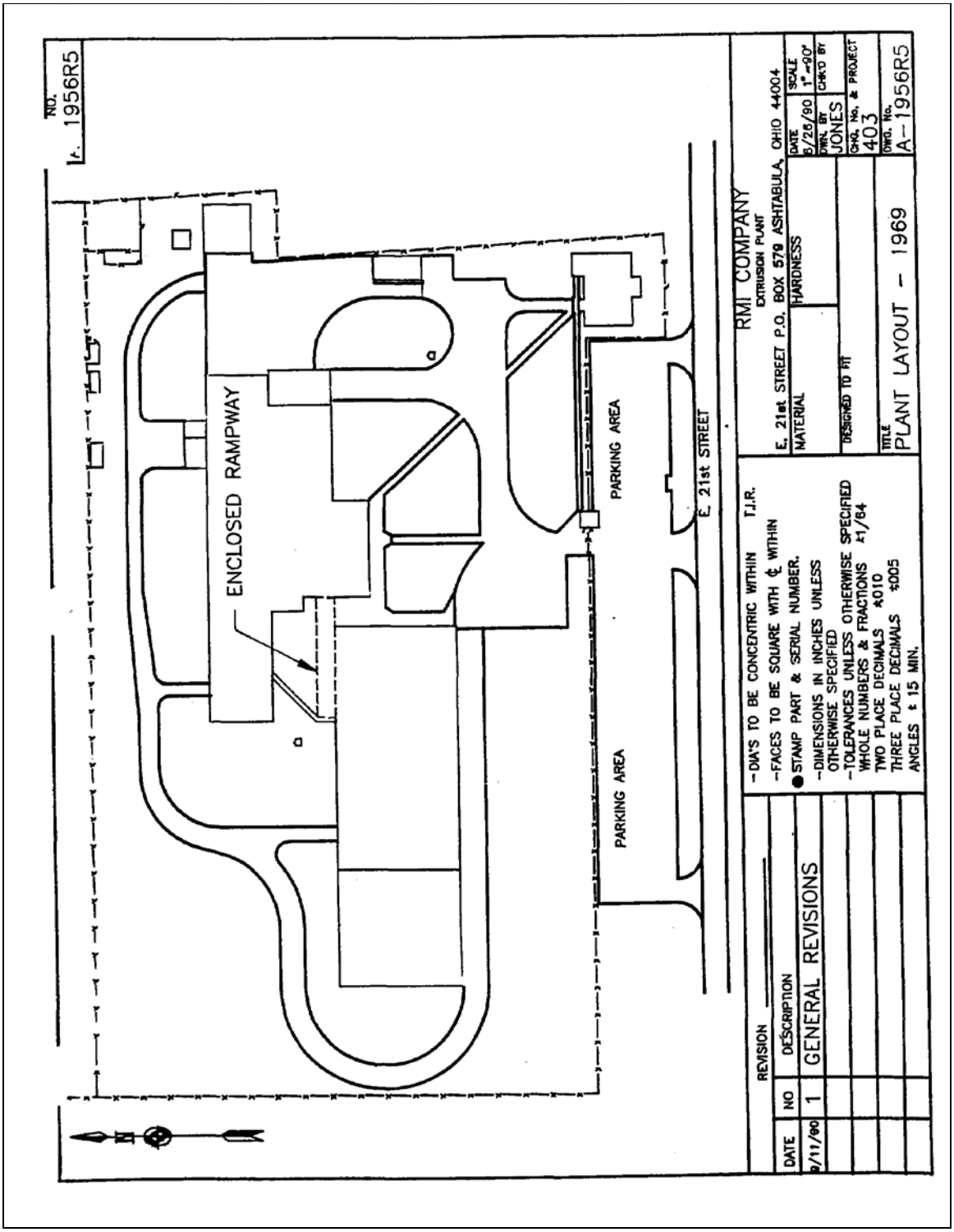

Figure A-7. Plant Layout – 1969.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 9 of 20

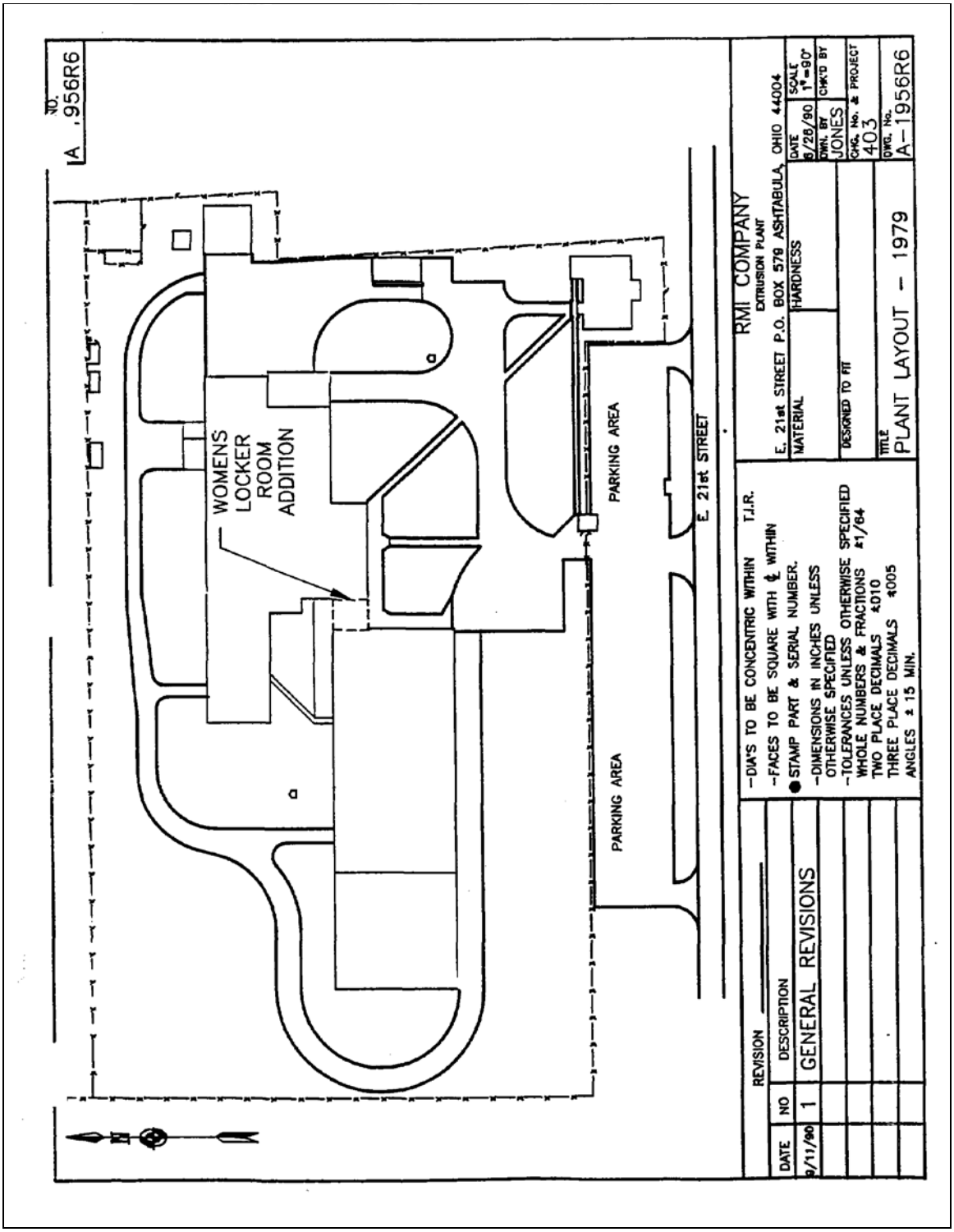

Figure A-8. Plant Layout – 1979.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 10 of 20

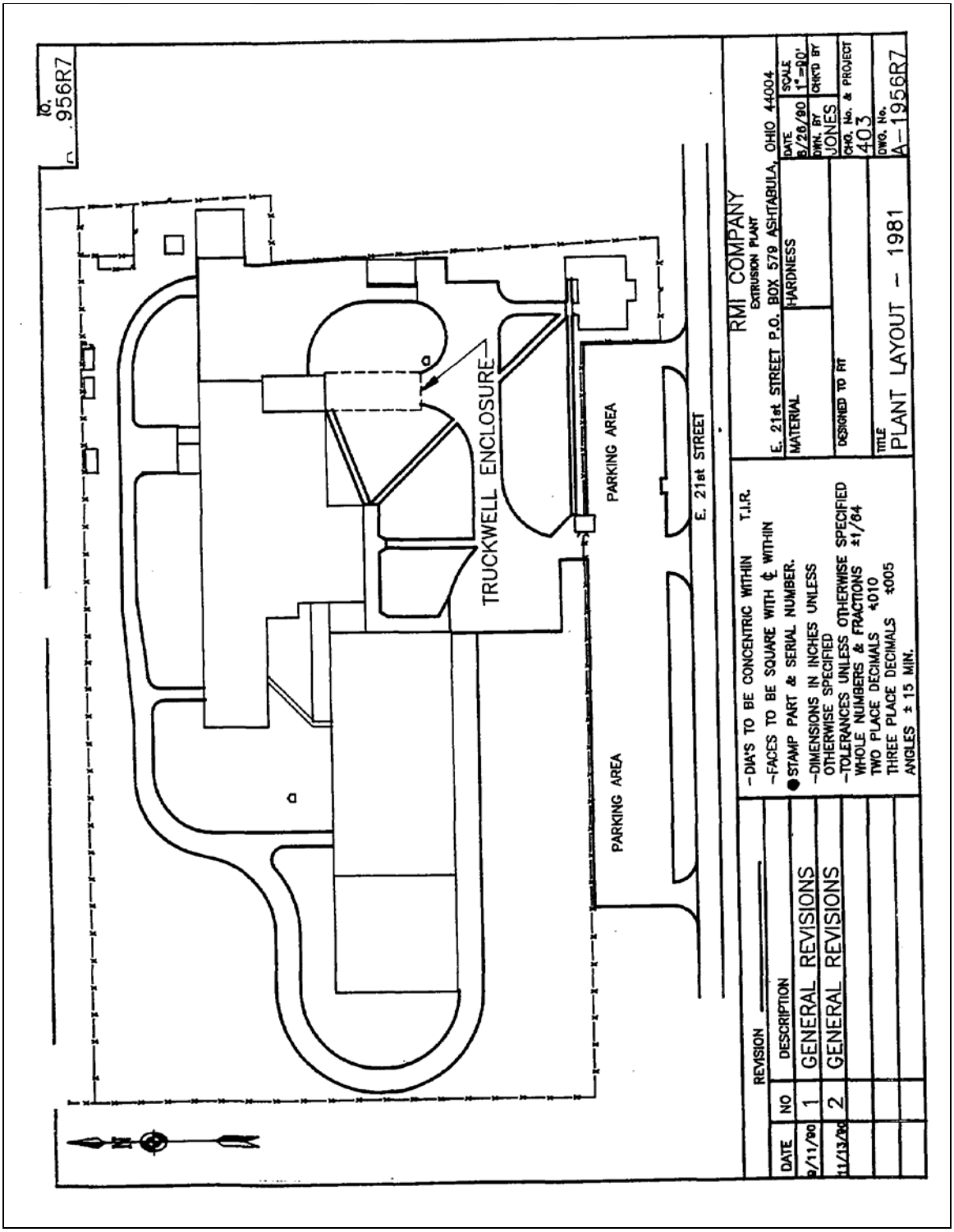

Figure A-9. Plant Layout – 1981.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS

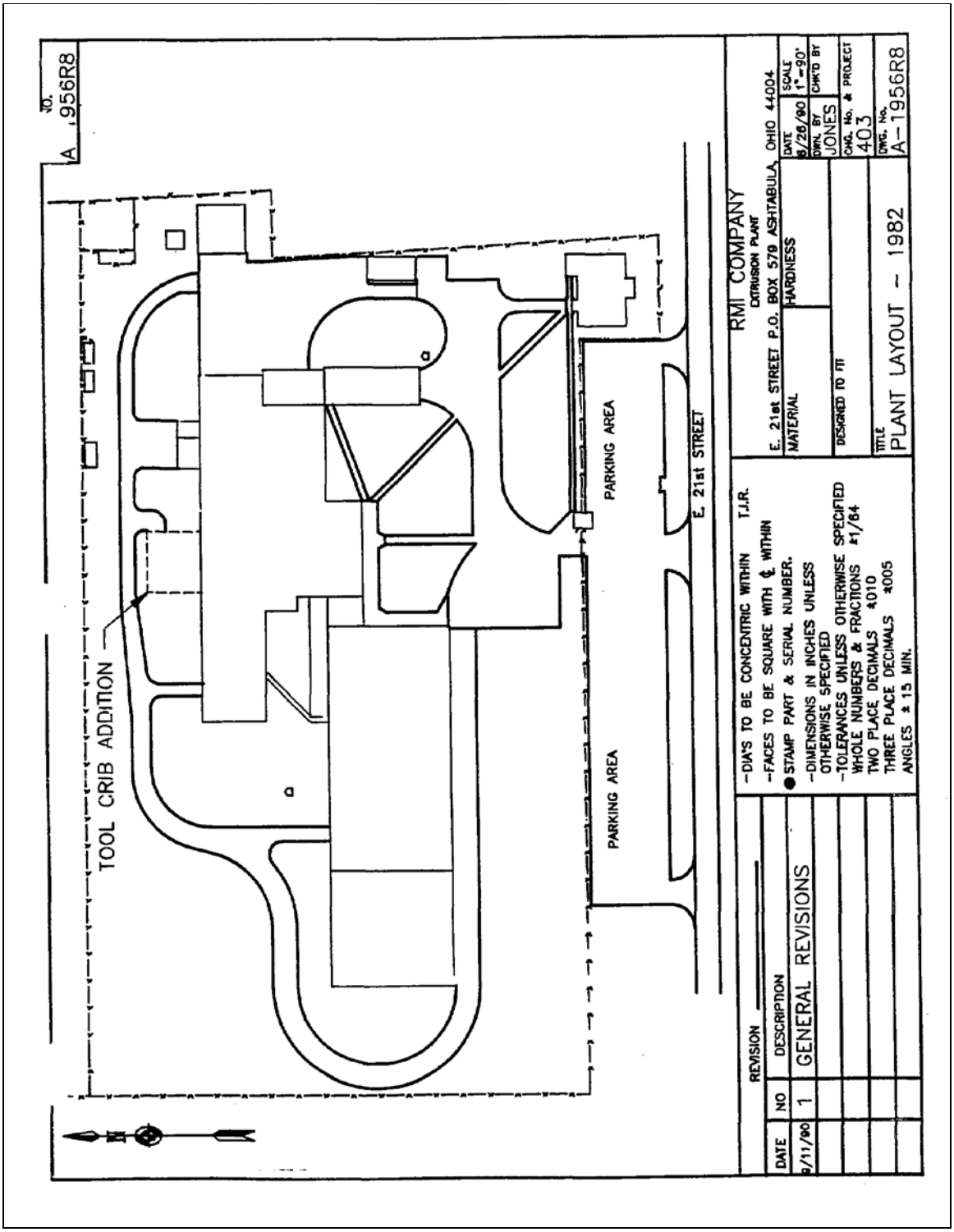

Figure A-10. Plant Layout – 1982.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 3 of 20

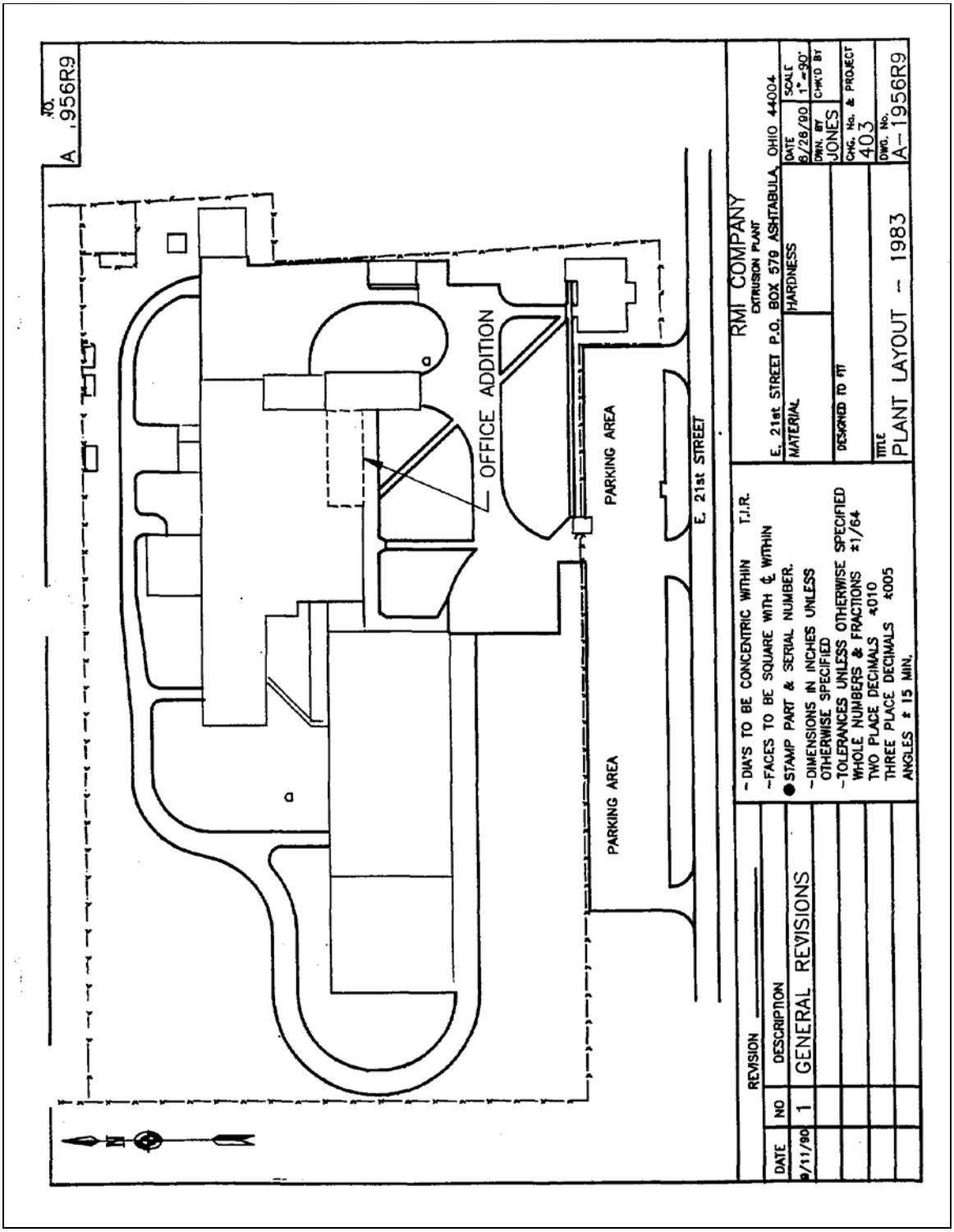

Figure A-11. Plant Layout – 1983.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 4 of 20

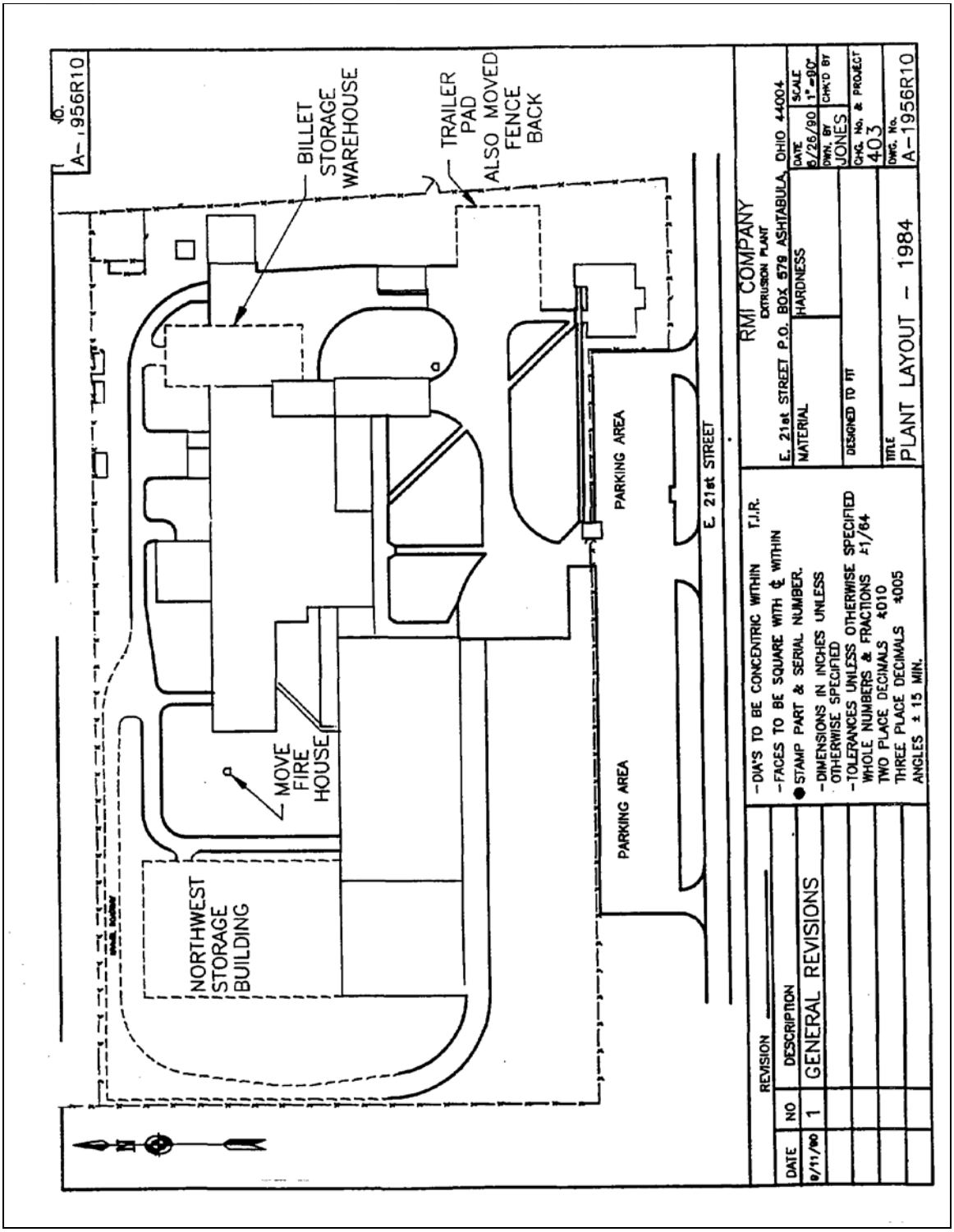

Figure A-12. Plant Layout – 1984.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 14 of 20

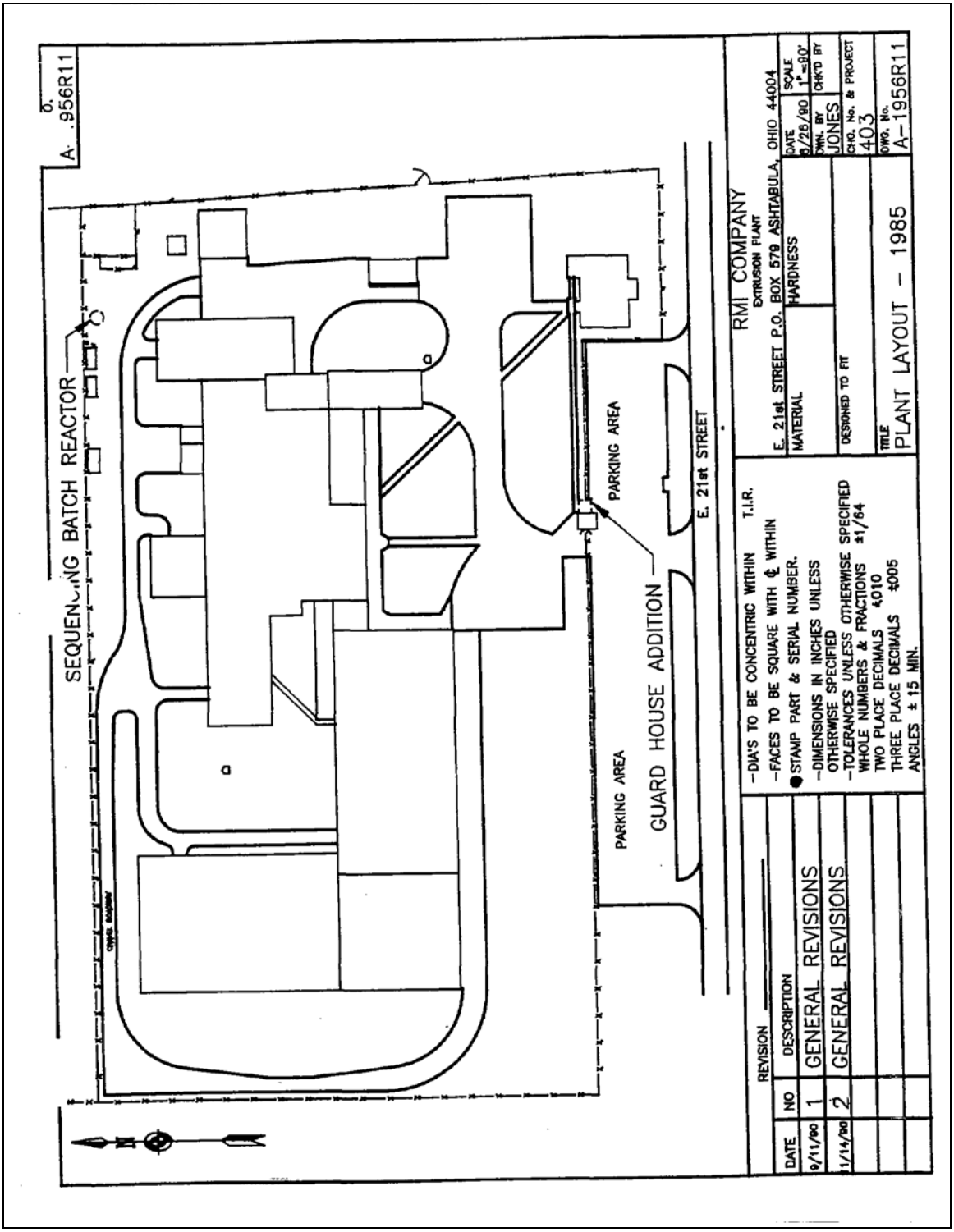

Figure A-13. Plant Layout – 1985.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 5 of 20

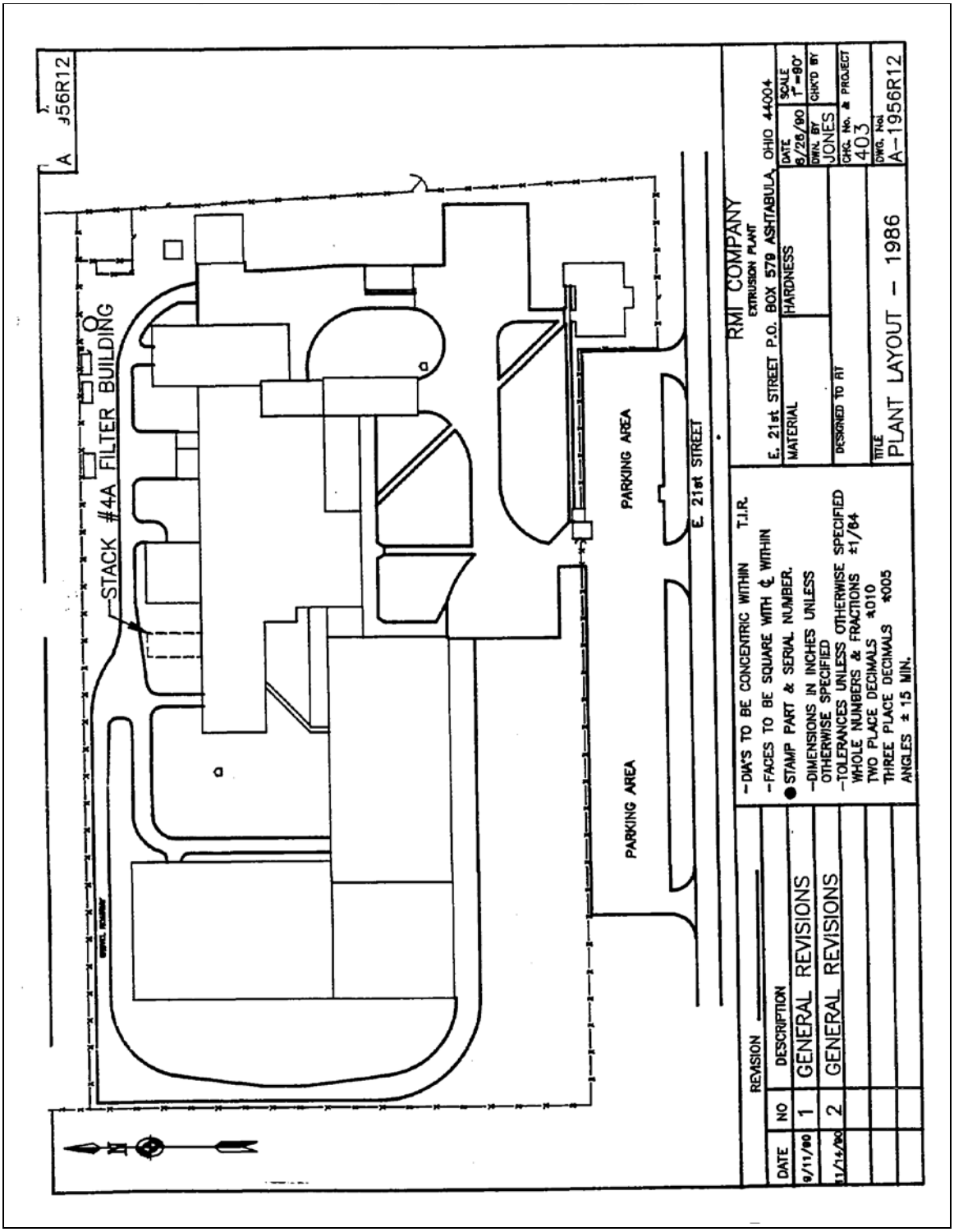

Figure A-14. Plant Layout – 1986.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 6 of 20

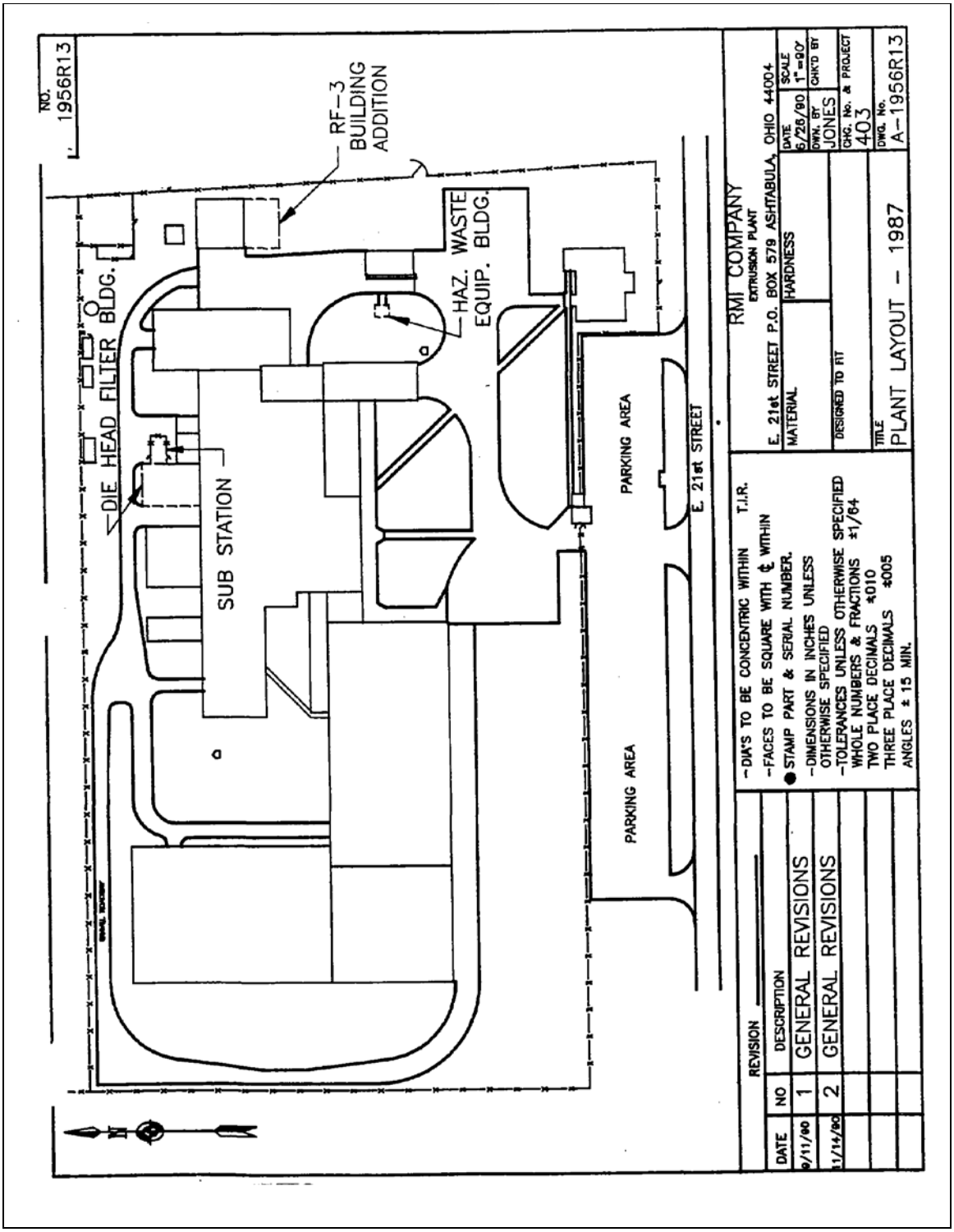

Figure A-15. Plant Layout – 1987.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 7 of 20

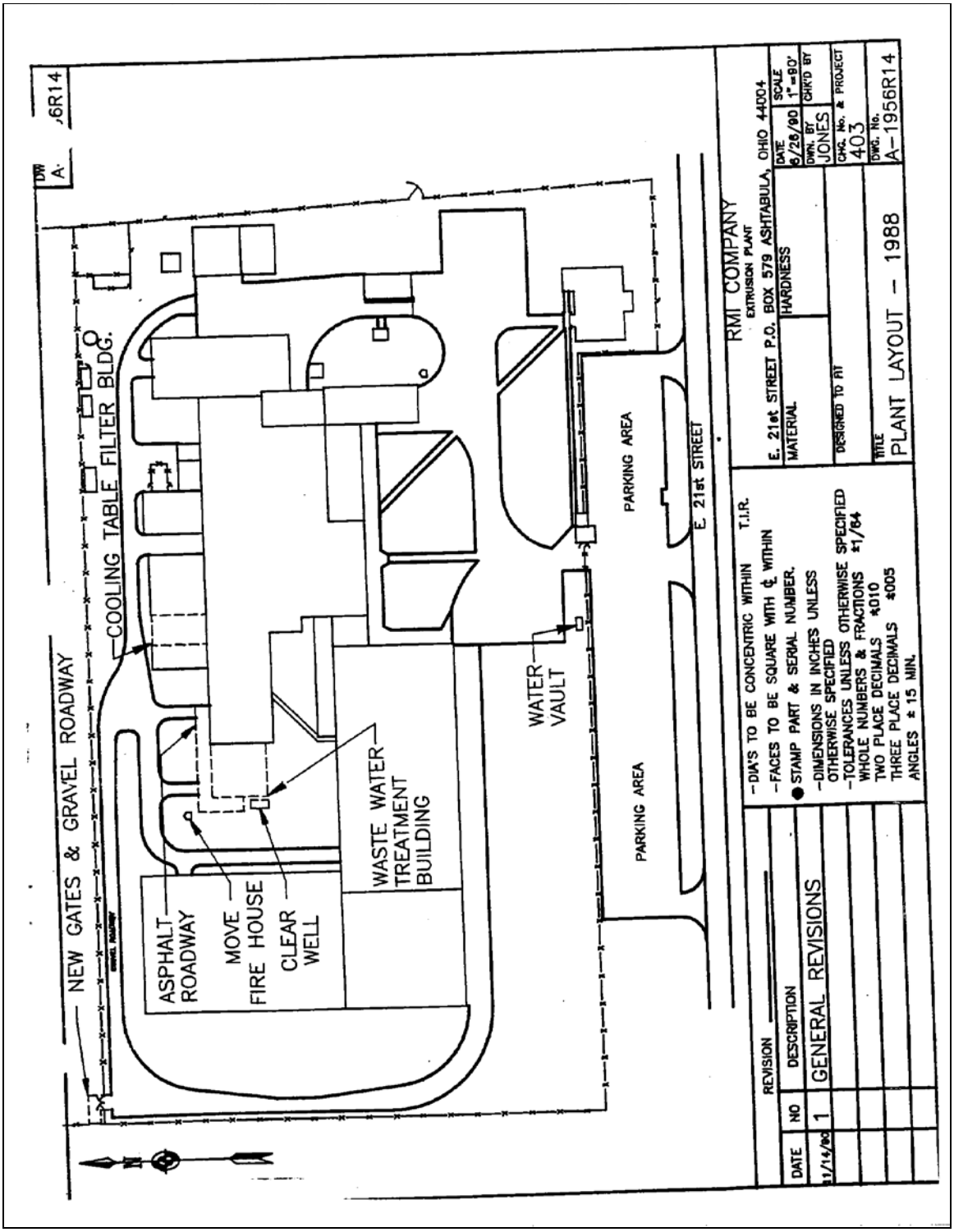

Figure A-16. Plant Layout – 1988.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 8 of 20

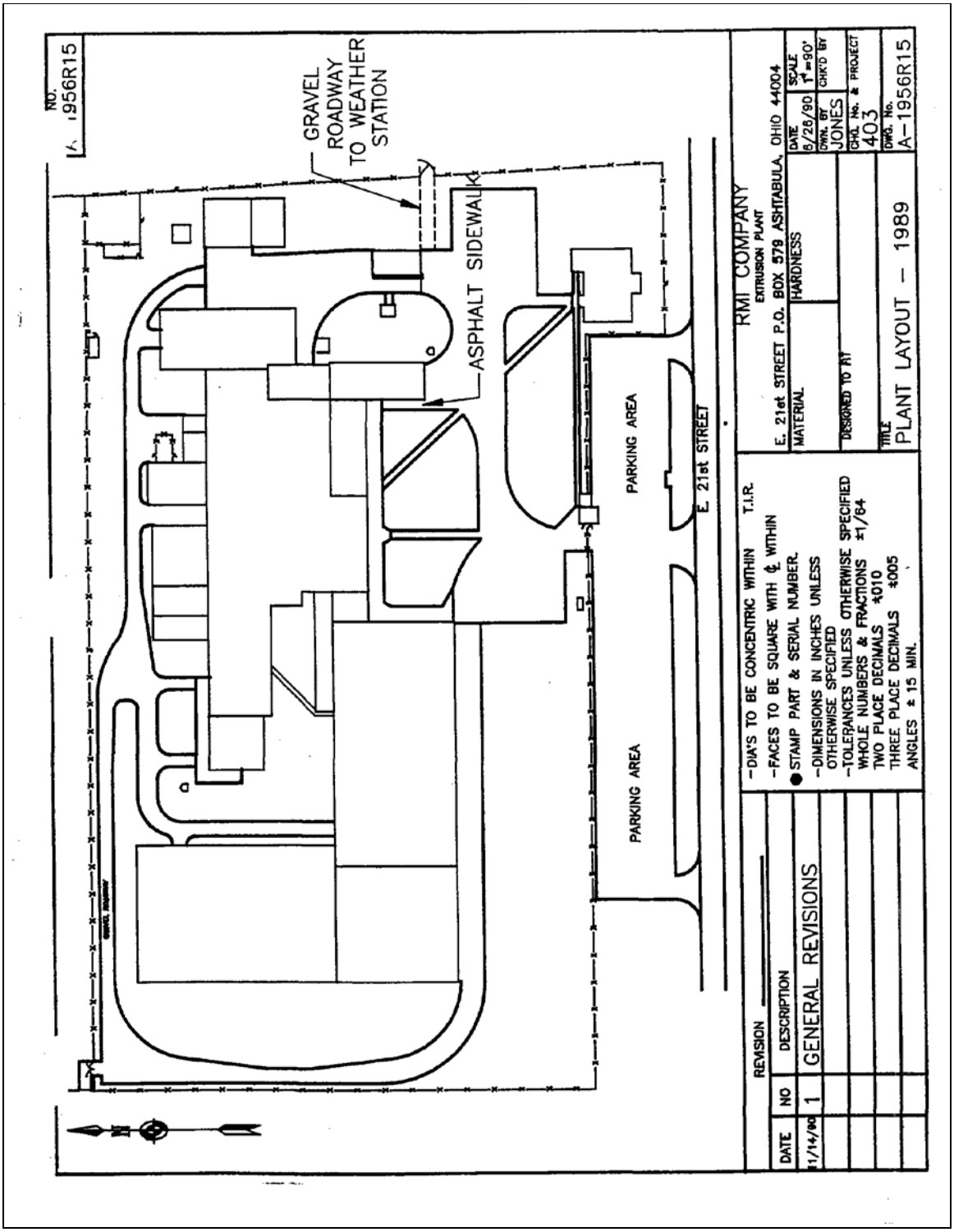

Figure A-17. Plant Layout – 1989.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 9 of 20

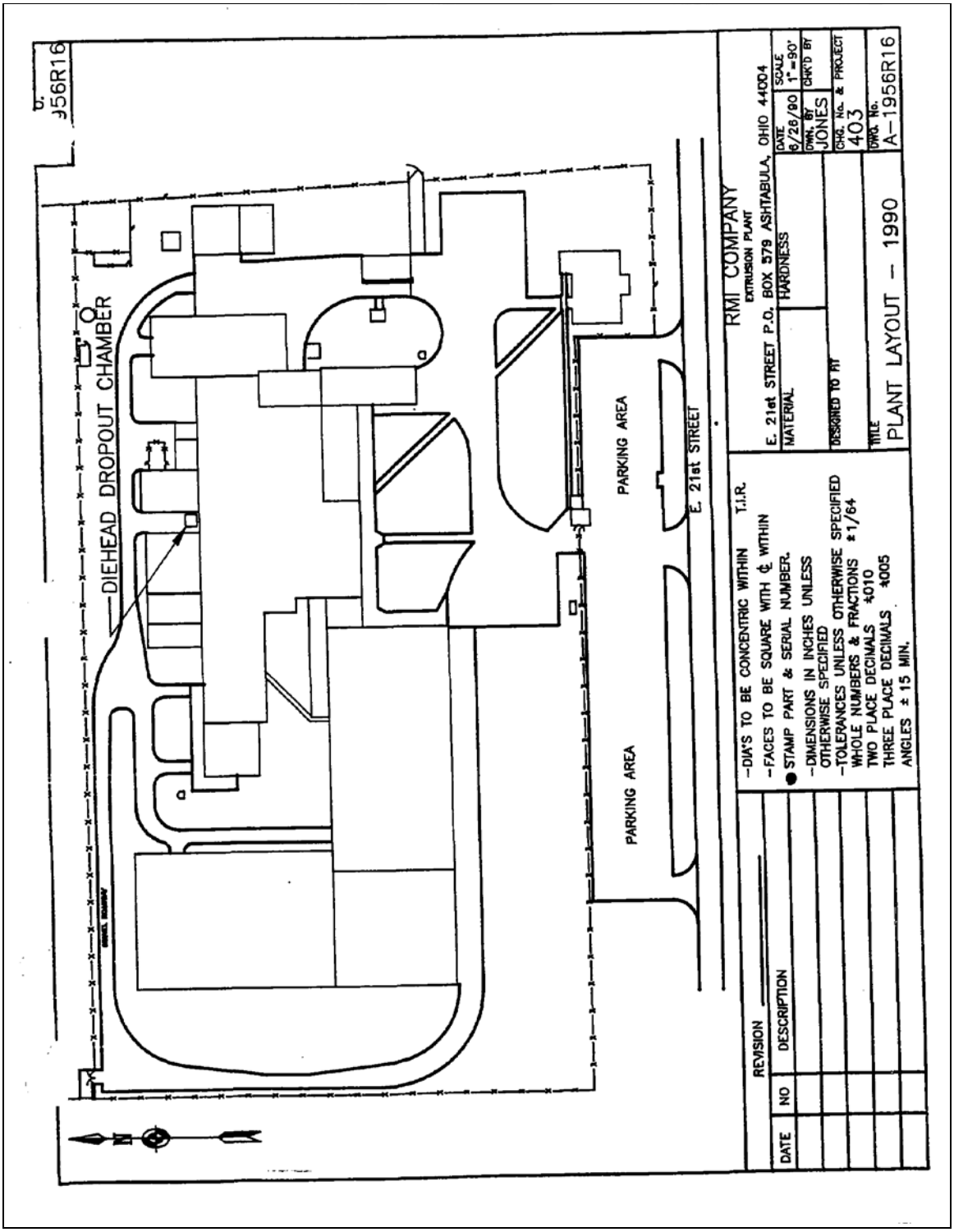

Figure A-18. Plant Layout – 1990.

ATTACHMENT A
EXTRUSION PLANT BUILDING LAYOUTS
Page 20 of 20

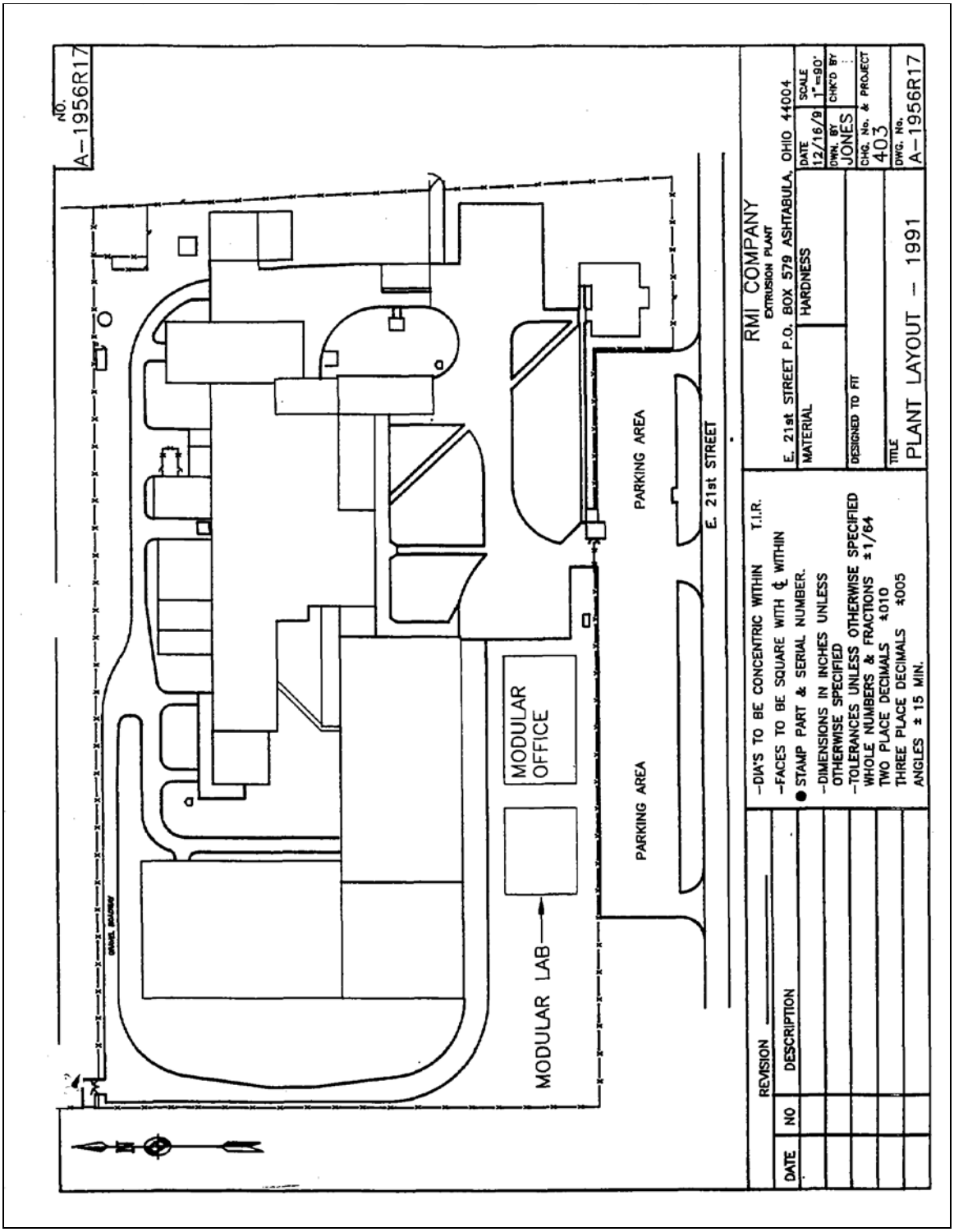

Figure A-19. Plant Layout – 1991.

ATTACHMENT B
EXTRUSION PLANT PROCESSES – N-REACTOR PRODUCTION
Page 1 of 2

According to RMI (1995a), "the N-Reactor Production consisted of a primary extrusion process followed by a forging process." The typical steps follow (RMI 1995a).

1. Ingots were received from FEMP.

2. Ingots were transferred to storage.

   Note: All onsite transfer of ingots, billets, forgings, and extrusions was accomplished by use of forklifts, fixtures, and overhead cranes.

3. Ingots were transferred to inspection.

4. Inspection was performed using an overhead monorail, scale, and inspection stand. Inspection included weighing and a dimensional and visual inspection.

5. Ingots were transferred back to storage.

6. Ingots were transferred to the salt baths and heated in molten salt to approximately 1,180°F for 1.5 hour minimum, 6 hour maximum.

7. Ingots were transferred to the press.

8. Ingots were extruded through the press into a heavy walled tube. This process included lubrication of press tooling to reduce friction during high-pressure extrusion.

9. The extrusion exited through the die head onto a runout table, and was placed on a rotating table and left for approximately 2.5 minutes.

10. The extrusion was transferred and lowered vertically into a water-filled quench tank for cooling for a minimum of 3 minutes.

11. The extrusion was transferred to a transfer table.

12. The extrusion was lifted horizontally and

    a. From 1962 to the mid-1960s, was placed into a trichloroethylene vapor degreaser tank to clean the extrusion.

    b. From the mid-1960s, was placed in a nitric acid pickle tank to clean the extrusion.

13. The extrusion was transferred to a water rinse tank, rinsed, and transferred to the packing station for inspection.

    a. Until the 1960s, extrusions were packed, stored, and shipped back to FEMP for further processing.

    b. In the late 1960s, further processing was performed at RMI as described below.

ATTACHMENT B
EXTRUSION PLANT PROCESSES – N-REACTOR PRODUCTION

14. The extrusion was cut into sections (billets).

15. Billets were nitric acid pickled, inspected, machined, and reinspected prior to a closed die forging process at the press.

16. Billets were transferred to the storage area to await forging.

17. Billets were transferred to the salt baths and heated in molten salt. Billets were heated to approximately 1,170°F for 1-hour minimum, 6-hour maximum.

18. Billets were transferred to the press.

19. Billets were forged (closed die process) in the press. This process shaped the billet to the approximate dimensions of the final size and included lubrication of press tooling.

20. After forging, billets were lifted directly from the die head and lowered into a water-filled quench tank for cooling for a minimum of 3 minutes.

21. Billets were transferred to a transfer table for postforging inspection.

22. Billets were nitric acid pickled, inspected, machined (if required, repickled and reinspected) and packed for shipment.

23. Packaged billets were stored for shipment to Richland, Washington.

24. Packaged billets were shipped.

Note: Residues and metal turnings generated throughout the production process were processed (dried, sampled, oxidized, etc.) and returned to FEMP.

Note: According to Breslin and Glauberman (1964), after extrusion, hand rolling was performed for 5 minutes.

ATTACHMENT C
EXTRUSION PLANT PROCESSES – SAVANNAH RIVER SITE PRODUCTION

The typical steps for uranium processing for the Savannah River reactors follow (RMI 1995a).

1. Ingots were received from FEMP.

2. Ingots were transferred into storage.

   Note: All onsite transferring of ingots, billets, forgings, and extrusions was accomplished by the use of forklifts, fixtures, and overhead cranes.

3. Ingots were transferred to inspection.

4. Inspection was performed using an overhead monorail, scale, and inspection stand. Inspection included weight and a dimensional and visual inspection.

5. Ingots were transferred back to storage.

6. Ingots were transferred to the salt baths and heated in molten salt to approximately 1,160°F for 75 minutes minimum.

7. Ingots were transferred to the press.

8. Ingots were extruded through the press into tubing. This process included lubrication of press tooling to reduce friction during high-pressure extrusion.

9. The extrusion exited through the press into tubing. This process included lubrication of press tooling to reduce friction during high-pressure extrusion.

10. The extrusions were lowered horizontally into a water-filled quench tank.

    a. Water quenching was begun in approximately 1966. Prior to this, extrusions were air-cooled.

11. The extrusions were cut into sections on an abrasive saw.

12. The extrusions were transferred to, and run through, the roll straightener

    a. From 1962 until approximately 1964, the extrusions were lowered horizontally.

    b. In approximately 1964, the hot oil bath was removed and an induction heater was installed in its place. Extrusions were run through the induction heater prior to the roll straightener. This process continued for approximately 1 year. After this, extrusions were not heated prior to straightening.

13. Extrusions were stored on the process table.

14. Extrusions were lifted horizontally and

    a. From 1962 to approximately 1964, were placed in a vapor degreaser tank to clean the extrusion.

ATTACHMENT C
EXTRUSION PLANT PROCESSES – SAVANNAH RIVER SITE PRODUCTION

b. After approximately 1964, the vapor degreaser tank was no longer used and extrusions were transferred to a water rinse tank, rinsed, and transferred to the packing station.

15. Extrusions were inspected, weighed, and packed for shipment to FEMP.

16. Packaged extrusions were stored prior to shipment.

17. Packaged extrusions were shipped.

Note: Residues and metal turnings generated throughout the production process were processed (dried, sampled, oxidized, etc.) and returned to FEMP.

ATTACHMENT D
EXTRUSION PLANT PROCESSES – DOD PENETRATOR PRODUCTION
Page 1 of 1

The typical steps for source material processing for DOD Penetrators follow (RMI 1995a).

1. Ingots were received.

2. Ingots were transferred to storage.

    a. Stored in main plant before 1984.
    b. Stored in main plant and northeast warehouse after 1984.

3. Ingot inspection

    a. Inspected at inspection station.
    b. Inspected at floor scale.

4. Storage

    a. Stored in main plant before 1984.
    b. Stored in main plant and northeast warehouse after 1984.

5. Heating

    a. Salt baths
    b. Sunbeam furnace (preheat only)
    c. IFSI furnace (preheat only)
    d. Other electric furnaces in, or transferred to the main plant salt bath area

6. Extrusion

    a. Extrusion press

7. Postextrusion included numerous different processes:

    a. Water quench
    b. Air cool
    c. Saw
    d. Transfer
    e. Pickle
    f. Water rinse
    g. Inspection and weighing at packing station or floor scale
    h. Storage

        (1) Stored in main plant before 1984.
        (2) Stored in main plant and northeast warehouse after 1984.

    i. Shipment

ATTACHMENT E
DETAILED PENETRATING WHOLE BODY DOSES

Year	Number monitored	Whole body deep dose (rem)				Assumed neutron dose ICRP 60 (rem)	Reference
		<0.010	0.01–0.099	0.100–0.249	95th percentile		
1999	1,202	1,170	32		<0.010	0	Eberline Dosimetry Services 2000
1998	–[a]	_	_	_	_	0	
1997	290	271	19		0.099	0	ThermoNUtech 1998
1996	285	241	44	1	0.099	0	Tauche, R.M. 1998
1995	255	220	35		0.099	0	ThermoNUtech 1996
1994	330	291	38	1	0.099	0	TMA Eberline 1995

a. – = No data available.

Year	Number monitored	Whole body beta-gamma dose (rem)						Assumed neutron dose ICRP 60 (rem)	Reference
		None	<0.100	0.100–0.249	0.250–0.499	0.500–0.749	95th percentile		
1984	117	23	48	33	13		0.499	0.439	Schaeffer 1985
1983	118	32	39	32	15		0.499	0.439	Schaeffer 1984
1982	117	20	54	32	10	1	0.499	0.439	Schaeffer 1983
1981	–[a]	_	_	_	_	_	_	0.439	
1980	80	16	32	28	4		0.249	0.439	Schaeffer 1981
1979	80	14	45	19	2		0.249	0.439	Van Looke 1980
1978	68	16	21	26	5		0.499	0.439	Schaeffer 1979
1977	_	_	_	_	_	_		0.439	Schaeffer 1977
1976	58	30	20	8			0.249	0.439	
1975	62	19	31	11	3		0.249	0.439	Heiser 1976
1974	69	22	27	17	1		0.249	0.439	Heiser 1975

a. – = No data available.