**WINCO METAL RECYCLE
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EXECUTIVE SUMMARY

This report is a summary of the first year progress of the WINCO Metal Recycle Program. Efforts were directed towards assessment of radioactive scrap metal inventories, economics and concepts for recycling, technology development, and transfer of technology to the private sector. Seven DOE laboratories worked together to develop a means for characterizing scrap metal. Radioactive scrap metal generation rates were established for several of these laboratories. Initial cost estimates indicate that recycle may be preferable over burial if sufficient decontamination factors can be achieved during melt refining. Radiation levels of resulting ingots must be minimized in order to keep fabrication costs low. Industry has much of the expertise and capability to execute the recycling of radioactive scrap metal. While no single company can sort, melt, refine, roll and fabricate, a combination of two to three can complete this operation. The one process which requires development is in melt refining for removal of radionuclides other than uranium. WINCO is developing this capability in conjunction with academia and industry. This work will continue into FY-94.

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1. INTRODUCTION: RADIOACTIVE SCRAP METAL (RSM)

In 1992, the DOE Office of Environmental Restoration and Waste Management (EM-30) directed Westinghouse Idaho Nuclear Company (WINCO) to alter the mission of the Idaho Chemical Processing Plant (ICPP) to include development of technologies for conditioning of spent fuels and high-level wastes for repository acceptance. In addition, a program plan was developed to address the recycle of radioactive scrap metal (RSM). Although a major motivation for the metal recycle program was the disposition of contaminated stainless steel generated during re-racking of fuels stored in the ICPP FAST fuel storage basin, the activities also apply to the needs of other INEL efforts, and national efforts, which address the disposition and beneficial reuse of RSM. The scope of WINCO activities has included systems analysis of the means for effecting RSM recycle, development of methodologies for material characterization and inventory assessment, consideration of criteria and regulations affecting RSM recycle, development of concepts for RSM reuse, assessment of technologies for decontamination and recycle of stainless steel, identification of private companies with interest in RSM recycle, and efforts to establish a market awareness which will lead to privatization of RSM recycle.

This report documents the progress of the WINCO Metal Recycle Program through September 1993. Program work will continue through FY-94. The body of the report is divided into seven sections which reflect major divisions in program work effort: 1) Regulations having impact on future recycling activities, 2) Efforts to inventory RSM located at DOE sites, 3) Concepts for fabrication of useful products from recycled RSM, 4) Economics of recycle versus the cost of waste disposal, 5) Technology applicable to decontamination of RSM, 6) Safety and Health issues associated with the processing of RSM, and 7) Initiatives promoting technology transfer and privatization of RSM recycle.

2. REGULATION OF RSM RECYCLE ACTIVITIES

2.1 Radiological Compliance

Recycle of any commodity is dependent upon the reuse conditions of the recycled product. In order to effect metal recycle, regulations must define what degree of cleanup is adequate, and what controls must be applied to products which have residual radioactivity. In the case of RSM, regulations for the release of the decontaminated material have been the subject of considerable controversy. Regulatory controls associated with RSM recycling were reviewed. The review was restricted to consideration of domestic controls, since the scope of the Metal Recycle program is primarily focused upon feedstock utilization and subsequent reuse within a domestic market.

The basis for free release of scrap materials bearing radioactive contamination may be found in Nuclear Regulatory Commission (NRC) Regulatory Guide 1.86, entitled, "Termination of Operating Licenses for Nuclear Reactors". This guide became policy in June of 1974. Section 4, "Decontamination for Release for Unrestricted Use", appears to be relevant to metal recycling. However, since guidance is restricted to materials bearing surface contamination, Regulatory Guide 1.86 is not directly applicable to metals bearing volumetric contamination. Furthermore, NRC representatives have argued that this section is not intended to address *de minimis* limits for recycling

Nevertheless, NRC attempted to institute a policy to form a framework for *de minimis* release of decontaminated materials for public use. This policy-making cycle was initiated in response to a Congressional mandate in the Low-Level Radioactive Waste Policy Amendments Act of 1985. This "Below Regulatory Concern" (BRC) policy proved a focal point for criticism from a broad spectrum of stakeholder groups, which mobilized an extensive campaign to resist implementation of a policy that would allow release of detectable quantities of radioactive material into the public resources. This resistance caused NRC to defer, and then, retract, the draft policy. Public opposition has sought to prevent release of any material that contains detectable radioactivity. This has led to increased concern about Naturally Occurring Radioactive Materials (NORM) amongst domestic scrap metal recyclers.

Exposure to low-levels of ionizing radiation cannot be correlated with discrete health effects. Therefore, it has been necessary to apply statistical analyses to assess risks to public health. Several methods for determination of risk, based on standards for release, are being developed by NRC, the International Atomic Energy Commission (IAEA), and DOE. These are computer-based models that consider a broad spectrum of radiologic contaminants and product use scenarios to arrive at control limits which will prevent public exposure from exceeding dosages which will be prescribed by local, national, and, perhaps, international regulatory agencies.

The success of a metal recycle program is a function of the processor's ability to secure feedstock and sell product. Radiologically contaminated materials are commonly viewed as intrinsically hazardous. A court tort deciding in favor of a claim for damages resulting from radiation exposure could establish strict liability, and hold the original generator liable for damages. The risk of this type of ruling could make NRC licensees extremely cautious about releasing contaminated material for conversion to consumer products. DOE contractors may be similarly unenthusiastic about free-release of recycled materials. DOE is currently maintaining a release moratorium for any material removed from a radioactive materials area. In view of continued public resistance to participation in efforts to frame clear and explicit regulatory guidance, and in light of the potential for product liability, the best available option for RSM recycle would appear to be the fabrication of products which would remain under DOE or NRC operational controls. Reuse of RSM in products such as waste packaging and fuel storage hardware would appear to be appropriate in the present political climate. This view has been supported by representatives of the Nuclear Information Research Service.

2.2 Environmental Compliance

Environmental regulatory requirements were discussed with representatives of DOE-HQ, DOE-ID, Westinghouse Hanford Company, Westinghouse Savannah River Company, EG&G Rocky Flats, Nevada Test Site, Sandia National Laboratory, and Los Alamos National Laboratory. Attention was focused on Subtitles C and D (Characteristics of Hazardous Waste, Lists of Hazardous Wastes) of the Resource Conservation and Recovery Act (RCRA) and how their interpretation could either promote or hinder RSM recycle. There was little discussion of other environmental laws and regulations, such as the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the Clean Water Act (CWA), and the Clean Air Act (CAA).

RCRA Subtitle C concerns were discussed at meetings in February and April. It was agreed that INEL and DOE-ID representatives would work with their Environmental staffs in preparation for a June meeting. The WINCO Metal Recycle representative worked with company legal and ES&H personnel, and with DOE Environmental Health staff.

RCRA issues considered at the June meeting included definition of byproduct materials as hazardous waste (52 FR 15937, May 1, 1987; 10 CFR, subparts 962.2 and 962.3), as well as determination of waste category, waste recycling, land disposal restrictions, and generator responsibilities (57 FR 37221, August 18, 1992; 40 CFR, subparts 261.1, 261.2, 261.4, 261.6, 262.11, and 268.2). The following statements reflect the majority opinion of the participants:

1. Only the radionuclides dispersed or suspended in a waste substance are byproduct materials exempt from RCRA regulation. The rest of the "waste stream" (the nonradioactive component) is subject to regulation under RCRA.
2. It is the generator's responsibility to determine the "status" of a waste (whether or not a material is hazardous). This determination can be made by means other than testing, such as documentation of process knowledge. However, since records for unsheltered piles of RSM ("boneyards") may be incomplete, some liabilities may be associated with avoidance of testing.
3. For ongoing processes, the sites will attempt to determine whether or not RSM is hazardous (by history and/or testing) as it is generated. If the metal is not itself a RCRA hazardous waste, or if it is not contaminated with a RCRA hazardous waste, then RCRA Subtitle C would not appear to apply. If the RSM is a mixed waste (hazardous and radioactive), it must be handled under RCRA, unless or until it can be recycled.

3. RSM INVENTORIES

3.1 DOE Site Coordination

In FY-93, WINCO Metal Recycle hosted three meetings in an effort to coordinate metal recycle efforts within the DOE complex. These meetings were attended by representatives from DOE-HQ (EM-30, 40 and 50), DOE-ID, Westinghouse Hanford Company, Westinghouse Savannah River Company, EG&G Rocky Flats, Nevada Test Site, Sandia National Laboratory, and Los Alamos National Laboratory. The agenda for the meetings included RCRA, RSM stockpiles, RSM/SM disposition, metal inventories, and development of a inventory survey form and integrated database.

At the February meeting, WINCO personnel presented information on RSM inventory management and development of technologies for RSM reuse. Site representatives described their sites and presented information on current means of RSM disposition. Discussions revealed that little RSM exists in unsheltered piles and that most of the estimated 1.8 million ton stockpile may be inaccessible material remaining in collapsed craters and tunnels from underground nuclear tests at the Nevada Test Site. WINCO personnel led a discussion on the design of a survey form and integrated database for RSM characterization and inventory. Site representatives were asked to comment on the survey form, to propose guidelines for release of RSM from site, and to construct decision trees for RSM disposition.

At the April meeting, WINCO personnel presented the Metal Recycle Program five-year plan and information pertinent to privatization of RSM recycle. Representatives from EM-30 and EM-50 discussed their involvement in RSM recycle. A discussion followed concerning how RSM might be regulated under RCRA, but no conclusions were reached. Site representatives gave presentations on instruments and procedures used to determine radioactive contamination, and decision trees used for material disposition. In general, the sites have adopted a more conservative approach to release of metals for unrestricted use than required by NRC Regulatory Guide 1.86. Some sites will not release metal if there is detectable activity above background. Other sites may release metals if they can be decontaminated to levels below background. If there is potential for contamination which cannot be detected, the material cannot be released for unrestricted use. Site representatives were requested to determine beryllium and lead inventories, to evaluate RCRA applicability, and to establish the amounts of scrap metal, both contaminated and clean, currently being recycled or disposed. Discussion of the survey form was continued.

At the June meeting, representatives from WINCO and DOE-ID led a discussion on the functions of EM-30, EM-40, and EM-50, and their interests in RSM recycling. A discussion on RCRA Subtitle C and RSM was held. A representative from EH-20 gave a presentation on mixed waste and materials management in the DOE complex, and how DOE is addressing them. Site representatives gave presentations concerning lead and beryllium inventories and disposition of scrap metal. WINCO personnel discussed instrumentation for materials characterization. Discussion of the survey form was continued. Final changes were noted so that the survey matrix could be formalized. It was decided that there would be no further meetings in FY-93.

Site representatives submitted monthly progress reports, and Memorandum Purchase Orders for FY '93 site activities were inactivated. Plans for FY-94 site characterization activities were discussed and will be finalized with the individual sites.

3.2 RSM Inventories

Representatives attending the WINCO Site Coordination meetings were asked to prepare an inventory of the amount of scrap metal, both contaminated and clean, currently being recycled or disposed. In many cases, these figures were not quantified, or were only rough estimates. This information is compiled in Tables 1 and 2. Information about the availability of RSM feedstocks is largely incomplete. Since this information will be necessary in order to develop a recycling program involving private industry, WINCO Metal Recycle will continue to work with six DOE sites and various INEL facilities in order to complete a detailed inventory of RSM feedstocks.

An inventory of RSM available at the Idaho National Engineering Laboratory (INEL) was performed for WINCO Metal Recycle by EG&G Idaho, Inc. The scope of work included determination of: 1) the amount, composition, and location of recyclable RSM at the INEL, 2) plans for collecting and burying by RSM at the Radioactive Waste Management Complex (RWMC), 3) the cost of burial at the RWMC, and 4) the tonnage and composition of RSM generated by future decontamination and decommissioning (D&D) activities at INEL.

An inventory of RSM currently stockpiled at the INEL is included as Appendix C. Most of this material is at Test Area North (TAN) or Test Reactor Area (TRA). Argonne National Laboratory-West does not stockpile RSM, but routinely buries it at the RWMC. Information on materials stockpiled at the Naval Reactor Facility was requested, but not received. The inventory currently includes approximately 2.2 million pounds of metallic scrap. The materials are readily divided into six generic feedstocks:

- ≈387,500 lb. iron or carbon steel
- ≈314,000 lb. carbon steel/stainless steel composites
- ≈648,185 lb. stainless steel
- ≈878,441 lb. carbon steel/stainless steel/lead composites
- ≈ 3,000 lb glass/lead composites
- ≈ 2,000 lb. unknown composition

Table 1: Seven Site Scrap Metal Disposition, 1992

Facility	Scrap Metal Buried		Scrap Metal Recycled Cold (tons)
	Cold	Radioactive	
INEL	1434 m ³	None	46
REECo/NTS	None	Unquantified	2100
SNL	None	Not Itemized	451
LANL	None	160 tons	362
WSRC	None	Not Itemized	2000
EG&G RF	None	None	93
WHC	None	8800 tons	600

Figures approximate.

Table 2: Seven Site Lead/Beryllium Inventory

Facility	Lead (tons)		Beryllium	
	Cold	Radioactive	Cold	Radioactive
INEL	80	1000	None	None
REECo/NTS	120	Unquantified	10 pounds	None
SNL	200	200	No excess	No excess
LANL	80	80	None	None
WSRC	2500	2500	1 can	None
EG&G RF	None	400	55 tons	55 tons
WHC	59	59	None	None

Figures approximate.
Some figures include lead still in use.
Include different shapes and sizes.

No estimate is made for the relative proportion of individual materials in composite structures. Inclusion of lead shielding in casks may compromise recovery of some ferrous feedstocks. Revisions will be made to the inventory as information becomes available.

Table 3 lists estimates of the tonnage and composition of RSM which would be generated by major decommissioning projects at the INEL.

3.3 Scrap Characterization

WINCO Metal Recycle will coordinate efforts to characterize stockpiled scrap metal at seven DOE sites in FY-94. Characterization efforts will begin at INEL in November of 1993. Los Alamos National Laboratory, Sandia National Laboratory, Nevada Test Site, Westinghouse Hanford Company, Westinghouse Savannah River Company, and EG&G Rocky Flats will be included in the survey effort. Characterization of RSM will include a determination of metal type, the identity and quantity of radioactive contaminants, and identification of scraps by bar coding. Information will be compiled in the Metal Recycle Integrated Database.

Metal type will be determined using a field-portable x-ray fluorescence (XRF) instrument. The unit is currently in procurement and will be available for use in mid-October. It uses two radioactive sources (^{109}Cd , ^{55}Fe) to induce secondary x-ray emissions which are characteristic of each alloying element. The system is capable of discriminating closely related alloys by computer-assisted analysis of emission spectra.

Prior to procurement, a portable x-ray fluorescence was leased and tested at Montana Tech with actual scrap metal. Twelve standards were analyzed before the scrap metal was analyzed and sorted. The analysis of the standards was performed at full precision (sensitivity). The cold scrap was then analyzed in a match mode using 0.5 precision. If the scrap did not match the standard in the match mode, it was put aside for later analysis. There were about three hundred pieces of pipe ranging from 1/4" to 9" diameter, 18" to 24' long, L-bar, and flat bar (2" x 1/4" x 24'). The breakdown of the metal type located at Montana Tech is as follows: 95% SS304, 1% SS316, trace Al, trace Zr, remainder SS347.

Table 3. D&D Projections for INEL RSM

<u>SITE</u>	<u>TOTAL METAL</u>	
	<u>STAINLESS STEEL</u> (lbs.)	<u>CARBON STEEL</u> (lbs.)
Idaho Chemical Processing Plant (ICPP)		
ICPP-601	*650,000	**500,000
ICPP-666 **	600,000	300,000
ICPP-633 **	700,000	400,000
Test Reactor Area (TRA)		
Engineering Test Reactor (ETR) *	22,000,000	7,200,000
Materials Test Reactor (MTR) **	4,400,000	5,300,000
Subsurface Disposal Area (SDA) **	24,000,000	22,800,000
Argonne National Laboratory - West (ANL-W) **	35,000	25,000
Test Area North (TAN) **	30,000,000	15,000,000
Auxiliary Reactor Area (ARA) - I ***	0	0
Auxiliary Reactor Area (ARA) - II ****	0	0
Auxiliary Reactor Area (ARA) - III *****	2,500	90,500
Boiling Water Reactor (BORAX) - V *****	<u>210,000</u>	<u>514,000</u>
TOTAL	82,848,300	52,333,900

Information Sources

- * Estimate based on calculations from facilities design, P. L. Winston, WINCO Metal Recycle.
- ** Memo from Jerry L. May to Ron E. Mizia et. al. dated October 20, 1992 on Contaminated Metal at INEL.
- *** "Waste Stream Projections for Environmental Restoration at the Idaho National Engineering Laboratory", DOE/ID-10417, June 1993.
- **** "Decontamination and Decommissioning Plan for the Auxiliary Reactor Area - II", WM-ERP-92-016, Rev. 0, T. N. Thiel, May 1992.
- ***** "Characterization and Decision Analysis of the Auxiliary Reactor Area - III of the Idaho National Engineering Laboratory", PG-WM-84-011, M. R. Dolenc & J. H. Clark, February 1985.
- ***** "Decision Analysis for the Decommissioning of the BORAX-V Reactor Facility", PG-WM-84-003, D.L. Smith, August 1984.

Contamination with gamma-emitting nuclides will be determined with a field portable gamma spectrometer. The instrument is currently in procurement and will be available for use in January 1994. A Health Physics Technician will do an initial survey to determine whether or not contamination exists. The gamma spectrometer will then be used to identify the types and quantities of nuclides present.

3.4 Integrated Database For Management Of RSM

Currently, a standardized methodology for tracking and reporting RSM inventories at DOE facilities does not exist. To expedite a national DOE program for beneficial reuse of RSM, it will be necessary to know the location and type of RSM inventories that are available and will be generated to match them with product demands.

One of the FY-93 objectives of the Metal Recycle/Waste Minimization Program was to develop standardized forms for RSM field surveys that would provide sufficient data for tracking DOE RSM inventories. The forms were to be structured in a way to use and augment current field survey practices and be compatible for data entry into a multiple relational database code (scheduled for development in FY-94). Once a metal item or group of items were characterized via the survey, its disposition would be tracked via the database and a bar code identifier until it was recycled or disposed of in a burial ground or repository.

Memorandum Purchase Orders were set up with DOE contractors at WSRP, SNL, LANL, WHC, RFP, and NTS to provide field contacts and input in developing the standardized RSM survey forms. Three workshops were held with representatives from the DOE contractors and from EM-30, EM-40, EM-50, EH-20 and DOE-ID to develop the survey forms discussed below. The collaborative effort produced survey forms which are streamlined to expedite field use while still providing sufficient data for inventory tracking via an integrated database.

The proposed inventory and tracking system would be made up of four forms:

1. Scrap Metal Location/Purpose Survey Form
2. Radioactive Contamination Survey Form
3. Type Metal & Quantity Survey Form
4. Scrap Metal Change of Location/Ownership Form

From a relational database perspective, the Location/Purpose form would have several data entry fields with long character strings and require about a kilobyte of memory/record. However, the Location/Purpose form would have information common to the remaining three forms and would avoid repetition of the information for a large number of metal items. The remaining forms would require 100-300 bytes of memory per record. When the code is developed, electronic versions of the forms will expedite data entry, data verification, and data recall. The forms are discussed in detail below with the architecture of multiple relational databases in mind.

3.4.1 Scrap Metal Location/Purpose Survey Form

The Scrap Metal Location/Purpose Form is shown in Table 4. There are 28 categories of data entry which are mostly self explanatory. The data shown is fictitious and serves to illustrate the format for data entry. The Relational Record Identifier is used to assign a record identifier which specifies the DOE site, year, and a sequential number (001-999) based on the number of prior surveys that year.

The form would be filled out in one's office prior to scheduling a field survey. Normally, it is assumed that both the radiation and type metal surveys will be conducted during the same time interval with the radiation survey having priority. However, the forms and the database would be flexible enough to permit one or the other survey taking place at different times and in either sequence or for only the Type and Quantity Metal Survey being conducted (i.e., process or prior use knowledge may indicate that a radiation survey is not needed and would be so indicated in the Scrap Metal Location/Purpose Form).

Information categories of concern during the workshops were to include data entries for: 1) the sponsor and Activity Data Sheet # which paid for the survey, and 2) photographs which were made of the Area/Building/Structure where the RSM was located. It was felt that this type of information would be difficult to find years later due to possible elimination or reorganization of sponsoring organizations and removal of the Area/Building/Structure.

The form contains a hierarchy list of categories on the RSM location which includes: 1) Operations Office, 2) DOE Site, 3) Contractor, 4) DOE Site Facility, 5) Area/Building/Structure, and 6) Sections/Rooms/Grids. Finally, several data entry lines are provided to indicate the description of the Area/Building/Structure and the reason for the survey. The location refers to where the RSM is or will be stored and not from where it originates.

3.4.2 Radioactive Contamination Survey Form

The Radioactive Contamination Survey Form is show in Table 5. This form is given priority over the Type and Quantity Survey Form because of the need to know whether the latter survey will require radiation protection procedures and to separate non-radioactive from radioactive items. The Radioactive Contamination Survey Form is designed for field use application with a display of the electronic form on a portable computer and interaction with a database. By entering the Relational Record Identifier, the code would access the database and retrieve the next two entries (the DOE Site Facility and the Area/Building/Structure) to verify that the Location/Purpose form had been logged in the database.

Table 4.

SCRAP METAL LOCATION/PURPOSE SURVEY FORM
(Sample Only)

Relational Record Identifier:	INEL-93-005
Operations Office:	ID
Sponsoring DOE/HQ Office:	EM-30
Activity Data Sheet #:	ID-1504-WN
DOE Site Name:	Idaho National Engineering Laboratory
Acronym:	INEL
Contractor Name:	Westinghouse Idaho Nuclear Company
Acronym:	WINCO
Primary Contact & Phone/Fax #:	Tom R. Thomas (208) 526-3086/3499
Secondary Contact & Phone/Fax #:	
Radioactive Contamination Survey (Y/N):	Y Start Date: 6/22/93 End Date: 8/14/93
Type and Quantity Metal Survey (Y/N):	Y Start Date: 6/22/93 End Date: 8/14/93
If Radioactive Contamination Survey is Not Needed Indicate Why:	
DOE Site Facility:	Idaho Chemical Processing Plant
Acronym:	ICPP
Area/Building/ or Structure:	Temporary Storage Surplus Equipment Area
Acronym:	TSSEA
Character-Numeric Identifier:	CPP-533
Sections/Rooms/Grids:	A1, A2, A3, B1, B2, B3
Area/Building/Structure Prior/Current Use Description:	Outside storage area with gravel base. About 2.5 acres which has been used for 25 years as temporary storage for cold or slightly contaminated steel items (process vessels, machinery, pipe, and structural materials).
Photograph(s) on File (Y/N):	Y Negative #s: 4512 - 4526
Update of Prior Survey (Y/N):	Y If Y, Prior Record: INEL-90-045
Reason for Survey:	To characterize metal inventory, amount of radioactive contamination, and segregate items by categories and amount of radioactivity.
Type of Instruments Used:	
A. For Radiation Survey:	Ludlum/2A, Eberline RM-14S HP100, Canberra Nuclear Portable Plus 1150
B. For Metal Survey:	TN Technology/Metallurgist-XR Model 20

Table 5.

RADIOACTIVE CONTAMINATION SURVEY FORM
(Sample Only)

Relational Record Identifier:	INEL-93-005
DOE Site Facility:	ICPP
Area/Building/Structure:	CPP-533
Section/Room/Grid:	A1
Item or Lot Code:	17
Sequential Item or Lot #:	003
Item or Lot Bar Code:	INEL9300517003
# Items/Lot	20
Lot Containment Code:	3
Prior Use Code:	05,08 (Up to 3 choices)
Total Gross β - γ Field Survey:	
Date:	06/24/93
Technician:	A. D. Hansen
Instrument Serial #:	73925BJ
Ave. & Max. mrem/hr @ 1 cm:	1000.0 2500
Total Gross α Field Survey:	
Date:	06/25/93
Technician:	A. D. Hansen
Instrument Serial #:	467896TY
Max. dpm/100 cm ² @ 1 cm:	300000
Total γ -Scan Field Survey:	
Date:	06/30/93
Technician:	T. R. Thomasalinsky
Instrument Serial #:	TCK456CZ
Radionuclide A/Max dpm:	Cs-137 105
Radionuclide B/Max dpm:	Co-60 25
Radionuclide C/Max dpm:	Sb-125 77

3.4.2 Radioactive Contamination Survey Form

The Item or Lot Code would be selected from the first pick list shown in Table 6. This would be a pop-up screen to expedite selection and entry. The "lot option" is included so that similar items can be surveyed, grouped together, and tracked as a single item. In this sample, Code 17 corresponds to "pipe" and this is the third pipe or group of pipes (i.e., 003) to be surveyed under the record identifier INEL-93-005. The Item or Lot Code # and Sequential Item or Lot # are added to the Relational Record Identifier to provide a unique 14 character identifier which would remain with the item or "lot of items" as a bar code tag until final disposition.

A single item or groups of like items which are to remain together are both identified as a "lot" until final disposition. The number of items would be entered in # Items/Lot. In this sample, 20 pipes are grouped together. The type of containment would be selected from the Lot Containment Code in Table 6. In this sample, the pipe are in a bundle bound by bands. The prior use of the pipe would be indicated by a selection of up to three entries from the Prior Use Code shown in Table 6. In this sample, the pipes were used to transport RCRA inorganic chemicals and LLW solutions/gases/solids.

The gross β - γ , α , and γ scans are meant to be of a spot-check nature rather than 100% survey techniques. The total gross and specific radionuclide surveys are required just prior to shipment of RSM to either LLW burial grounds or to facilities which could recycle RSM. The spot check procedures would be adequate for inventory characterization and tracking and avoid repetition of the much more costly type surveys required when shipping occurs.

3.5.3 Type Metal & Quantity Survey Form

The Type Metal & Quantity Survey Form is shown in Table 7. The first nine data entries or displays (for categories recalled from the Location/Purpose and/or Radioactive Contamination Survey Forms) would be identical to the first nine categories of the Radioactive Contamination Survey form. If the categories of Item or Lot Code, Sequential Item or Lot #, Item or Lot Bar Code, # Items/Lot, Prior Use Code, and Item or Lot Bar Code had already been entered via the Radioactive Contamination Survey Form, they would be displayed in the same categories on this form to avoid duplication of effort. Otherwise one would fill in these categories using the pick lists shown in Table 6 and attach a bar code tag to the item or "lot of items".

Average dimensions and weight would be entered by lot size since the main interest is knowing bulk quantities and weights of metal for shipping, handling, and recycle and not precise dimensions of items. In this example, 20 pipe of one-inch Schedule 40 each 610 cm long are in a bundle approximately 14 by 14 cm in width and height. The lot weight is estimated from standard shapes, dimensions and weight/unit length (i.e., Code # 3 in the Weight Method Code in Table 8). The type of metal or metals would be selected from the METAL/ALLOY CODE and the method of measurement from the TYPE METAL MEASUREMENT CODE show in the pick lists on Table 8.

Table 6.

CODES FOR THE RADIOACTIVE CONTAMINATION SURVEY FORM

ITEM OR LOT CODE

CODE	ITEM	CODE	ITEM	CODE	ITEM
01	Barrel	12	Heat Exchanger	23	Scrap - one type
02	Bench	13	Hood	24	Scrap - mixture
03	Blower	14	Housing	25	Bolt/Nut
04	Box	15	Machinery	26	Flange
05	Conduit	16	Motor	27	Tank
06	Control Box	17	Pipe	28	Tool
07	Condenser	18	Pump	29	Tubing
08	Door	19	Roofing	30	Valve
09	Ductwork	20	Siding	31	Vessel
10	Electrical Device	21	Sheet	32	Wire (electrical)
11	Equipment	22	Structural Support	33	Wire/Cable/Chain

LOT CONTAINMENT CODE

CODE	CONTAINMENT	CODE	CONTAINMENT
0	Single Item	4	Contained in Barrel
1	Unconstrained Pile	5	Contained in Metal Box
2	Constrained Pile	6	Contained in Wood Box
3	Bundle Bound by Bands	7	Contained in Plastic Box

PRIOR USE CODE

CODE	PRIOR USE	CODE	PRIOR USE
01	Never used	10	TRU Solutions/Gases/Solids
02	Non-radioactive, Non-RCRA Chemicals	11	Fissile Solutions/Gases/Solids
03	Non-RCRA Inorganic Chemicals	12	Uranium Solutions/Gases/Solids
04	Non-RCRA Organic Chemicals	13	Neutron Activated
05	RCRA Inorganic Chemicals	14	Mixed LLW/RCRA Materials
06	RCRA Organic Chemicals	15	Mixed HLW/RCRA Materials
07	Tritium	16	Mixed TRU/RCRA Materials
08	LLW Solutions/Gases/Solids	17	Explosive Compounds
09	HLW Solutions/Gases/Solids	18	Unknown
		19	Not Investigated

Table 7.

TYPE METAL & QUANTITY SURVEY FORM
(Sample Only)

Relational Record Identifier:	<u>INEL-93-005</u>
DOE Site Facility:	<u>ICPP</u>
Area/Building/Structure:	<u>CPP-533</u>
Section/Room/Grid:	<u>A1</u>
Item or Lot Code:	<u>17</u>
Sequential Item or Lot #:	<u>003</u>
Item or Lot Bar Code:	<u>INEL9300517003</u>
Prior Use Code:	<u>05,08</u> (up to 3 choices)
# Items/Lot:	<u>20</u>
Lot Containment Code:	<u>3</u>
Date:	<u>06/22/93</u>
Technician:	<u>T. R. Thomasalinsky</u>
Survey Instrument Serial #:	<u>73925BJ</u>
Average Dimensions/Lot (cm):	
Width/diam:	<u>14</u>
Length:	<u>610</u>
Height:	<u>14</u>
Thickness:	<u> </u>
Weight/Lot (kg):	<u>305.00</u>
Type Metal Measurement Code:	<u>3</u>
Weight Method Code:	<u>3</u>
Main Metal/Alloy Code:	<u>GS</u>
% by wt:	<u>100</u>
Secondary Metal/Alloy Code:	<u> </u>
% by wt:	<u> </u>
Photograph Taken (Y/N):	<u>Y</u>
Negative #s:	<u>4512, 4513</u>

Table 8.

CODES FOR THE TYPE METAL & QUANTITY SURVEY FORM

WEIGHT METHOD CODE

CODE	WEIGHT METHOD
1	Estimated from Approximate Dimensions and Density
2	Estimated from Measured Dimensions and Density
3	Estimated from Standard Shapes, Dimensions, and Weight/Unit Length
4	Obtained from Records (recorded weights or standard dimensions and densities)
5	Weighed

METAL/ALLOY CODE

CODE	METAL/ALLOY	CODE	METAL/ALLOY
CS	Carbon Steel	CD	Cadmium
ZNGS	Galvanized Steel	CU	Copper
SN	Tin	CR	Chromium
304SS	304 Stainless Steel	HG	Mercury
316SS	316 Stainless Steel	NI	Nickel
ZIR	Zircaloy	PB	Lead
HA	Hastelloy	PT	Platinum
IN	Inconel/Incoloy	TI	Titanium
AL	Aluminum	ZN	Zinc
AG	Silver	ZR	Zirconium
AU	Gold	V	Vanadium
BE	Beryllium		

TYPE METAL MEASUREMENT CODE

CODE	TYPE METAL MEASUREMENT
1	Based on Visual Examination Only
2	Available from Records
3	Field X-ray Analysis
4	Laboratory Analysis of Sample

3.4.4 Scrap Metal Change of Location/Ownership Form

The Scrap Metal Change of Location/Ownership Form is shown in Table 9. This form would serve to track minor changes such as transfer of items between rooms, grids, areas, buildings, and site facilities and also serve to track major changes such as transfer among DOE sites, change of contractor ownership at DOE sites, transfer to non-DOE facilities, and transfer to the commercial sector. When transferred out of DOE control, the item would be zeroed out from the DOE integrated database inventory.

The tracking of changes would be done by adding CH1, CH2, CH3, etc. to the Item or Lot Bar Code. Since the bar code is already a unique record identifier, appending CH1, etc. to it will generate a unique Change Location/Ownership Code for each change. No change in the original Item or Lot Bar Code would be required either in the integrated database or the bar code tag on the item because a history of the changes would be accessible through the Change of Location/Ownership database. The database design would automatically subtract the inventory of the item from its previous location and add it to its current location to expedite record keeping.

The categories under LOCATION/OWNER BEFORE CHANGE would be recalled from the multiple relational databases and the data entries under the LOCATION/OWNER AFTER CHANGE would be almost identical to the format in the Scrap Metal Location/Purpose Survey Form. The minor change is the addition of Commercial Name and Commercial Facility. The reason for the change would be indicated and if the item were being shipped out, a log # for shipping given. Finally a decision would be made if the inventory should be zeroed out of the integrated database.

3.4.5 Planned FY-1994 Activities

It was the intent of the collaborative working group to produce a first draft set of forms that would contain the essential categories for tracking RSM inventories but streamlined enough to expedite the acceptance and use of the forms throughout the DOE community. If an integrated database is to be implemented within the DOE/contractor community, a simplified and uniform approach must be adopted. Since these forms represent a first cut, it is anticipated that revisions will be needed after application in the field.

To test the concepts in the proposed survey forms, the planned FY-1994 activities include development of a source code for the integrated database and electronic forms and demonstration of survey techniques and data entry in a prototype field survey. The planned field survey will involve the use of gross β - γ , gross α , γ spectroscopy, X-ray fluorescence, bar code, and portable weight scale instruments. Based on the results of the field survey, the survey forms will be modified if necessary. Although the prototype field survey will involve the use of an existing RSM storage yard, it is anticipated that the greatest potential use for the survey forms and database will be for tracking RSM generated during D&D of DOE buildings and structures.

Table 9.

SCRAP METAL CHANGE OF LOCATION/OWNERSHIP FORM
(Sample Only)

Relational Record Identifier: INEL-93-005

Item or Lot Barcode: INEL9300517003

Change Location/Ownership Code: INEL9300517003CH1

Date of Change: 06/22/94

LOCATION/OWNER BEFORE CHANGE:

DOE Site Name: Idaho National Engineering Laboratory

Contractor Name: Westinghouse Idaho Nuclear Company

Primary Contact: Tom R. Thomas

Phone/Fax Number: (208) 526-3086/3499

LOCATION/OWNER AFTER CHANGE:

DOE Site or Commercial Name: Scientific Metal Recycle of America (SMRA)

Contractor Name: Same

Primary Contract: Bob M. Keslinger

Phone/Fax Number: (208) 526-3086/3499

DOE Site or Commercial Facility: Radioactive Processing Facility

Area, Building, or Structure: Scrap Melting Recycle Building

Section/Rooms/Grids: Not Applicable

Reason for Change: SMRA purchased item for recycle into Type B
LLW burial boxes

Shipping and Material Management Log #: 75649325

Date: 06/22/94

Zero out item inventory from
Integrated Database (Y/N)? Y

4. ECONOMICS OF RECYCLE AND COST OF DISPOSAL

4.1 Cost Of Disposal By Burial

The burial cost used in this report is estimated to be approximately \$53/ft³. This was developed by taking the two operating commercial low level waste management facilities (Barnwell and Richland Washington site) base rate charge and averaging and is in accord with the cost of burial at INEL (RWMC), Westinghouse Savannah River, and Westinghouse Hanford. Burial costs for individual sites are listed in Table 10. It is conceivable for the actual cost to be four to five times greater than the base charge when membership, out of compact, and curies fees are added in with the base rate. This cost does not include size reduction, packaging, and shipping cost which are expected to remain stable. However, burial cost will escalate as land disposal restrictions become more stringent and disposal space becomes limiting.

Table 10. Burial Costs

Doe and Commercial Burial sites	Base Rate for Low Level Waste per Cubic Foot	Membership fee	Compact fee	Curie fee
Idaho National Engineering Laboratory	\$50-\$55	no	no	no
Hanford	\$58.70	no	no	no
Savannah River	\$50	no	no	no
Barnwell site	\$59	yes*	yes*	yes*
Richland Washington site	\$46.20	yes*	yes*	yes*

* Membership, compact, and curie fees can result in a substantial increase in burial cost. For example, the Barnwell site charges an out-of-compact fee of \$220 per cubic foot. Subsequent addition of curie fees can result in burial costs in excess of \$300 per cubic foot.

4.2 Cost Of Canister Fabrication Using Recycled RSM

Nuclear utilities have been forced to investigate spent fuel storage since a high-level waste repository is not yet available. One alternative is to place fuel assemblies in dry storage. Several companies have developed dry storage systems. A typical system consists of a

stainless steel storage canister and a lead-shielded transport over-pack. One such canister is approximately five feet in diameter and 15 feet long, and contains 20 tons of type 304 stainless steel. It has capacity for 24 PWR or 52 BWR fuel assemblies. The loaded canister is inserted into the shielded over-pack for transported to a concrete storage module. WINCO Metal Recycle estimates that 6,990 dry storage canisters will be used by the commercial nuclear industry over the next 20 years.

A feasibility study was initiated to determine potential cost savings when RSM disposal costs were avoided and metal was recycled for fabrication of dry storage canisters. The cost of fabrication using recycled stainless steel RSM was compared to the cost of fabrication using stainless steel purchased at free-market prices. Disposal costs were assumed to be approximately \$2,280/ton. Disposal costs for secondary wastes (radioactive slag) were considered. A profit of 8% was applied to each canister produced. The result suggests a potential savings of \$32,000 per canister at 1993 disposal and material costs. These savings will increase as disposal costs escalate.

4.3 Market Analysis Of RSM Recycling

Market evaluation of RSM reuse by the commercial nuclear industry is being conducted for WINCO Metal Recycle by the Department of Materials Science and Engineering at the Oregon Graduate Institute. The purpose of this evaluation is to predict the economic viability of RSM recycling and how a commercial marketplace might evolve.

The study has five principal objectives: 1) to perform a resource evaluation for commercial RSM, 2) to perform an evaluation of market potential for RSM reuse in storage, transport, or disposal of high-level radioactive wastes, 3) to develop a basis for evaluation of cost effectiveness in RSM recycle, 4) to prepare a business strategy for privatization of RSM recycle, and 5) to generate a time/cost breakdown for anticipated recycle activities. The scope of study is limited to restricted use of stainless steel removed from commercial nuclear facilities. The analysis assumes that a RSM recycle compact will be formed to match transient supply and demand fluctuations. The OGI market analysis is expected in October 1994.

Initial contacts with utility managers suggest that private industry is receptive to the concept of RSM recycle. However, questions have been raised concerning issues of ownership and liability. It appears that the utilities may not be willing to release direct control of their materials. Radioactive material has been transferred between NRC licensed storage and treatment facilities with the receiving party claiming to accept responsibility for future disposition. However, this may be contradictory to the "cradle to grave" responsibilities mandated by the Resource Conservation and Recovery Act (RCRA). Even without explicit liability of the radioactive waste generator, there may be another avenue of liability. Within the definition of hazardous substance used in the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), there is a category of "inherently hazardous"

substances, where liability may be applied to all parties associated with waste handling. Under strict negligence theory, a primary waste generator could be held responsible for injury if a connection could be made with exposure to radionuclides released to the environment.

5. CONCEPTS FOR RSM RECYCLE

Emphasis is placed upon recycle of stainless steel because of its high resource value and wide use in the nuclear, petroleum and chemical processing industries. However, much larger amounts of low-alloy steel will be removed from nuclear service during the next 20 years. In addition, substantial amounts of non-ferrous metals (copper, lead, aluminum) will require processing if their disposal is to be avoided.

5.1 Beneficial Reuse Of Stainless Steel

Chromium and nickel are the major alloying elements of stainless steel. Steel production is the major end use for both elements. Each has a net import reliance of approximately 80%, and each is considered strategic. Industry takes great effort to conserve chromium and nickel usage. Recycling of stainless steel scraps accounts for nearly half the chromium units used in domestic steel production. Chromium is also recovered from steelmaking baghouse dusts for economic, as well as environmental, reasons. Therefore, recycle of stainless steel removed from nuclear service would result in conservation of the nation's mineral, environmental, and economic resources.

The anticipated end-use for recycled stainless steel RSM would be fabrication of canisters for transport and storage of spent nuclear fuels and nuclear wastes. Thin-walled stainless steel vessels provide limited shielding from gamma-emitting sources. Therefore, these containers will require integral or accessory shielding materials for handling and shipping. Stainless steel transport casks incorporating poured-in-place lead shielding have been used within the DOE complex for several decades. One disadvantage of these systems is that the lead shielding would probably need to be separated from the stainless steel vessel if subsequent recycling were contemplated. NRC licenses have been issued for several stainless steel fuel storage canisters which utilize separable lead-shielded transport casks. Storage canisters and transport casks of similar design, so-called "universal" canisters, are prime candidates for use at proposed Monitored Retrievable Storage (MRS) sites.

Typical designs for universal canisters utilize a 5 by 15 foot stainless steel cylinder with a 3/4 inch wall thickness. The complete canister weighs approximately 20 tons. Internal spacers and fuel channels can account for up to 60% of total material usage. Seven thousand of these canisters may be required for storage of fuels discharged from commercial reactors between 1990 and the end of the century. This application would consume more than 140,000 tons of stainless steel. Material demand for manufacture of canisters to contain fuel controlled by DOE have not been determined.

Some low and high level nuclear wastes from the Savannah River, Hanford, West Valley, and INEL sites will be processed into glass or ceramic forms. These waste forms will be packaged in a stainless steel can which will be placed in an overpack for storage or disposal. Proposed cans for glass packaging are 24 inches in diameter, 15 feet long, and have a wall thickness of 3/8 inch. It has been estimated that 2500 to 6700 of these cans would be required during vitrification of ICPP calcines. This application would consume approximately 12,000 to 32,000 tons of stainless steel. Tens of thousands of these cans might be used during vitrification of low-level wastes at the Hanford site.

Compactors are used at several DOE sites for management of waste materials which have become contaminated with transuranic elements (TRU). The first stage of volume reduction is performed in 30 gallon stainless steel drums. The size-reduced "puck" is then placed in a 55 gallon stainless steel overpack. It has been estimated that 6,000 to 7,000 of the 30 gallon drums and 1,250 to 2,500 of the overpacks will be used at the Rocky Flats site over the next five years. This application would consume approximately 300 tons of stainless steel.

5.2 Beneficial Reuse Of Low-Alloy Iron and Steel

While recycle of high-alloy RSM is driven, in part, by the economic and strategic value of recycled alloying elements, recycle of low-alloy RSM appears to be much less favorable. However, the amount of low-alloy steel to be retired from nuclear service over the next 20 years may be ten times greater than the amount of stainless steel. Beneficial reuse of low-alloy scraps is thought to be preferable to accepting the cost of their disposal. Therefore, a simple and continuous process is required which would yield a value-added product with a ready and secure market. Two options have been considered. First, low-alloy RSM could be melted, rolled, and fabricated into carbon steel boxes for disposal of low level radioactive wastes. Alternatively, low-alloy steel scraps could be melted and cast as iron storage canisters.

A considerable fraction of the waste generated during D&D efforts will include personnel protective clothing which is usually compacted prior to disposal. Typical compaction boxes (4'x4'x6') are fabricated from 10 guage carbon steel. The INEL currently uses approximately 1000 of these boxes per year. Approximately 750 tons of recycled carbon steel would be required to meet this demand. Proposed D&D activities within the DOE complex might consume as many as one million carbon steel boxes over the next ten years. This application would result in the dissipative use of over 600,000 tons of low alloy steel.

Iron storage canisters have been developed for transport and storage of nuclear materials. The preferred material form is ductile iron, a cast iron which has spheroidal graphite inclusions in its bulk structure. These inclusions give the material properties of toughness and strength. Large cross section ductile iron castings provide more effective

shielding than thin-walled high-alloy fabrications. The castings can probably be produced with less radiation exposure than is associated with stainless steel production and fabrication. This would allow acceptance of low-alloy feedstocks with elevated surface contamination levels, or which contain contaminants that are not amenable to melt-refinement.

The choice between recycle of low-alloy RSM for steel or ductile iron production will be determined, in part, by feedstock characterization, since residual elements found detrimental in one process may be acceptable in the other. For example, copper ($\leq 0.2\%$) is a concern in rolled steel products since it is associated with "hot shortness", a tendency for alloys to tear along grain boundaries when deformed. In contrast, cast irons are commonly alloyed with copper (up to 10%) to confer corrosion and heat resistance. Similarly, many low-alloy scraps contain manganese at concentrations which are undesirable for ductile iron production ($> 0.25\%$), but would be suitable for recycle as stainless steel. High-alloy scraps which are low in manganese and sulfur are usually suitable for ductile iron production.

5.3 Beneficial Reuse Of Copper, Lead, and Aluminum

Lacking consistent and quantifiable guidance on *de minimis* release of volumetrically contaminated materials, beneficial reuse of copper, lead, and aluminum RSM is effectively restricted to reuse under DOE or NRC oversight. Nevertheless, contaminated copper and lead can be consistently decontaminated to radionuclide levels approaching pre-1942 NBS standards. Commercial processing of aluminum may prove to be much more problematic.

Copper is being investigated for use in barrier materials for geologic disposal of high level radioactive wastes (HLW). Contaminated lead would be most easily recycled as radiation shielding materials. However, since growth of the domestic nuclear industry may be severely limited, and since export of recycled RSM may be restricted, alternative domestic reuse scenarios are required. Two such options would be recycle of copper and lead RSM into underground utility cables and recycle of lead RSM into stationary batteries for government or industry use.

Aluminum has not been used extensively in the commercial nuclear industry. However, it has enjoyed wide use in research reactors, in Defense Department production reactors, in gaseous diffusion plants, and in DOE fuel storage pools. In many cases the materials were engineered for applications where only short storage periods were anticipated. Therefore, severe corrosion problems have been experienced at some facilities as defense production activities have been curtailed. It may be possible to surface decontaminate some aluminum feedstocks and process them for fabrication into relatively complex products such as sheet and tubing. However, a significant portion of these materials may be severely corroded as well as heavily contaminated.

For corroded aluminum RSM a simple and direct process of "beneficial waste minimization" would seem appropriate. Recent advances in plasma processing allows

separation of liquid metal from aluminum scraps and dross. A major byproduct is aluminum oxide, or "alumina". Either aluminum metal or alumina can be formed into an open reticulated matrix, or foam, which could be made into a canister inner-pack for storage and disposal of nuclear wastes. Either material would be an excellent impact limiter or containment matrix for neutron poisons. An aluminum matrix would be an excellent heat exchanger, while the alumina matrix would decouple any galvanic potential between the waste and waste canister.

6. CONCERNS IN PROCESSING OF RSM

6.1 Nuclear and NORM

Radionuclide contamination of metals occurs in the nuclear power, uranium enrichment and fuel reprocessing industries. In power generating facilities these result from accidental release of fission products and out-of-core deposition of elements which activate while circulating through the primary coolant loop.^{1,2,3} In fuel reprocessing facilities, they are released upon dissolution of irradiated fuel elements. With mildly oxidized steel, these contaminants appear to partition to a subsurface layer of Fe-Cr-O spinel.^{4,5} Numerous methods have been developed for surface decontamination of stainless steel. Low-alloy iron and steel may present greater difficulties, since they are likely to have greater surface corrosion. Uncorroded copper and lead are unlikely to sequester substantial amounts of contaminants. However, unique product forms, such as wire, wool, and shot, are probably not amenable to surface decontamination. Decontamination and recycle of corroded aluminum from pool storage of irradiated fuel would present a particularly difficult problem. In many cases, melt refining of molten metal may be the preferred route of decontamination.

Radionuclide contamination is not unique to the nuclear industry. Contamination with Naturally Occurring Radioactive Materials (NORM) is an increasing problem in the petroleum, phosphate, geothermal, and metals processing industries.⁶ Concern regarding NORM contamination has severely restricted recycle of metals excesses from these industries. Representatives of the American Petroleum Institute have requested DOE and EPA guidance. Criteria for recycle of NORM contaminated metals have not been established. Inclusion of NORM contaminated metals could improve the economics of RSM recycle.

6.2 Radioisotopes, RCRA, and Residuals

Elements of concern in RSM recycle are: 1) radioactive contaminants (see 6.4), 2) elements of regulatory concern which may become associated with end products or secondary waste streams, and 3) residual or "tramp" elements which compromise the performance or acceptance of a particular product.

Chromium, nickel, copper, lead, cadmium, and zinc are a concern because release to air or water can have adverse effects on human health and the environment. Chromium and

nickel are major alloying elements of stainless steel. Lead, zinc, and cadmium are commonly applied to steel to confer corrosion resistance. Dusts, vapors, and liquid wastes are generated during scrap handling, melting, and fabrication. When recovered, these wastes require recycle or disposal. Major secondary wastes associated with steelmaking are slags and refractories (≈ 3 to 8% of total charge weight), baghouse dusts ($\approx 0.2\%$), "mill scales" ($\approx 2\%$) and spent metal finishing liquids ("pickle liquors"). Baghouse dusts from stainless steelmaking commonly contain chromium (≈ 9 - 11%), nickel (≈ 2 - 4%), lead ($< 1\%$), and zinc ($\leq 5\%$). Mill scales contain similar amounts of chromium and nickel, but much lower amounts of lead and zinc ($\leq 0.1\%$, respectively). Spent pickle liquors and emission control dusts from primary production of steel are classified as RCRA Hazardous Waste in 40 CFR 261.32 (specified sources K061 and K062). Many iron foundries generate emission control dusts which fail the RCRA Toxicity Characteristic Leaching Procedure (TCLP) for lead or cadmium (40 CFR 261.24). Integrated steel producers regularly recycle mill scales and baghouse dusts to recover chromium and avoid waste disposal costs.

While recycling of secondary wastes is commonly practiced in the iron and steelmaking industries, concern has been voiced about accumulation of tramp elements or "residuals". Small amounts of boron, chromium, copper, lead, and tin can be detrimental to the physical properties of iron and steel products.⁷ Molybdenum may not be acceptable in some alloy steels (eg. ASTM 304 stainless). Studies conducted by the US Bureau of Mines have documented an increase in chromium residuals in gray and ductile irons.^{8,9} Data suggest that chromium residuals result from increased amounts of high-alloy steel in select domestic scraps. Most problems with residuals result from incomplete segregation of scraps in foundries which manufacture both iron and high-alloy steel castings. RSM will need to be rigorously selected and segregated if alloy chemistries are to be controlled.

Use of lanthanide elements by the metals processing industry may introduce residuals which will complicate analysis of recycled RSM. Rare Earth Metals (REM) are commonly added to cast iron, carbon steel, and High-strength Low-Alloy (HSLA) steel. REM "inoculation" helps control the shape of nonmetallic inclusions; improving hot and cold workability, and inhibiting hydrogen-induced cracking. "Mischmetal" (mixed metal) is the most common REM additive.¹⁰ It is an alloy of cerium (45-51%), lanthanum (23-26%), neodymium (15-19%), praseodymium (4-6%), "other" REM (1-2%), and iron (3%). Mischmetal addition is proprietary and not reported in chemical specifications. Typical addition rates are 1.5 to 2.5 pounds per ton ($\approx 0.1\%$). While REM inoculation of hot metal is inefficient, lanthanide concentrations in the final product will range from ≈ 10 to 100 ppm. Analysis of recycled RSM products by neutron activation may reveal lanthanide residuals resulting from REM additions to the original metal stock. REM residuals might be mistakenly identified as lanthanide fission products resulting from contamination with spent nuclear fuel. REM inoculated products will contain several naturally occurring radioactive isotopes [^{142}Ce (11.08% abundance), ^{138}La (0.09%), ^{144}Nd (23.80%), ^{145}Nd (8.30%)].

6.3 Airborne Health Risks

Air dispersal of environmental contaminants can occur at several stages during the metal recycle process. Of greatest concern will be aerosols generated by high temperature processes such as the cutting, melting, and casting. Of secondary concern will be mechanically generated aerosols resulting from the handling of refractories, slag, and mill scale.

Aerosols generated by iron foundries and steelworks have been well characterized.^{11,12} Analysis of these aerosols reveals two distinct classes of particles, 1) a coarse fraction with mean particle diameters greater than 10 μ m, and 2) a fine fraction with mean particle diameters less than 10 μ m.

The coarse fraction is enriched in lithophilic elements such as Na, K, Mg, Ca, Sc, La, Ce, and Eu.¹³ Coarse aerosols are generated during fluxing, pouring, and molding processes. They probably result from gas entrainment of flux, slag, and mold components. Ce, La, and Eu may be derived from molding sands or from "inoculation" with REM.¹⁴

The fine or "respirable" fraction is thought to form by explosive-oxidation of droplets ejected from the molten metal.^{15,16} These particles exhibit surface enrichment of Cr, Mn, Co, Cu, Zn, Pb, As, Sb, and Rb. Zn, Mn, Cu, and Pb are thought to volatilize and condense upon iron oxide particles. Cr, Co, As, Sb, and Rb are associated with fine oxide agglomerations which accumulate on the surface of respirable particles.

Control of particulate emissions from RSM recycling activities will present few unique problems. Control of fugitive emissions from thermal cutting for size reduction will be a major concern. Portable source collection systems may not be capable of handling the volume of fumes generated by torch cutting operations. An environmental control booth may be required for size reduction in the field. Quench dilution of furnace off-gases with facility air has proven effective for condensation of semivolatile metallic fumes.¹⁷ The resulting submicron aerosols are effectively controlled by either wet-scrubbing or dry filtration. Wet scrubbing may be required for removal of some volatiles. Dry filtration is finding greater application, since modern baghouse materials have filtration efficiencies approaching those of HEPA (High Efficiency Particulate) filters, and because dry wastes are often easier to manage than scrubber liquids and sludges. Inclusion of self-cleaning baghouse collectors should extend the service life of HEPA filters, which remain the standard for final filtration of process air at nuclear facilities.

6.4 Exposure Risks in RSM Processing and Fabrication

Isotopes of concern for feed materials and waste byproducts were reviewed by Metal Recycle. Given a feedstock generated by D&D of a commercial power reactor, it has been determined that ⁶⁰Co, ¹³⁷Cs, ¹³⁴Cs, ⁵⁵Fe, ⁵⁴Mn, ⁶³Ni, ¹²⁵Sb, and ⁶⁵Zn are the largest radiologic contributors.⁷ Secondary contributions are seen from ¹⁴C, ⁵⁷Co, ⁵⁹Ni, ^{93m}Nb, ¹⁰⁶Ru, ^{110m}Ag,

^{144}Ce , ^{241}Pu and tertiary level contributors are ^{45}Ca , ^{58}Co , ^{90}Sr , ^{154}Eu , and ^{155}Eu . To compare the levels of contribution as these isotopes decay, Figure 1 shows one curie total activity with the following assumed isotope composition: 0.27 Ci ^{60}Co , 0.54 Ci ^{55}Fe , 0.081 Ci ^{54}Mn , 0.009 Ci ^{137}Cs , (primary constituents); 0.0675 Ci ^{63}Ni , 0.00216 Ci ^{125}Sb , 0.0009 Ci ^{106}Ru , (secondary constituents); and 0.0054 Ci ^{65}Zn , 0.00351 Ci ^{154}Eu , 0.0009 Ci ^{90}Sr . The decay of short-lived nuclides rapidly reduces the contribution of cobalt-60, which is the highest energy gamma emitter. If an exposure comparison is done, it becomes apparent that activation products like cobalt deserve a large consideration in dose minimization. From Figure 1, it is seen that an order of magnitude decay of cobalt will occur in approximately 20 years. If reactor plants are maintained in SAFESTOR mothballed status for that period, it is much more possible to perform contact D&D work. The resulting metal could be easily handled in a melt facility after such a decay period. The very important subject of exposure risk will be studied in more detail in FY-94.

Figure 1

7. TECHNOLOGIES FOR DECONTAMINATION OF RSM

7.1 Surface Decontamination Of Stainless Steel¹⁸

The identification of RSM for recycle is one of the primary objectives of the WINCO Metal Recycle program. Closely related are activities associated with the identification of decontamination techniques that will allow beneficial reuse of DOE and commercial feedstocks. One application will be decontamination of stainless steel removed from the Idaho Chemical Processing Plant (ICPP) Fuel Storage Area FSA basins contain spent nuclear fuels. Fuel elements are stored under water in stainless steel racks. Additional hardware is placed to guarantee criticality control. Recently, a program of fuel reracking was initiated, and some barriers were removed from the basins. Water in the basins is monitored for radionuclide content and treated to maintain purity. Nevertheless, radionuclides are detected on stainless steel surfaces.

During the initial stages of the rerack activity, stainless steel criticality barriers were removed from the basin and sampled. Analyses detected ^{60}Co ($\leq 60 \text{ d/s/cm}^2$) and ^{137}Cs ($\leq 0.6 \text{ d/s/cm}^2$). Surface etching of the samples suggests that the samples are not volumetrically contaminated. These levels are 70 and 336 times higher than the suggested free release criteria for fixed and smearable β/γ contamination, respectively, as specified in NRC Regulatory Guide 1.86.

A wide variety of technologies have been developed for surface decontamination of RSM. These are readily divided into chemical methods, physical methods, and methods combining chemical and physical means. Chemical methods include rinsing with water, acid washing, and electropolishing. Physical methods include abrasive grit blasting, solid CO_2 blasting, high pressure water blasting, ultrasonic cleaning, and laser ablation. Combined methods couple a mechanical process with electrochemical dissolution.

7.1.1 Chemical Methods

Chemical methods include those agents which react with the contaminants, or the base metal, and effects their removal from a surface. The simplest, least corrosive, example of this technique is the use of water to remove water-soluble surface contamination. More aggressive treatments include complexants and/or acids and bases. A variety of reagents have been used for surface decontamination of stainless steels. Only acids, commercial products, metal ion solutions, and electropolishing will be discussed in detail.

7.1.1.1 Acids. Organic acids, especially citric and oxalic, are commonly used for surface decontamination of stainless steel. They are less corrosive than mineral acids, and the ease with which they can be decomposed simplifies subsequent neutralization.

A standard technique for decontamination of PWR cooling loop components involves a two step, alkaline permanganate, ammoniated citric acid (APAC) process. In the first step,

alkaline permanganate (pH 14, 60°C) is used to oxidize the contaminated surface. Subsequent treatment with a chelating acid (citric or oxalic) removes the embrittled contamination layer and prohibits redeposition of contaminants. A corrosion inhibitor is usually added to the acid wash.¹⁹ This technique has been used at the ICPP to successfully remove contamination from processing equipment and reagent lines.²⁰

The CONAP process is a proprietary permanganate process. First, the contaminated surface receives an alkaline pretreatment. Next it is oxidized with acidic potassium permanganate. The contaminants are dissolved and removed using an organic complexant. Decontamination factors greater than 10,000 have been achieved during routine decontamination activities.

Use of glycolic acid (2.5 w/o)-citric acid (2.5 w/o) mixtures for decontamination of liquid metal fast breeder reactor (LMFBR) components has been investigated at both the laboratory and pilot scale. The development of this process includes batch decontamination tests involving test material removed from the hot leg of the reactor cooling system. A maximum DF of 6.9 was achieved.²¹

A recent application of a multiple acid method is the very soft (VS) process.²² This is a two-step process. First, the surface is treated with a permanganic acid-chromic acid mixture. Next, with an oxalic acid solution. This technique has been used for decontamination of PWR, BWR and HTGR components. Mean DFs were 400 for HTGR components and 150 for BWR components.

Mineral acids are not generally used for decontamination due to corrosion problems (eg. HCl), passivation problems (eg. HNO₃), and safety concerns related to hydrogen gas generation. However, these solutions have been shown to be effective for removing surface contamination from stainless steels.²³

The aggressive reaction of chloride ions with stainless steel has been exploited for surface decontamination of stainless steel. Mixtures of HCl and hydroxylamine hydrochloride (NH₂OH·HCl) and HCl and AlCl₃ have been shown to be effective for bulk dissolution of stainless steel. Hydrochloric acid alone caused extreme pitting of the base metal.²⁴

Dilute solutions of nitric acid (0.5 to 1.0 w/o), and hydrofluoric acids (0.05 w/o), have been shown effective for surface decontamination of stainless steel for free release in Canada. These studies included development of a cation exchange system for regeneration of the decontamination solutions. Potential waste volume reductions could facilitate operation of a full-scale process. Other workers have also examined solutions of mixed acids that have shown promising results as well.^{25,26}

7.1.1.2 Commercial Products. A variety of commercial solutions are available for decontamination of stainless steel. The decontamination efficiency of sixteen of these has been compared.²⁷ Treatment with dilute oxalic acid (10%) was used as a reference standard. Test

coupons were prepared by baking an aqueous suspension of simulated Savannah River waste tank sludge onto stainless steel (type 304L). Solutions were prepared per the manufacturer's protocol. Since these reagents are proprietary, chemical compositions are not available in open literature. Descriptions of the most effective treatments are presented below.

Turco Decon 4521 and Turco Decon 4518 are oxalic acid-based solutions. Turco Decon 4306D is low in chloride and fluoride, and contains bisulfite. It does not etch stainless steel. Atomic Products Radiacwash is a noncorrosive, nonalkaline, biodegradable solution that contains no phosphate, chromate, silicate, borate, carbonate, aluminate or halide salts. It decontaminates by dissolution and complexation. Nutek 750C is a noncorrosive, biodegradable solution which is marketed as a calcium sulfate scale remover. Nutek 75C/2X is a nonacidic, biodegradable solution that dissolves inorganic coatings from stainless steel. Research Products International Lift-Away is a noncorrosive, nonacidic, biodegradable solution that contains no phosphate, chromate, borate, carbonate or halide salts.

Results show that Turco Decon 4521, Turco Decon 4518, Turco Decon 4306D, Atomic Products Radiacwash, and 10% oxalic acid had infinite DFs for removal of the simulated contamination. Nutek 75C/2X, Nutek 750C and Research Products International Lift-Away had DFs of 72, 13.7 and 8.83, respectively.

7.1.1.3 Metal Ion Reagents. Several studies have evaluated the effectiveness of metal ion reagents for removal of surface contamination.^{28,29,30,31,32} These reagents can be divided into two groups, low oxidation state (transition) metal ions (LOMI) and high oxidation state metal ions.

LOMI reagents shown effective for surface decontamination of stainless steel contain Vanadium (II) and Chromium (II). LOMI decontamination occurs because metal ions in the +2 oxidation state (II) can reduce and dissolve metal oxides without forming a particulate "crud". LOMI reagents do not attack the underlying base metal. Once reduced, contaminants readily dissolve in acidic solutions. At high pH, organic complexants can be added to increase solubility and retard redeposition of both the LOMI and contaminants.³³

Vanadium(II) picolinate has been shown effective in removing reactor boiler deposits and primary cooling loop contamination.^{34,35} V(II) is effective for removal of iron oxide deposits since the Fe(III)/Fe(II) reduction potential (0.771 v) is much more positive than the V(III)/V(II) couple (-0.255 v).³⁶ This reagent is not effective for removal of high chromium spinels since reduction of Cr(III) by V(II) is not thermodynamically favorable.

However, Cr(II) complexes (coordination compounds) have been found effective for removal of high-chromium deposits in BWR primary cooling systems. The effectiveness of this reagent is believed to be due to the stability of Cr(III) complexes, and regeneration of free Cr(II) by reaction of Cr(II) complex with Cr(III) in the contamination layer.³⁷

Cerium (IV), a "high oxidation state metal ion", has been investigated for use in decontamination of stainless steel.³⁸ Reagents prepared with sulfuric, hydrochloric, and nitric acids have proved effective. However, because of metal pitting associated with the hydrochloric reagent, only the sulfuric and nitric acid reagents have found extensive application. Effectiveness of the reagent is directly proportional to both acid and Ce(IV) concentrations. In tests using stainless steel RSM, the sulfuric acid/Ce(IV) reagent was shown to be superior to the nitric acid reagent. Decontamination factors were 460 for the sulfuric acid reagent [1.3 mM Ce(IV)/0.25 M H₂SO₄] and 4.3 for the nitric acid reagent [5 M Ce(IV)/0.5 M HNO₃].³⁹ A proprietary process has been developed which uses Ce(IV) as an active ingredient.

7.1.1.4 Gels. Gelling agents are finding increased use in chemical decontamination.⁴⁰ When used in conjunction with conventional reagents, gels increase contact time, decrease reagent usage, and decrease waste generation. Gelled reagents were used to decontaminate the cooling system (CO₂) of a French G2 reactor.⁴¹ DFs of approximately 500 were achieved using sequential alkaline (3 M NaOH) and acidic (3 M H₃PO₄/ 3 M H₂SO₄) gel treatments.

7.1.2 Electropolishing

Electropolishing has been used extensively for surface decontamination of metals. The item to be decontaminated serves as the anode of an electrolytic cell. The cell usually contains a phosphoric acid or phosphoric/sulfuric acid solution (electrolyte). A stainless steel electrode serves as the cathode. When an electric current is passed through the cell, oxidation occurs at the anode, and the metal surface is eroded or "etched". A thickness of 5 to 50 µm can be removed in a period of 3 to 30 minutes (8-12 VDC, 5-20 A/dm²). Surface contamination enters the electrolyte as the base metal is etched.

Electropolishing is quite versatile. It has been used in batch mode for disassembly of composites. It is also used for *in situ* decontamination of tools and equipment.⁴² In batch mode, the electrolyte is recirculated through an external loop where contaminants may be removed by filtration or chemical treatment.

Electropolishing is usually performed with an acidic electrolyte. However, some downstream processes, such as waste isolation or electrolyte regeneration, may require basic electrolytes. A basic electrolyte has been used for electropolishing of plutonium contaminated stainless steel. The electrolyte contained 0.052 M sodium tetraborate decahydrate, 2.35 M sodium nitrate, 0.015 M sodium oxalate, and 0.060 M sodium fluoride. Borate, added for criticality control, causes the pH to elevate (8.5-8.9). Oxalate complexes with metal ions and allows their separation by precipitation. Fluoride forms complexes with plutonium. Decontamination factors of $\approx 7 \times 10^6$ were achieved.⁴³

Electropolishing can also be performed using an alternating current.⁴⁴ An alternating current can often achieve higher DF's than standard anodic electropolishing techniques

because the surface contamination is alternately oxidized and reduced. Anodic electropolishing techniques are not effective for removal of contaminants associated with oxide coatings.

7.1.3 Physical Methods

A variety of physical methods can be used for surface decontamination of RSM. These range from simple methods, such as scrubbing with brushes, to sophisticated methods, such as abrasive "blasting", honing, and laser ablation.

Scrubbing is effective for soluble and loosely bound surface contaminations. However, more aggressive techniques are required for removal of chemically bound contaminants.

Blasting with abrasives usually involves the use of water and/or non-volatile solids. However, when contaminants are removed, they are mixed with relatively large volumes of water or inert solids. Water can be removed by evaporation. Solids are recovered and treated for reuse or disposal. Blasting with solid carbon dioxide (eg. CO₂ pellets) offers a promising alternative, since CO₂ sublimates at normal operating temperatures, leaving a small volume of dry process residuals.

Carbon dioxide blasting has been successfully applied to the removal of "soft crud" during maintenance of BWR cooling loop components. "Hard machining" is a standard method of surface decontamination. A mildly aggressive technique is used to remove hematite-containing "soft crud". "Hard crud" (magnetite) is then removed by machining. Use of vibratory finishing, brush cleaning, and high pressure water for removal of "soft crud" results in large volumes of secondary wastes. Carbon dioxide blasting was shown to be highly effective and secondary wastes were negligible.⁴⁵

Abrasive honing is well suited to decontamination of the inside surface of long pipe lengths.⁴⁶ Flex-hone ® is a set of abrasive honing stones attached to a "brush" of nylon bristles. Flex-hone ® is attached to a flexible shaft and can be rotated at up to 1800 rpm. Decontamination factors of 100 to 300 were achieved during decontamination of carbon steel and stainless steel pipes. This technique produces considerably less waste than grit blasting since the stones can be used for extended periods of time.

Laser ablation decontamination, though by no means a mature technology, does hold promise for reducing worker exposure, for minimization of secondary wastes, and for on-line monitoring of the decontamination process.⁴⁷ These advantages result from the applicability of remote operation, the absence of solvents and carriers, and the ability to monitor emissions from laser-induced high temperature plasma. Decontamination is thought to occur by vaporization of surface contaminants. Laboratory scale studies have demonstrated that a 100 watt Kerf excimer laser can remove about 1 µm of stainless steel (type 430) per pulse at

frequencies approaching 300 Hz.⁴⁸ This technique will also destroy organic coatings used to fix radionuclide contamination.

7.1.4 Combined Methods

Electrohonning is a combination of electropolishing and abrasive decontamination. This technique is best applied to large plane surfaces. Rotating abrasive cylinders serve as cathodes. Electrolyte is circulated from the cell bath to the surface of the cylinders. Acid and neutral salt electrolytes were used during development.⁴⁹ Decontamination factors were not reported.

High pressure washing has been performed with alkaline and acidic solutions. Completing agents can also be added to the wash media. Additives can clearly improve the decontamination efficiency of high pressure washing. However, they could also make waste management more difficult.

Hot oxalic acid treatment has been used in combination with ultrasonic cleaning and mechanical scrubbing.⁵⁰ This technique has been used on pipe weld specimens removed from a BWR. Decontamination factors were 7×10^4 and 1×10^5 for β - γ and α contamination, respectively.

7.1.5 Comparison of Surface Decontamination Methods

Comparison of methods for surface decontamination of stainless steel RSM should address: 1) the type and quantity of contamination present on RSM, 2) the technical sophistication of the method, 3) the acceptable level of residual contamination, 4) the volume of secondary wastes, and 5) the total cost. Technical sophistication is a major concern, since ease of operation will result in a substantial savings of time and money. Secondary waste generation will also have a substantial impact on cost.

The type and level of contamination present on RSM will determine all other criteria. Different types of contamination will require different decontamination methods and will generate different secondary wastes.

Preliminary data on the contamination associated with stainless steel removed from the ICPP fuel storage area (FSA) pools suggests that ⁶⁰Co is the primary contaminant, and that the contamination is limited to a surface layer. Most of the physical and chemical techniques considered in this section would be worth investigating. However, since it is not clear whether the contamination is "soft" or "hard", mildly abrasive methods may have limited effectiveness. Chemicals agents must be compatible with ongoing ICPP waste treatment operations, since this would result in optimal cost effectiveness.

7.2 Melt Decontamination of Iron and Steel

Pure iron is nearly as deformable as copper. Therefore, it must be alloyed to gain the strength required for engineered designs. There are two generic families of iron-based alloys, the cast irons and the steels. These are largely differentiated by their carbon and silicon contents.

Cast irons are high-carbon iron alloys. Carbon is the most important alloying element of both irons and steels. At low concentration and elevated temperature, carbon occurs in solid-solution with iron. However, at higher concentrations, and upon cooling, dissolved carbon can precipitate and form graphite inclusions. The frequency and shape of these inclusions determines the mechanical properties of cast iron. Cast iron normally contains 0.7 to 3.7% carbon and up to 14.75% silicon. Cast irons are commonly "inoculated" with magnesium or cerium to initiate precipitation of graphite spherules. Other alloying elements (eg. Mn, Si, Cr, Ni, Cu, Mo) may be added to increase strength and hardness, or to confer corrosion or heat resistance. Steels, in contrast, are low-carbon iron alloys which usually contain greater than 0.25% manganese and less than 1% silicon. The physical characteristics of steels are determined by microstructural phases which depend on chemistry and processing steps such as hot and cold working and heat treatment. Phases can be altered by adjusting the carbon concentration, by addition of phase formers or stabilizers (eg. Mn, Si, Cr, Ni, Mo), by altering the temperature, and by controlling the time allowed for phase formation. "Mild", low-alloy steels normally contain less than 0.25% carbon and less than 5% metallic alloying elements.

Several processes are commonly used for melt refining of iron and steel. Unalloyed iron normally contains carbon, silicon, manganese, phosphorus and sulfur at levels characteristic of the particular smelting process. Secondary refining for iron casting or steel production is largely concerned with adjustment of carbon equivalents [$CE = \text{total carbon} + 0.3 (\text{Si} + \text{P})$], removal of sulfur, deoxidation, control of non-metallic inclusions, and addition of alloying elements or inoculants. These processes are normally performed in a secondary vessel, such as a ladle or mold. Oxygen/argon sparging is a proven means for carbon and hydrogen removal during steel production. Desulfurization is usually achieved by addition of calcium, magnesium, or a silica-calcia-alumina slag. Deoxidation is achieved by addition of silicon or aluminum, or by vacuum degassing. Fluorspar (CaF_2) may be added to facilitate separation of oxide inclusions. In addition, inclusions can be driven to the slag layer by sparging with an inert gas. Elements such as silicon, manganese, and zinc are readily removed by oxidation. However, copper, lead, tin, cobalt, and nickel cannot be removed by oxidation since their free energies of formation are less negative than that of iron oxide. Alloying elements and inoculants can be added by direct immersion, lance injection of powders, or wire feed.

7.2.1 Melt decontamination of Low-alloy Iron and Steel.

Melt-refining of low-alloy steels for removal of radioactive contaminants has been reported by Mautz,⁵¹ Cavendish,⁵² Seitz,⁵³ Heshmatpour and Copeland,⁵⁴ and Abe *et al.*⁵⁵ In addition, anecdotal information is available concerning various melting activities conducted in Great Britain and the European nations.

Mautz summarized production-scale melting of uranium contaminated low-alloy steel. In one effort, 6000 tons of discarded ore concentrate drums and uranium processing equipment were melted in an electric arc furnace. No initial characterization was performed and no refining processes were specified. The product ingots were reported to have uranium residuals of less than 3 ppm. The resulting slag (8.5% of charge) had a mean uranium concentration of 2.12% (21,120 ppm). Assuming that all the uranium was oxidized and retained in the slag, these data suggest that the initial uranium content of the scrap was ≈ 2500 ppm. Therefore, by back calculation, it appears that an apparent DF of ≈ 830 was achieved. In a second effort, 27,000 tons of uranium hexafluoride contaminated low-alloy steel were melted in 2037 separate heats in a 10 ton electric arc furnace. Molten steel was poured at 3100°C following a four hour charge/melt cycle. No initial characterization was reported and refining processes were not specified. Nearly half (46.3%) the product ingots had uranium residuals of 0.2 ppm or less. This compares favorably with uranium residual concentrations determined for eleven pre-1942 NBS low-alloy steel standards (0.05 ± 0.06 ppm). Only 1% of the ingots had uranium residuals in excess of 2 ppm. Uranium concentrations in slag ranged from 707 to 8406 ppm. Assuming slag yields comparable to the previous melting effort (8.5%), the apparent DFs range from 416 to 4945.

Cavendish reported the results of melting 24,000 pounds of contaminated steel from the Oak Ridge Cascade Improvement Program. Six 4000 pound heats were melted in an alumina crucible using a six ton induction furnace. A calcium silicate slag was used for four of the six heats. Initial contamination levels were reported to be approximately 100 to 300 ppm for uranium, 10 to 30 ppb for ^{237}Ne , and less than 10 ppb for ^{239}Pu . The product ingots had uranium residuals of less than 1 ppm. Uranium concentrations in slag ranged from 835 to 7,200 ppm. Assuming slag yields of approximately 8.5%, apparent DFs for uranium range from 98 to 847. ^{237}Ne residuals were less than 1 ppb. ^{239}Pu residuals were less than 0.01 ppb. ^{237}Ne appeared to partition to the slag (6-85 ppb). ^{239}Pu concentration in the slag was less than 0.05 ppb. Apparent decontamination factors for ^{237}Ne and ^{239}Pu are less than 10. ^{99}Tc was found in both the metal (≤ 30 ppb) and slag (≤ 8 ppb).

Seitz reported laboratory-scale melting of low-alloy steel with chemically-defined slags which had been "spiked" with a known amount of plutonium oxide (400 ppm, final). Samples were melted using a resistance furnace (1500°C ; 1 to 2 h; helium, 400 torr), and allowed to solidify in the crucible (alumina). Calcium silicate, calcium-aluminum silicate, calcium-magnesium silicate, calcium-iron silicate, and borosilicate slags were evaluated.

Plutonium residuals in the bulk metal were less than 0.1 ppm when borosilicate slag was used. The apparent decontamination factor was ≈ 4000 . Autoradiographic analysis revealed that the residual activity was largely associated with intermetallic "defects".

Heshmatpour and Copeland studied melt-refining of low-alloy steel which had been contaminated with known amounts of uranium dioxide. Samples were melted in resistance or induction furnaces, using quartz, alumina, or zirconia crucibles. Calcium-iron oxide, calcium-aluminum oxide, calcium silicate, aluminum silicate, calcium-iron silicate, and fluoride-containing slags were evaluated. Uranium dioxide (500 ppm) was added directly to the metal or slag. The temperature was maintained at $\approx 100^\circ$ above the melting point. Samples were allowed to solidify in the crucible. Melting without slag resulted in uranium residuals of ≈ 0.52 ppm (apparent DF ≈ 1000). Uranium residuals could be reduced to less than 0.01 ppm (apparent DF $\approx 50,000$) using a slag composed of CaO (50%), Al_2O_3 (25%), SiO_2 (10%), Fe_2O_3 (5%), and CaF_2 (10%). All experiments were complicated by corrosion of the crucibles.

Abe *et al* studied melt-refining of uranium contaminated low-alloy steel. Sample ingots were surface contaminated with known amounts of uranyl nitrate and melted in an argon purged, vacuum resistance furnace (200 torr). Melts were performed in alumina crucibles. Initial experiments were performed with a calcium-aluminum silicate slag. When contamination levels were varied over a range of 9 to 900 ppm, uranium residuals remained almost constant. Uranium reached equilibrium concentrations within 10 minutes after melting. DFs increased in direct proportion to the initial contamination level. A slag basicity of 1.5 [mole ratio $CaO/SiO_2 + Al_2O_3$] was found to be optimal. Uranium residuals dropped to less than pre-contamination levels (0.005 vs 0.02 ppm; DF $\approx 10,000$) when nickel oxide was added to the slag [SiO_2 (10%), CaO(40%), Al_2O_3 (40%), NiO(10%)].

Table 11 summarizes the results of laboratory and industrial scale melt refining for removal of uranium and plutonium.

Nakamura and Fujiki⁵⁶ studied the behavior of ^{60}Co , ^{54}Mn , ^{65}Zn , ^{85}Sr , and ^{137}Cs during melt refining of low-alloy steel. Melts were performed at pilot-scale (500 lb.) using a high-frequency induction furnace. Radioisotope tracers were selected to be representative of those found on RSM removed from light water reactors. Tracers were added as solid alloy "tips". A calcium silicate slag was used (basicity 1.0). Data were reported in semi-quantitative terms. ^{60}Co and ^{54}Mn remained in the melt (≈ 90 -100% recovery). ^{85}Sr partitioned to the slag ($\approx 73\%$ recovery), as did some ^{54}Mn (not specified). ^{137}Cs reported to the baghouse dust ($\approx 77\%$ recovery).

Gomer and Lambley,⁵⁷ Lacroix and Tailliez,⁵⁸ Menon,⁵⁹ and Sappok and Rettig⁶⁰ have reported the results of melting low-alloy steel RSM removed from light water reactors. Melts were performed in electric arc or induction furnaces equipped with conventional dust collection systems. Transfer of contaminating radionuclides to ingot, slag, and baghouse dusts were reported in semi-quantitative terms.

Table 12 shows the characteristic modes of partition for 10 radionuclides. Approximately 95% of the charge weight is recovered as cast metal. The balance is recovered as slag (2-8%) or baghouse dust ($\leq 0.3\%$). Greater than 50% of the initial radionuclide activity is recovered in the melt. Approximately 99% of the ingot activity is associated with ^{60}Co . The data suggest that major radioactive contaminants can be separated into three groups. 1) elements which remain in the melt (eg. ^{54}Mn , ^{63}Ni , ^{60}Co), 2) elements which form high-temperature intermetallics in metal and slag (eg. ^{144}Ce), 3) elements which oxidize and partition to the slag (eg. ^{90}Sr , $^{235/238}\text{U}$), and 4) elements which vaporize and report to the off-gas system (eg. $^{134/137}\text{Cs}$, ^{64}Zn).

In summary, available data suggest that melt decontamination of low-alloy RSM could reduce uranium contamination to levels which approach pre-1942 reference levels. Transuranics, such as ^{239}Pu , might also be reduced to near background levels. However, activation products such as ^{60}Co , ^{55}Fe , and ^{63}Ni will remain in the melt. In the near term, this will limit melt decontamination to treatment of process and reactor components which bear relatively small amounts of these contaminants. In the long term, however, ^{137}Cs and ^{63}Ni will be the nuclides of greatest concern. ^{137}Cs could be removed from the metal by melt decontamination. ^{63}Ni should be avoided. Clearly, transfer of $^{134/137}\text{Cs}$ and ^{65}Zn to the off-gas system will complicate management of secondary wastes such as baghouse dusts and scrubber liquors.

7.3 Melt Decontamination of Stainless Steel

Stainless steels are generally defined as steels that contain 12% to 30% chromium as the principal alloying element. They are characterized as having corrosion resistance in aqueous environments due to passivity imparted by the chromium addition. The austenitic stainless steels (AISI 300 series) are the alloys normally encountered in nuclear service. These steels have an austenitic metallurgical phase structure which makes them non-hardenable by heat treatment.

A major research goal of the WINCO Metal Recycle program is the assessment and testing of technologies that will decontaminate stainless steel RSM by melting and slagging with a possible further refining step to obtain the proper chemistry and metallurgical properties. WINCO Metal Recycle has engaged Montana College of Mineral Science and Technology (Montana Tech) and Oregon Graduate Institute (OGI) to perform this research effort.

Table 11. Removal of Uranium and Plutonium from Low Alloy Steel by Melt Refining

Scale (citation)	Contaminant	Furnace	[Initial]	[Product]	[Slag]	Decontamination Factor
LS (55)	UO ₂	RES/IND	500 ppm	0.01-0.5 ppm	NT	1,000 - 50,000
LS (56)	UO ₂ (NO ₃) ₂ ·6H ₂ O	RES (Ar)	9-900 ppm	0.005 ppm	NT	≤10,000 (varied with [initial])
12 t (53)	U (NC)	IND	100-300 ppm	<1 ppm	835-7,200 ppm	>100 - 300 98 - 847 (est)
6,000 t (52)	U (NC)	EAF	ND	<3 ppm	21,120 ppm	830 (est)
27,000 t (52)	UF ₆	EAF	ND	0.2 ppm	707-8,406 ppm	416 - 4,945 (est)
LS (54)	Pu (NC)	RES (He)	400 ppm	<0.1 ppm	NT	≈4,000

Decontamination factor = [initial] ÷ [product]

(est) - estimated decontamination factor assuming complete partition to slag (5wt%)

LS - laboratory scale experiment

NC - no chemical characterization

ND - not determined

RES - resistance heating (Argon or Helium atmosphere)

IND - high-frequency induction heating

EAF - electric arc furnace

Table 12. Partition of Radionuclides in Melt Decontamination of Low-alloy Steel (adapted from Sappok and Rettig, 1992)⁶⁰

Nuclide	Metal (%)	Slag (%)	Dust (%)
55 - Fe	100	ND	ND
4 - Mn	> 90	< 10	BD
63 - Ni	90	10	ND
60 - Co	> 90	< 10	BD
144 - Ce	50	50	BD
90 - Sr	3	95	2
134/137 - Cs	BD	< 50	> 50
65 - Zn	BD	10	90
ND - not determined BD - below detection			

To start this process, a literature search was completed by Montana Tech that identified over 280 publications that dealt with the decontamination of RSM.⁶¹ The survey included information on the melting of radioactively contaminated carbon steel, stainless steel, nickel, aluminum, uranium, copper, lead, tin, zinc, and plutonium. The search identified coreless induction and electric arc furnace melting as the preferred choices for the melting and decontamination of ferrous metals. The coreless induction method was chosen as one of the melt techniques for further study in this program due to reduced off-gas (fume) emissions, better molten metal agitation, rapid heatup, and ease of application in a laboratory environment. The literature search results show that slagging decontamination of uranium and plutonium from carbon and stainless steel is an effective technology. A slag is defined as, "A nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in smelting, refining, and certain welding operations. In steelmaking operations, the slag serves to protect the molten metal from the air and extract certain impurities."⁶² It appears that slagging and volatilization will work for treatment of RSM. However, the report also concluded that optimum decontaminating slag compositions for stainless steels cannot be specified based solely on the presently available literature data. Activation products of iron, nickel, cobalt, manganese, and chromium will be retained in the ingot and will not transfer to

the slag or fume. Three slag compositions for induction melting were identified by Montana Tech for further study and optimization.

The slag optimization study will be aided by use of two thermochemistry computer calculational programs (CSIRO and OUTOKUMPO HSC). These programs will calculate high temperature, multicomponent thermodynamic equilibrium that will be used to plan experimental test melts using various slag chemistries. The experimental work will measure the partitioning of the surrogate radionuclides between the melt, slag, and vapor phases.

An area that received much study is the choice and application of proper chemical surrogates to model the expected radioactive contamination in the RSM.⁶³ The surrogate metals were chosen to imitate the chemistry of specific fission products and actinides. Cesium and Sr were chosen to imitate the chemistry of the radioisotopes of these two elements. Cerium was chosen to imitate the chemistry of U and Pu. Neodymium is present as a fission product in spent fuel and will imitate the chemistry of Am and Cm. Lanthanum was chosen as generally representative of the rare earths.

For the laboratory studies, stainless steel "master melts" with the surrogates must be made so each experiment in melt decontamination uses the same initial material. Two methods of surrogate addition have been used to make master melts from stainless steel scrap provided by WINCO.

Montana Tech encapsulated the surrogates as pure metals (Ce, La, Nd) and fluorides (Sr, Ce) in an inert gas environment in a sealed stainless steel tube. This tube was melted with other stainless steel scrap in a plasma arc furnace under an inert gas blanket. The target concentrations for the surrogates in the ingot is 0.1% by weight.

OGI has been developing a method of surrogate addition by use of a plasma spray technique. The initial development effort used lanthanum and cerium oxide powders that are co-sprayed with a stainless steel wire onto a stainless steel surface to yield a coating that is approximately 0.05 inches thick. The coating will yield an approximately 0.1% (metals basis) of each oxide in the final ingot. Further development of this technique for incorporation of all surrogates onto the test sample surface will be performed in FY-94. OGI has also prepared plasma sprayed ingots that were remelted in an induction furnace. All of these master melt ingots will be characterized for chemical composition including surrogate levels in FY-94.

OGI has started research into the use of the Electroslag Remelt process for decontamination and refining of stainless steel RSM. This process uses a consumable electrode that melts through a liquid slag and then solidifies in a water cooled mold. The high degree of reaction of the molten metal droplets and the slag makes an ingot of high metallurgical purity and homogeneity. This process is presently used for the secondary refinement of stainless steels and nickel-based superalloys. OGI has fabricated and tested a laboratory scale ESR unit. Test melts of stainless steel have been made on this unit and a full

size ESR. OGI will study the slag/metal interactions in the ESR process and compare results with the Montana Tech work with induction melting.

Another melting technique that is being considered is plasma cold hearth melting. The heat of a thermal plasma torch is used to melt the feed metal on a water cooled hearth. The molten metal then flows to the withdrawal mold. Since the process operates under a inert gas atmosphere, it has been used to cast reactive metals such as titanium and zirconium. The master melts for surrogate addition were performed with this process. The process can be used with a slag. A research program for use of this technology will be developed in FY-94.

7.4 Melt Decontamination Of Copper, Lead, and Aluminum

7.4.1 Melt Decontamination Of Copper

Copper and copper alloys are readily refined by "oxygen blowing". The low free energy of formation for cuprous oxide allows preferential oxidation of aluminum, manganese, silicon, phosphorus, iron, zinc, tin, and lead. Sulphur, arsenic, selenium, antimony, bismuth and tellurium can be removed by fluxing with sodium or potassium carbonate. Magnesium, aluminum, manganese, iron, silicon, zinc, and lead can be removed by fluxing with chlorine gas. Nickel, zinc, and tin can be removed by reduction and evaporation. One problem unique to copper refining is the formation of eutectic cuprous oxide (1065°C), which precipitates upon cooling, seriously impairing the quality of cast products. Therefore, molten copper is routinely deoxidized with phosphorus, magnesium, boron, or lithium.

Melt-refining of copper for removal of radioactive contaminants has been reported by Klevin and Harris,⁶⁴ Mautz,⁵¹ Cavendish,⁵² Heshmatpour and Copeland,⁵⁴ Abe *et al*,⁵⁵ and Sappok and Rettig.⁶⁰

Klevin melted uranium contaminated copper in magnesia or clay graphite crucibles using a high frequency induction furnace. No refining process was mentioned. Average uranium contamination of the feed metal was 1,663 ppm. The product metal had average uranium residuals of 0.37 ppm, which is comparable to a pre-1942 NBS copper standard (0.2 ppm). The apparent DF was ≈ 4495 .

Mautz summarizes data from production-scale melting of copper contaminated with uranium. In one effort, copper and copper alloy from a gaseous diffusion plant was melted in a reverberatory furnace. Pre-melt contamination values were not reported, and no refining process is mentioned. The resulting ingots had uranium residuals of 1 ppm or less. In a second effort, 100 tons of copper scrap having surface alpha activities up to 150,000 d/m/100cm² were melted in a reverberatory furnace. No refinement is mentioned. The resulting ingots had mean uranium residuals of less than 0.022 to 3.10 ppm. In most cases, the associated slags contained greater than 1000 ppm uranium.

Cavendish reported laboratory and production-scale melting of copper scraps generated by the Oak Ridge Cascade Improvement Program. Feedstocks were mechanically shredded copper cables. Contaminants were not characterized prior to melting. Melts were performed in a vacuum induction furnace using a graphite crucible and silica flux. Insulating materials were not removed for most melts, but were burned off in air at 427 to 454°C. The charge was melted and poured under vacuum. Uranium residuals in product ingots ranged from 1 to 37 ppm. Uranium partition to the slag was not reported. Some problem was experienced with silicon residuals which resulted from inclusion of insulating materials.

Heshmatpour and Copeland reported melt-refining of copper using eleven different slag compositions. Melts were performed in alumina crucibles using a resistance furnace. Uranium dioxide was added with flux to a final concentration of 500 ppm. Samples were held at 1250°C to allow separation of slag and metal. The metal product was sampled following solidification. Uranium residuals in the metal were reduced to less than 2 ppm with or without flux. Flux composition had little effect on the efficiency of decontamination (0.04 to 1.36 ppm).

Abe *et al.* reported the results of melt refining of uranium-contaminated copper using a chemically-defined slag. Sample ingots were surface contaminated with known amounts of uranyl nitrate and melted in an argon purged, vacuum resistance furnace. Melts were performed in an alumina crucible. Heating rates were programmed so that the sample reached a final temperature of 1500°C within five hours. A flux composed of SiO₂ (40%), CaO (30%), Al₂O₃ (20%), and CaF₂ (10%) was found effective for decontamination of copper. Uranium residuals in the metal were 0.075 ppm before contamination, and 0.083 after melt-refining. The apparent DF was $\approx 6,024$. Uranium residuals were nearly constant when contamination levels were varied from 9 to 900 ppm, suggesting that equilibrium conditions had been achieved. No experiments were performed without a refining slag.

Sappok and Rettig reported the results of production-scale melting of copper and copper alloys removed from nuclear power facilities. Data are limited to the behavior of gamma emitting radioisotopes. Electrical cables with an average specific activity of 15.3 Bq/g were stripped of insulation. The bare copper had an average activity of 0.05 Bq/g. Contaminating radionuclides were ⁶⁰Co (42.1%), ¹³⁷Cs (24.8%), ⁵⁵Fe (22.8%), and ⁶³Ni (10.1%). Scraps were melted in an induction furnace. No refining process was described. The final cast weight was 76% of charge weight. Less than 2% of the charge weight was collected as bag dust. Approximately 7% of the charge weight was recovered as dross. Fifteen percent of the charge weight was not accounted for. The product ingots had a specific activity less than 0.01 Bq/g, which was solely attributable to ⁶⁰Co. ⁶⁰Co and ¹³⁷Cs were found in baghouse dusts (2.5-9.2 Bq/g) and dross (0.03 Bq/g). ⁵⁵Fe and ⁶³Ni were not accounted for. Brass condenser tubes with an average specific activity of 21 Bq/g were melted as above. No refining process was described. The final cast weight was 89% of charge weight. Approximately 0.1% of the charge weight was recovered as baghouse dust. More than 10% of the charge weight was not accounted for. No slag was removed. The product ingots had an

average specific activity of 0.36 Bq/g, solely attributable to ^{60}Co . ^{137}Cs specific activities ranging from 291 to 1027 Bq/g were observed in baghouse dusts.

In sum, these data suggest that copper is readily decontaminated by melt refining. Uranium can be removed to levels approaching pre-contamination levels, and, in contrast with iron and steel, ^{60}Co activities could be reduced to levels which are significantly lower than proposed limits for free release.

7.4.2 Melt Decontamination of Lead

The low melting point of lead and lead alloys (315 to 425°C) lends itself to melt-refining and molten metal processing.

Sequential refining processes are used in commercial lead recycling. First, lead is cooled to near its freeze temperature, and copper, nickel, cobalt, and zinc are removed as an insoluble dross. Next, tin, arsenic, and antimony are oxidized and extracted with an $\text{NaOH}/\text{NaNO}_3$ flux. Silver and gold may be removed by coprecipitation with zinc. Excess zinc is removed by oxidation, chlorination or vacuum extraction. Bismuth can be removed by adding magnesium, which causes precipitation of CaMg_2Bi_2 . Final refining with an NaOH flux results in 99.99% pure lead.

This purification scheme is noteworthy, because alloying elements which are less likely to oxidize (silver, gold, bismuth), are removed by physical separation of insoluble intermetallic compounds. In most cases, these compounds are separated by gravity sedimentation. Filtration using ceramic media is finding increased use in molten metal processing.

Melt-refining of lead for removal of radioactive contaminants has been reported by Heshmatpour and Copeland⁵⁴ and Davis.⁶⁵

Heshmatpour and Copeland reported melt-refining of uranium contaminated lead using an $\text{NaOH}/\text{NaNO}_3$ flux. Melts were performed at laboratory scale using resistance or induction heating. Uranium dioxide was added to a final concentration of 500 ppm. The melt-refined lead had uranium residuals as low as 0.1 ppm. Apparent DFs ranged from ≈ 500 to 5000, with or without flux addition. Similar results were obtained with lead-tin alloys.

Davis reported pilot-scale melt-decontamination of lead. Melts were performed in a 500 lb capacity, propane-fired, refining kettle. Uncontaminated metal was "spiked" with ^{85}Sr , ^{137}Cs , and ^{60}Co to mimic the behavior of common radioactive contaminants. The metal was refined with an $\text{NaOH}/\text{NaNO}_3$ flux. Initial radiotracer concentrations were approximately 200 to 1000 pCi/g. When lead was refined at 343°C, contaminants were reduced to less than 0.2 pCi/g. DFs as high as 4700 were achieved. However, when refined at 427°C, much larger amounts of ^{137}Cs and ^{60}Co remained. This suggests that ^{137}Cs and ^{60}Co are more effectively removed at temperatures approaching the freeze point of pure lead.

Standard melt-refining processes appear to be applicable to decontamination of lead removed from nuclear facilities. Melt-refining appears capable of yielding a recycled product with residual activity substantially less than proposed free release values. Melt decontamination may be the only practical way to recycle unique lead forms such as wool, shot and cast shielding. However, this process has two major limitations. First, it will generate large volumes of alkali wastes. Second, great effort will be required to control lead vapors and semi-volatile contaminants. A large savings in cost could be realized if alkali fluxes and molten metal/gas interfaces could be minimized or eliminated from the lead recycling process.

7.4.3 Melt Decontamination of Aluminum

Aluminum recycling is complicated by the metal's propensity to oxidize. Once oxidized, aluminum metal can only be recovered by electrolytic reduction. Therefore, aluminum reprocessing makes extensive use of "cover" fluxes, which control oxidation, and "drossing" fluxes, which promote separation of oxide inclusions from the molten metal. Alkali metal halides are the major components used in fluxes for aluminum processing. Aluminum recycling is also complicated by the metal's susceptibility to hydrogen absorption in the molten state.

Lithium, calcium, and sodium are routinely removed from recycled aluminum, since they can have detrimental effects on cast integrity at concentrations as low as 20 ppm. Magnesium may also be removed to meet material specifications. Each is readily removed by introduction of chlorine or fluorine to the melt. This is most often accomplished by injection of chlorine or Freon[®] gas, or injection of a reactant powder such as AlF_3 or hexachloroethane (C_2Cl_6). In most cases, these additions are coupled with mechanical processes which optimize degassing of the molten metal.

Another approach used for commercial refining of high-grade aluminum is chemical precipitation of high melting point intermetallics, followed by fractional crystallization.⁶⁶ First, transition elements, such as titanium, vanadium, and zirconium, are precipitated as insoluble boride compounds. Next, the molten metal is fractionally crystallized, and soluble impurities are drained with the supernatant. Product crystals are then washed by directional melting of the upper-most material. Fractional crystallization effectively removes eutectoid impurities such as silicon, iron, zinc and excess boron. The remaining filter cake (≈ 30 -40%) is 99.99% pure aluminum.

Concerns over the environmental impact of halide effluents has spurred research to identify alternative aluminum processing technologies. Removal of zinc, magnesium, lithium, and cadmium by vacuum degassing has been demonstrated on an industrial scale. A salt-free process for recovery of aluminum from dross and scrap has recently been commercialized.⁶⁷ This process uses a plasma arc torch to yield free metal and refractory grade alumina.

Melt-refining of aluminum for removal of radioactive contaminants has been reported by Klevin and Harris,⁶⁴ Mautz,⁵¹ Cavendish,⁵² and Heshmatpour and Copeland.⁵⁴

Klevin melted aluminum scraps from various AEC feedstocks. The scrap was melted at 1400°C in a silicon carbide crucible using a gas-fired furnace. The ingot was solidified without dross removal, and no flux was added. Uranium residuals were not uniformly distributed within the product, showing some concentration at the ingot skin. The interior of the ingot exhibited average uranium residuals of 800 ppm, or approximately one thousand times that observed in a pre-1942 NBS standard.

Mautz summarizes production-scale melting of aluminum contaminated with uranium hexafluoride. Melts were performed in an oil-fired furnace. Initial contamination levels were not reported. Scraps were surface decontaminated prior to melting. No fluxing agents were added. Administrative selection of scrap feedstocks resulted in two groups of product, one with mean uranium residuals of approximately 200 ppm, and one with mean uranium residuals of approximately 850 ppm.

Cavendish reported laboratory-scale melting of contaminated aluminum removed from a gaseous diffusion plant. Melts were performed using an induction furnace. Drossing procedures were not specified. Characteristic contamination levels before melting were 500 to 2000 ppm uranium and 3 to 40 ppm ⁹⁹Tc. Residuals in the product metal were 300 to 500 ppm uranium and 5 to 25 ppm ⁹⁹Tc, indicating little or no decontamination associated with melting.

Heshmatpour and Copeland reported melt-refining of uranium contaminated aluminum. Studies were conducted at laboratory-scale using resistance and induction heating. Melts were contained in quartz tubes and zirconia crucibles. Uranium dioxide was added with slag to a final concentration of 500 ppm. The mixture was melted and held at 1300°C for an unspecified period of time. Slag and metal were allowed to separate and cool *in situ*. Slag/metal interactions were determined for 19 melt-refining compounds. Additives were calcium and sodium fluorides, low-melting fluoride fluxes, gas refiners (hexachloroethane), and elements which might form high-temperature intermetallic compounds (carbon, boron, sulfur, antimony, silicon). Melting without flux resulted in uranium residuals of 430 to 469 ppm, suggesting that uranium was effectively alloyed with aluminum. Fluoride fluxes were found effective in reducing uranium residuals to levels approaching those exhibited by pre-1942 NBS standards (≈1 ppm). Addition of hexachloroethane, carbon, boron, sulfur, antimony, or silicon resulted in residual uranium concentrations of 66 to 95 ppm.

Lacking information on mass balance and product characterization, the available information on melt refining of uranium contaminated aluminum is difficult to interpret. Removal of elemental uranium from molten aluminum is not thermodynamically favorable, since aluminum oxide has a lower free energy of formation than uranium dioxide

Some elemental uranium may exist in solution with aluminum at equilibrium conditions. However, since its formation energy is not highly negative, it may be possible to remove elemental uranium (drive the reaction to the left) if uranium dioxide can be physically removed from the melt. This may explain why fluoride fluxes are effective, since they are thought to "wet" oxide inclusions, and facilitate their transfer to the dross.

Several types of solid-phase inclusions occur in molten aluminum, such as borides (TiB_2 , VB_2 , ZrB_2), carbides (Al_3C_4 , TiC), nitrides (AlN), oxides (Al_2O_3 , MgO), and intermetallics (MnAl_3 , NiAl_3 , CrAl_3 , FeAl_3). Standard methods of inclusion removal, such as gravity sedimentation and dross skimming, are not always effective, since inclusions differ in shape, density and propensity to separate with the slag ("wettability"). Therefore, failure to melt-refine aluminum by addition of elements which form inclusions may indicate either an inability to combine with the contaminant, or an inability to physically separate the inclusion once it has formed.

7.5 Electrorefining Of RSM⁶⁸

Electrorefining is a preferred method for the production of high purity metals. However, it is less suited to treatment of alloys, since it can seriously alter the chemistry of the starting material. Electrorefining is accomplished by plating either the pure product or contaminant onto the cathode of an electrochemical cell.

The net chemical reaction which occurs during electrorefining can be represented by equation (1), where $\text{M}(\text{s, contaminated})$ is the contaminated metal, and $\text{M}(\text{s, pure})$ is the refined metal.

Individual reactions, which are summed to produce the net reaction, are complex and specific to the metal being refined.

Electrorefining involves the oxidation and preferential deposition of soluble metal ions. Energy to oxidize, transport, and reduce the metal is provided by an external power supply. The contaminated metal is oxidized at the anode. Metal ions are transported through an electrolyte, which is usually an aqueous or molten halide salt. Operational parameters are adjusted so that the contaminants remain in the electrolyte. Pure metal is deposited at the cathode. The cathode is made from a metal or alloy which will not react with the deposited material (eg. stainless steel), or from the pure metal itself.

Anode and cathode reactions are described by equations (2) and (3), where e^- is an electron, and M^{x+} is a metal ion of valence x .

The performance of the cell is dependent on several operational parameters, including, cell voltage, cell current, composition of the electrolyte, and purity of the starting materials. The deposition rate of purified metal is proportional to the current passing through the cell.⁶⁹ Electrorefining is usually performed in the constant current mode, allowing voltage to vary in response to changes in cell resistance. Use of this mode results in a constant deposition rate and a product of uniform purity. Use of high current usually results in codeposition of contaminants.

Metal refinement depends on the selectivity of oxidation and reduction reactions occurring at the anode and cathode. Codeposition of impurities occurs when a contaminant is as readily reduced as the desired product. Deposition voltages for a particular metal ion will vary according to the electrolyte chosen. Reduction potentials for reactions occurring in aqueous electrolytes can be calculated from tabulated electrode potentials. Reduction potentials for reactions occurring in molten salt electrolytes must be determined experimentally. The relative difference between reduction potentials for two metal ions can change markedly when the composition of a molten salt is altered. Therefore, electrolyte compositions (and cell temperatures) are chosen so that the difference between the reduction potentials of the product and contaminants is large enough to allow for efficient separation. Molten salt electrolytes are also formulated for operational ease, since viscosity and corrosiveness are important concerns.

Electrorefining has been applied to a variety of scrap recovery problems. A common application is recovery of valuable alloys from manufacturing scraps. Starting materials include machine turnings, cutting scraps, and casting skull. Among the metals commercially recovered are aluminum,⁷⁰ beryllium,⁷¹ copper,^{72,73} gold,⁷⁴ lead,⁷⁵ molybdenum,⁷⁶ nickel,⁷⁷ plutonium,⁷⁸ silver,⁷⁹ titanium,⁸⁰ uranium,⁸¹ vanadium,⁸² zirconium,^{83,84} and nickel and cobalt in alloy^{85,86}.

7.5.1 Electrorefining of Aluminum

Primary aluminum is produced using one of four electrolytic processes: the Hall-Heroult process, the Hoopes process, the Pechiney process, and the AIAG-Neuhausen process.

The Hall-Heroult process, and processes based on it, are widely used.⁸⁷ Aluminum oxide (alumina) is produced from bauxite ore by the Bayer process. The alumina is then loaded into an electrolytic cell which contains graphite electrodes. The electrolyte is molten cryolite (Na_3AlF_6) with CaF_2 (5-7%), AlF_3 (5-7%), and LiF ($\leq 7\%$). Joule heating, resulting from current passage through the electrolyte, raises the cell temperature, which is maintained at 940 to 980°C. Alumina dissolves in the molten salt and aluminum metal is deposited at the cathode.⁸⁸ Oxygen, freed by reduction of alumina, combines with the graphite anode, and exits the cell as CO_2 gas.

The Hoopes process was developed for production of high purity aluminum (>99.9%).⁸⁹ The starting material is an aluminum alloy which acts as the anode. The electrolyte is composed of sodium, aluminum, and barium fluorides, and some alumina ($\leq 7\%$). The cathode is made of graphite. As current passes through the cell, the aluminum in the anode is oxidized and passes into the electrolyte. Al^{3+} is reduced to aluminum metal at the cathode. Cell temperatures are maintained at 950 to 1000°C. Typical operating parameters are 5-7 VDC at 20kA.⁹⁰

The Pechiney and AIAG-Neuhausen processes are similar to the Hoopes process.⁹¹ The Pechiney process employs a mixed fluoride-chloride salt and operates at a temperatures of $\approx 750^\circ\text{C}$. The AIAG-Neuhausen process employs a fluoride electrolyte and operates at a temperatures of $\approx 740^\circ\text{C}$. Both furnaces are lined with magnesia brick. Advantages over the Hall-Heroult process are lower operating temperatures and higher product purity. The AIAG-Neuhausen process has the additional advantage of lower power consumption.⁹²

Laboratory-scale investigations have addressed the recycle of aluminum scrap contaminated with a variety of elements. Singleton and Sullivan⁹³ recovered 99.9% pure aluminum from electronic scraps. The starting material was $\approx 70\%$ aluminum, 20% copper. The balance (10%) was lead, tin, silver, and gold. Scraps were melted and formed into an anode. The electrolyte was composed of was BaCl_2 (60%), NaF (17%), and AlF_3 (23%).

Pemslar and coworkers⁹⁴ electrorefined an aluminum alloy containing silicon (8.08%), copper (3.17%), zinc (2.88%), iron (0.90%), nickel (0.54%), manganese (0.48%) and titanium (0.14%). The alloy was used as the anode. Molten NaAlCl_4 was used as the electrolyte. The product metal was 99.97% pure aluminum.

The primary source of aluminum RSM will be uranium enrichment cascades removed from gaseous diffusion plants. These materials will be contaminated with mercury, as well as uranium. Mercury should present few difficulties, since mercuric halides will decompose or evaporate at normal electrorefining temperatures.⁹⁵ The reduction potential for uranium in a LiCl/KCl electrolyte (700°C) is approximately -1.2 VDC.⁹⁶ Since this is significantly more positive than the $\text{Al}^{3+}/\text{Al(s)}$ couple (≈ -1.8 VDC)⁹⁷, it should be possible to separate aluminum from contaminating uranium, and deposit it on the cathode.

7.5.2 Electrorefining of Copper

Electrorefining of copper is a mature technology, and should be applicable to the separation of copper and a variety of radionuclide contaminants.

Following primary smelting, "blister" copper is cast into anodes and electrorefined. Continuous cast wire rod, made from refined copper cathode ($\approx 99.3\%$), is the predominate copper form in trade. Blister copper commonly contains zinc, nickel, selenium, and tellurium. The cell electrolyte is an aqueous sulfuric acid-copper sulfate solution. High purity copper sheets serve as the cathode. These cells generally operate at 0.2 - 0.4 VDC and

175 - 230 A/m². Cathodic deposits may be dendritic, and occlude considerable amounts of electrolyte. To limit these contaminants, electrolytic deposition is often performed with additives which eliminate most surface imperfections.^{98,99}

Copper removed from nuclear facilities is likely to be contaminated with fission products, actinides, and activation products. These would include ^{134/137}Cs, ⁹⁰Sr, ⁶³Ni, ^{235/238}U, ²⁴¹Pu, and ^{93m}Nb. The standard reduction potential for each of these metals (aqueous) is more negative than that of copper. Therefore, it should be possible to remove these contaminants from copper by electrorefining.

7.5 Electrorefining of Nickel

Electrorefining of nickel is also a mature technology. The process makes use of cell divided by a porous diaphragm. The diaphragm protects the cathode from insoluble contaminants which precipitate at the anode ("anode sludge").¹⁰⁰

Aqueous electrolyte is circulated through a treatment loop to remove soluble contaminants. The draw-off point is near the anode. The treated anolyte is returned to the cell on the cathodic side. Fe²⁺ and Cr³⁺ can be precipitated with NaOH. Precipitation and complexation could also be used to remove radionuclides. One possible electrolyte is a hydrochloric /sulfuric /boric acid mixture (pH≈1), with Ni²⁺(≈0.75 M). Anode sludge can be processed to recover valuable metals.¹⁰¹

Uranium enrichment cascades removed from gaseous diffusion plants are expected to be the major source of nickel RSM. This material would be contaminated with both mercury and uranium. Elimination of mercury should be straight forward, since the reduction potential for the Hg²⁺/Hg couple is more positive than that of Ni²⁺/Ni.¹⁰² Mercury should not migrate from the anode during electrorefining.

Surface contaminant U could be removed by a chemical treatment (or electropolishing) prior to the electrorefining process. Uranium present as volume contamination could be removed during anolyte treatment.

7.5.4 Electrorefining of Lead

Electrorefining has been investigated as a means for recycle of lead/acid batteries.¹⁰³ Anodes were formed by melt consolidation of battery wastes. The product was deposited onto lead cathodes. Major contaminants in the anodes were arsenic (≈2%) and antimony (≈4.5%). The electrolyte contained H₂SiF₆ (0.34 M) and Pb²⁺ (0.62 M). The cell was maintained at 35°C. Gelatin and calcium lignin sulfonate were added to promote growth of cathodic deposits. The cell was operated at 0.27 to 0.30 VDC and 170 A/m². The Pb²⁺ concentration remained essentially constant throughout the process. The refined product, 99.6 to 99.9% lead, was pure enough for manufacture of maintenance-free batteries.

Radionuclides found on lead removed from nuclear service will include $^{134/137}\text{Cs}$, ^{90}Sr , and ^{60}Co . Surface contaminants could be removed by electropolishing or chemical decontamination. During electrorefining, contaminants could be removed by precipitation or complexation, as described for electrorefining of nickel.

7.5.5 Conclusion

Electrorefining is a mature process for producing high purity metals. It should be a preferred technique when recovery of pure metals is contemplated.

Among the metals for which this technology has been demonstrated are those which have wide application in the nuclear industry. While removal of radioactive contaminants by electrorefining has not been demonstrated, it appears to be possible. The Hoopes, Pechiney, and AIAG-Neuhausen processes should be directly applicable to decontamination of aluminum RSM. Electrorefining could also be applied to decontamination of copper, nickel, and lead RSM.

7.6 Molten Metal Processing

Modern advances in molten metal processing offer unique opportunities to 1) improve yields from liquid metal to finished product, 2) improve the quality of cast products, and 3) improve "cleanliness" by removal of intermetallic compounds.¹⁰⁴

Continuous casting of liquid metal has become the norm in the metal processing industry.¹⁰⁵ Greater than 60% of total steel production is continuously cast. Continuously cast wire rod is the dominant trade form of copper. Continuous casting is also used in the production of aluminum and zinc wire.

In continuous casting of steel, molten metal is poured into a liquid-cooled mold, and the ingot is withdrawn as a solid "shell" forms. Hot metal yields for conventional ingot-mold casting are approximately 87%. Hot metal yields for continuous casting can be as high as 94 to 98%. Continuous casting can reduce the volume of in-house scrap returns by nearly 50%. Product quality is good to excellent. Continuous casting is feasible for small-tonnage mills, since the capital costs are low. Continuous casting and shrouding of molten metal can also decrease airborne emissions associated with conventional casting practices.

The most common cause of defects in metal castings is the presence of non-metallic inclusions. Non-metallic inclusions can be exogenous or indigenous to the melt. Exogenous inclusions are derived from slags and furnace refractories. Indigenous inclusions can result from addition of reagents for melt-refining.

Exogenous and indigenous inclusions can be removed by filtration of molten metal using open pore ceramic filters.^{106,107} Filtration can be done at the furnace or refining ladle,

or within the casting mold. Molten metal filtration can markedly improve the quality of cast aluminum, ductile iron, steel, and nickel superalloys.

In iron, the most common indigenous inclusions are sulfide "stringers" which result from "inoculation" with calcium and magnesium. Calcium and magnesium sulfides form highly stable inclusions which are readily removed by molten metal filtration.

Consideration of the free energies of formation for metal sulfides suggests that rare earth fission products (eg. ^{144}Ce) could form highly stable sulfides, which might be removed by molten metal filtration. This would provide yet another strategy for decontamination of RSM.

The advent of molten metal processing could lead to the development of slag-free refining processes which may be applicable to decontamination of RSM. Methods based on physical separation of insoluble intermetallic compounds are presently used in commercial refining of lead and aluminum. Another option would be the use of immiscible metal phases for refinement by molten metal extraction.¹⁰⁸

One possible application of molten metal extraction would be removal of ^{125}Sb from contaminated lead. Lead and aluminum are virtually immiscible in the liquid state. Molten aluminum should act as an extraction "solvent" for antimony in lead alloys. ^{125}Sb contaminants would precipitate as an Al-Sb intermetallic at 1085°C. The Al-Sb intermetallic could then be removed by molten metal filtration.

Molten metal extraction would be especially practical for recycle of non-ferrous RSM such as lead, aluminum, and zinc, where oxidation and fume control are major concerns. Extraction cells could be constructed which would allow precise control of melt atmosphere and gaseous effluents. Insoluble inclusions (eg. sulfides, borides, carbides) and intermetallic phases would be removed by molten metal filtration. Decontamination might be augmented by simultaneous electrorefining, using one metal phase as the anode, and the other as the cathode. Immiscible phases can be established between lead and aluminum, and lead and zinc. A series of molten metal extraction cells might be developed to allow simultaneous refinement of several non-ferrous RSM. Inclusion of a lead-zinc cell might provide treatment for zinc wastes generated during recycle of galvanized RSM.

7.7 Facilities Design For Melt-Decontamination Of Steel

As part of its lead support activities, WINCO Metal Recycle has subcontracted a study which will provide a conceptual design and estimate of cost for construction of a melting and rolling facility. The final report will include process flow charts, plant plan drawings, and a major equipment list. A draft design report is expected in October of 1993.

WINCO Metal Recycle has contacted the Westinghouse Science and Technology Center concerning interest in recycle of iron and steel RSM using a plasma-fired cupola. The plasma cupola generates a much smaller off-gas flow than a carbon-fired cupola. This allows recycle of fine particles such as machine turnings, mill scale, and air pollution control dusts. The use of high-temperature plasma results in complete destruction of organic contaminants (eg. oil in mill scales and machine turnings). Plasma cupola processing is currently used to recycle cast iron engine blocks and machine turnings. The plasma cupola can also process high-alloy steel.

8. TECHNOLOGY TRANSFER AND PRIVATIZATION

8.1 Industrial Contacts and Capabilities

Contacts have been made within the nuclear utility industry in an effort to estimate an annual generation rate for RSM. This metal would be a valuable addition to RSM feedstocks which may be used for storage or disposal of spent nuclear fuels. Contacts were established with:

Dairyland Power Company
Commonwealth Edison Company
Duke Power Company
Pacific Gas and Electric Company
Arizona Public Service Company
Southern California Edison Company
Tennessee Valley Authority
Long Island Lighting Company

Long Island Lighting Company had recently decommissioned one reactor. Approximately 2.5 million pounds of scrap metal was sent to Scientific Ecology Group (SEG), Oakridge, TN for disposal. The metal was melted and cast into shielding blocks. Long Island Light reported that this option had resulted in a substantial savings in cost. They also believe that liabilities associated with disposition of the RSM had been transferred to SEG. Decommissioning of two other reactors is anticipated; one at Dairyland Power, the other at Commonwealth Edison.

Contacts were made with the Institute of Scrap Recycling Industries, the American Petroleum Institute, and Ashland Exploration concerning inclusion of NORM contaminated drill pipe within the scope of WINCO Metal Recycle activities.

8.2 Technology Transfer

On April 14, 1993 and May 5, 1993, WINCO Metal Recycle placed advertisements in the Commerce Business Daily requesting expressions of interest by private industry in a

cooperative agreement for the purpose of participating in the WINCO Metal Recycle program for recycle of DOE RSM into useful products. Twenty eight private companies responded to the advertisements. All companies received an information packet which described the program and the three-phased workscope. It also included a list of possible contributions for participation in a cooperative agreement/contract. All respondents received invitations to the Metal Recycle Program Business Meeting, held on August 2, 1993.

Representatives of fourteen private companies attended the August 2 meeting. The meeting was also attended by a representative from DOE-HQ (EM-40). The meeting was called in order to solicit comments on the scope of work for demonstration of metal recycle. Major issues of discussion were: 1) the magnitude of DOE involvement (eg. provision of metal and commitment to purchasing products), 2) elements for a feasibility study, and 3) revision of scope of work for cold demonstrations of the recycle of RSM.

On August 20, 1993, WINCO Metal Recycle mailed the revised scope of work to 20 companies which had voiced continued interest. The companies were requested to:

- 1) determine which part(s) of the scope of work their company would perform or fund,
- 2) provide a cost estimate for those specific part(s) of the scope of work, and 3) indicate an initial cost sharing contribution their company would make towards accomplishing a specific part(s) of the scope of work. Companies which did not desire to participate in specific parts of the scope of work, but desired access to the results of the demonstration, were instructed to provide an indication of their cost sharing contributions. Responses have been received from represents approximately 84% of estimated development costs.

WINCO Metal Recycle has drafted a Development and Demonstration Agreement. The document has been submitted to DOE for informal review. The draft will be sent to industry participants once it has gained DOE approval. When a satisfactory draft has been negotiated, it will be submitted for formal review by DOE. Protection of proprietary information appears to be the major concern of industry participants.

Other national laboratories and private concerns have voiced interest in RSM recycle. Several of these proposals include concepts which have been disseminated by WINCO Metal Recycle (eg. the Rocky Flats and "Northwest Consortium" proposals). It appears that WINCO Metal Recycle has been successful in generating a market awareness which may lead to privatization of RSM recycle.

Appendix A Active Participants for the Recycle of Radioactive Scrap Metal

PERFORMING ORGANIZATION	ACTIVITY	FUNDING SPONSOR
Department of Energy Headquarters (DOE-HQ)	Guidelines for BRC for free release of RSM.	EH-20 Air, Water and Radiation
Savannah River Site (SRS)	Study tritium behavior during melting of stainless steel.	EM-30 DP
Westinghouse Idaho Nuclear Company, Inc. (WINCO)	Provide national EM-30 Metal Recycle Program by: 1) performing an inventory of existing RSM, 2) assessing market economics, 3) developing technology for melt refining, and 4) privatize the recycling of RSM.	EM-30
DOE-HQ	Container for DOE spent fuel from recycled RSM.	EM-37
Environmental Protection Agency (EPA), Radiation Studies	Dose modeling for BRC, RSM inventory estimate.	EM-40 IAG
Argonne National Laboratory (ANL)	Tech support for international criteria for release of RSM, develop international inventory of potential scrap metal. Provide report to IAEA.	EM-42
Battelle Northwest Laboratory	RSM (SS) plasma melt Mixed Waste IDP	EM-50 (proposed)
Energy Technology Engineering	Prepare sampling plans for stainless steel characterization and tritium measurements	EM-50
Los Alamos National Laboratory (LANL)	Recycle Demonstration Projects: - melt refining and electrorefining of RSM - RSM/ ³ H recovery/recycle - concrete decon/recycle - asbestos decon/recycle. Technology Evaluations: - assessment of thermodynamic and kinetic data for slagging decon - technology development of slagging decon - pilot scale development of slagging decon process. ³ H - Contaminated RSM: - recovery/recycle of RSM and ³ H - development of portable unit for ³ H - contaminated RSM processing	EM-50
Manufacturing Sciences Corp.	PRDA to produce SS from contaminated nickel ingots, carbon steel, and chromium.	EM-50
Martin Marietta Energy Systems Inc.	D&D Integrated Demonstration Coordinator.	EM-50
Molten Metals Technology, Inc.	PRDA to incinerate hazardous waste in a molten metal bath.	EM-50
Oak Ridge National Laboratory (ORNL)	RSM(?) structural vessels GDP	EM-50

Quadrex Corp.	Decon and Recycle of RSM: - commercial decontamination - free release of decontaminated materials	EM-50
SAIC	Utility recycle potential	EM-50
Scientific Ecology Group, Inc.	PRDA for SS boxes rebar, and mat	EM-50
Sandia National Laboratory (SNL)	Small - Scale Melting Facility: - design, construct & operate RSM melting facility - cast "type A" packages - waste into billets for disposal	EM-50 (proposed)
	Thermodynamics of Melt Processing of RSM: - kinetics of melt processing of RSM - technologies associated with RSM melt processing	EM-50
SRS	Stainless Steel Beneficial Reuse Demonstration. Melt 200 tons of stainless steel; fabricate 55 gallon drums and 100 ft ³ waste boxes.	EM-50
University of Tennessee	Stakeholder analysis of major players in RSM standard setting process.	EM-52
EG&G, Rocky Flats	Pilot Project to recycle DOE contaminated scrap metals, reuse facilities, rehire workers.	EM-60 (Proposed)
ICF, Inc.	Data for RSM recycle	EPA
Sanford Cohen Assoc.	Dose modeling for BRC, RSM inventory estimate, melt portioning study at SEG.	EPA
ANL	Waste Management Working Group, Dispositioning, Accelerator RSM	NE
Nuclear Regulatory Commission (NRC)	Recycle standards (former member, Scrap Metal Working Group)	NRC
SAIC	Establish free release criteria	NRC
Battelle, Columbus	Facility D&D @ Battelle, Columbus Facility: - decontamination of RSM for free release - re-use of D&D'd facilities - disposal of wastes at commercial facility in Utah and at govt facility @ Hanford	Unknown
Grumman Aircraft (TOKAMAK)	D&D of Tokamak Facility: - decon of RSM stainless steel (volume and surface contamination) - D&D of facility for reuse - recycling of decontaminated RSM	Unknown

Appendix B Systems Analysis: Identified Causal Loops for Metal Recycle

During FY-93, the Systems Analysis section has provided various support for the Metal Recycle Program. On July 15 and 16, System Analysis facilitated a meeting to discover the critical issues that needed to be addressed to make the Metal Recycle Program a success. In the meeting, the group agreed upon the objective for the program: *To implement full-scale contaminated metal recycle on a national basis with private companies.*

Next, everyone was asked to list the most important issues and concerns for completing this objective. These issues were then clustered into eight major categories using hexagons on a whiteboard. The categories were:

- Partnering/Marketing with industry
- Operating costs
- Market analysis
- Feedstock availability
- DOE coordinated effort
- Regulatory drivers
- Public acceptance
- Environmental compliance

We broke into small groups and identified the goals, measures of success, and key variables for each category. On the July 16, we generated a causal loop diagram (Figure 2) containing the identified cause and effect relationships for each of the measurable variables. In a relatively short period of time, the group identified the major issues to consider for success of the program and start on a system map to gain a better understanding of what needs to be done.

Several results came from the meeting. The group was able to better understand each other's point of view. Marketing with industry and public acceptance were found to be very important to the success of the program. Actions were taken to cover some of the issues that were not currently being addressed. Also, the system map generated formed a basis for a computer model to simulate a contaminated metal recycle plant to test strategies, monitor supply and demand, and estimate operating costs. Systems Analysis is currently developing this model.

Systems Analysis has also set up several seminars for Metal Recycle personnel to attend. A seminar on marketing was held on August 20 to help develop marketing skills and ideas. A seminar on environmental regulations will be held on September 8 to inform Applied Technology and Projects personnel on the purpose and applicability of regulations. The seminar will encourage up-front understanding and consideration of environmental regulations to avoid losses in time and money.

CAUSAL LOOP DIAGRAM - Issues and Interactions Influencing the Implementation of Full-Scale Recycle of Radioactive Scrap Metal by Private Industry.

s	responds same as
o	responds opposite to
$\neq$	delayed response

Figure 2.

Appendix C Radiologically Contaminated Scrap Metal Inventory

Item	Location	Contamination Level	Size	Metal Type	Weight (lbs.)	Contact
5000 gal. tanker truck	RPPSA	unknown	5000 gal.	Carbon Steel	12,000	Dave Harvey, EG&G
Rail Car	RPPSA	<0.1 mR/hr	4 - railcars	Carbon Steel	320,000	Dave Harvey, EG&G
ETR Bucket Grid & Inspection Tray	TRA North Storage Area	200 mR/hr	3'x20'x8'	Carbon Steel	3,500	Steve Keating, EG&G
ETR Canal Short Bulkhead	TRA North Storage Area	34 mR/hr	1'x5'x10'	Carbon Steel	8,000	Steve Keating, EG&G
ETR Canal Underwater Saw	TRA North Storage Area	5 mR/hr	1-4'x4'x8' box	Carbon Steel Stainless Steel	4,500	Steve Keating, EG&G
ETR Canal Underwater Saw Table	TRA North Storage Area	150 mR/hr	2-4'x4'x8' boxes	Carbon Steel Stainless Steel	8,000	Steve Keating, EG&G
ETR Reactor Work Platform	TRA North Storage Area	1 mR/hr	12'x12'x8'	Stainless Steel	1,200	Tom Wheeler, EG&G
#1 ETR Tank	TRA Tank Yard	1 mR/hr	1500 gallons	Carbon Steel	2,000	Steve Keating, EG&G
#2 ETR Tank	TRA Tank Yard	1 mR/hr	1500 gallons	Carbon Steel	2,000	Steve Keating, EG&G
Filter Housing	TRA Tank Yard	1 mR/hr	1-4'x4'x8' box	Carbon Steel	3,500	Steve Keating, EG&G

Ping Stack Monitor	RWMC Cargo Container	15000 dpm internal	1.5'x3'x4'	Carbon Steel	500	Keith Branter, EG&G
NCE Cam	RWMC Cargo Container	1600 dpm	1.5'x3'x4'	Carbon Steel	500	Keith Branter, EG&G
Freon Unit Cleaner	PER 635	1000 dpm	6'x5'x5'	Stainless Steel & Carbon Steel	1,500	Keith Branter, EG&G
Cask & Dolly ARA (White Elephant)	ARA-I	3000 dpm 0.5 mR/hr	4'x4'x5'	Lead and Cast Iron	12,000	Tom Thiel, EG&G
ARA-III Milling Machine	ARA-III	unknown	4'x4'x10'	Carbon Steel and Cast Iron	6,000	Tom Thiel, EG&G
Piping	ARA-III	1500 dpm 1.5 mR/hr	1- 6"x10' 2-4"x20'	Stainless Steel	620	Tom Thiel, EG&G
Panel for Ultrasonic	TAN 647	unknown	1-4'x4'x8' box	Carbon Steel	6,000	Dave Harvey, EG&G
Master Slaves	TAN 647	<0.1 mR/hr	6-6'x3'	Stainless Steel Aluminum & Lead	6,000	Dave Harvey, EG&G
Scanner	TAN 647	<0.1 mR/hr	1-4'x4'x8' box	unknown	2,000	Dave Harvey, EG&G
Lathe	TAN 647	5 mR/hr	3-4'x4'x8' boxes	Carbon Steel & Cast Iron	18,000	Dave Harvey, EG&G
Turntable & Rail	TAN 647	5 mR/hr	449 sq. ft.	Stainless Steel	300,000	Dave Harvey, EG&G
Turntable & Rail	TAN 647	5 mR/hr	819 sq. ft.	Stainless Steel	300,000	Dave Harvey, EG&G
Frame, HEPA Bank	TAN 647	<0.1 mR/hr	2-4'x4'x8' boxes	Stainless Steel	6,000	Dave Harvey, EG&G

Concrete, Rollers	TAN 647	<0.1 mR/hr	2-4'x4'x8' boxes	Stainless Steel	12,000	Dave Harvey, EG&G
TC Lead Support	TAN 647	<0.1 mR/hr	1-4'x4'x8' box	Stainless Steel	3,000	Dave Harvey, EG&G
Funnel & Resin	TAN 647	<0.3 mR/hr	1-4'x4'x8' box	Stainless Steel	3,000	Dave Harvey, EG&G
Glove Box	TAN 647	<0.1 mR/hr	4'x4'x8'	Stainless Steel & Lead	42,250	Dave Harvey, EG&G
Silo Shield Plug	TAN 647	<0.1 mR/hr	4-1'x1'x15' boxes	Stainless Steel	12,000	Dave Harvey, EG&G
Barrels Steel Shot	TAN 647	<0.1 mR/hr	2-55 gal. drums	Carbon Steel	2,000	Dave Harvey, EG&G
Filters, Ses Mat	TAN 647	0.6 mR/hr	1-4'x4'x8' box	Stainless Steel	2,000	Dave Harvey, EG&G
Spreader Bar	TAN 647	<0.1 mR/hr	16 sq. ft.	Carbon Steel	1,000	Dave Harvey, EG&G
Decon Pump	TAN 647	<0.1 mR/hr	20 sq. ft.	Carbon Steel	2,000	Dave Harvey, EG&G
TMI Equipment	TAN 647	0.5 mR/hr	1'x1'x15'	Stainless Steel	1,000	Dave Harvey, EG&G
TMI Misc. Equip.	TAN 647	<0.1 mR/hr	1-4'x4'x8' box	Stainless Steel	565	Dave Harvey, EG&G
Shield View Win	TAN 647	<0.1 mR/hr	4'x4'x4'	Glass & Lead	1,000	Dave Harvey, EG&G
Acid Fume Hood	TAN 647	12 mR/hr	1-4'x4'x8' box	Stainless Steel	3,000	Dave Harvey, EG&G
Oman Motor Housing	TAN 647	2200 cpm fixed	3'x3'x3'	Carbon Steel	500	Dave Harvey, EG&G
Window	TAN 647	<0.1 mR/hr	4'x4'x4'	Glass & Lead	1,000	Dave Harvey, EG&G
Window "P"	TAN 647	0.2 mR/hr internal	4'x4'x4'	Glass & Lead	1,000	Dave Harvey, EG&G

Loft Control Fixture	TAN 647	<0.1 mR/hr	4'x4'x4'	Stainless Steel	500	Dave Harvey, EG&G
Filter Silver Zeolite	TAN 647	0.3 mR/hr	1-4'x4'x8' box	Stainless Steel	2,000	Dave Harvey, EG&G
Periscopes	TAN 647	0.3 mR/hr	2'x2'x12'	Stainless Steel	1,000	Dave Harvey, EG&G
Go/No-Go Gauge	TAN 647	<0.1 mR/hr	1'x1'x15'	Stainless Steel	300	Dave Harvey, EG&G
Misc. Savannah Material (fuel transfer equipment, wire rope, lift fixture, 2 rings, 2 bands)	TAN 647	<0.1 mR/hr	various sizes	Stainless Steel	300,000	Dave Harvey, EG&G
Cask HS #353	TAN 647	195 mR/hr	26.25" dia. x 31.25" high	Stainless Steel, Carbon Steel & Lead	5,700	Dave Harvey, EG&G
Cask PP #3	TAN 647	1.0 mR/hr	9.75" dia. x 12.75" high	Stainless Steel, Carbon Steel & Lead	330	Dave Harvey, EG&G
Cask HS #301	TAN 647	1.5 mR/hr	20.5" dia. x 27.0" high	Stainless Steel, Carbon Steel & Lead	3,150	Dave Harvey, EG&G
Cask XMTR #12	TAN 647	200 mR/hr	12.75" dia. x 25.0" high	Stainless Steel, Carbon Steel & Lead	1,100	Dave Harvey, EG&G
Cask PP #5	TAN 647	0.2 mR/hr	9.75" dia. x 12.75" high	Stainless Steel, Carbon Steel & Lead	330	Dave Harvey, EG&G

Cask TRA-085	TAN 647	0.1 mR/hr	24.0" dia. x 32.0" high	Stainless Steel, Carbon Steel & Lead	6,000	Dave Harvey, EG&G
Cask LOFT Downcomer	TAN 647	5 mR/hr	20.0" dia. x 286.0" long	Stainless Steel, Carbon Steel & Lead	24,000	Dave Harvey, EG&G
Cask HS #309	TAN 647	4 mR/hr	20.0" dia. x 27.25" high	Stainless Steel, Carbon Steel & Lead	3,020	Dave Harvey, EG&G
Cask HS #154	TAN 647	2.0 mR/hr	18.0" dia. x 32.5" high	Stainless Steel, Carbon Steel & Lead	2,500	Dave Harvey, EG&G
Cask HS #151	TAN 647	4 mR/hr	18.0" dia. x 32.5" high	Stainless Steel, Carbon Steel & Lead	2,500	Dave Harvey, EG&G
Cask PBF 001	TAN 647	51 mR/hr	47" l. x 25" w. x 41" high	Stainless Steel, Carbon Steel & Lead	17,100	Dave Harvey, EG&G
Cask PBF 002	TAN 647	1.5 mR/hr	47" l. x 25" w. x 41" high	Stainless Steel, Carbon Steel & Lead	17,100	Dave Harvey, EG&G
Cask TRA 074	TAN 647	50 mR/hr	27.0" dia. x 65.0" high	Stainless Steel, Carbon Steel & Lead	1,800	Dave Harvey, EG&G

Cask HS #352	TAN 647	6 mR/hr	26.25" dia. x 31.25" high	Stainless Steel, Carbon Steel & Lead	5,900	Dave Harvey, EG&G
Cask HS #153	TAN 647	20 mR/hr	18.0" dia. x 32.5" high	Stainless Steel, Carbon Steel & Lead	2,500	Dave Harvey, EG&G
Cask TRA 078	TAN 647	0.5 mR/hr	60.25 gal.	Stainless Steel, Carbon Steel & Lead	2,980	Dave Harvey, EG&G
Cask HS #351	TAN 647	1,500 mR/hr	26.25" dia. x 31.25" high	Stainless Steel, Carbon Steel & Lead	5,900	Dave Harvey, EG&G
Cask HS #202	TAN 647	0.1 mR/hr	16.75" dia. x 20.5" high	Stainless Steel, Carbon Steel & Lead	1,800	Dave Harvey, EG&G
Cask TRA 089	TAN 647	0.5 mR/hr	33.0" dia. x 36.0" high	Stainless Steel, Carbon Steel & Lead	2,000	Dave Harvey, EG&G
Cask PP #2	TAN 647	5 mR/hr	9.75" dia. x 12.75" high	Stainless Steel, Carbon Steel & Lead	330	Dave Harvey, EG&G
Cask HCA 001	TAN 647	0.5 mR/hr	26.0" dia. x 51.0" high	Stainless Steel, Carbon Steel & Lead	9,000	Dave Harvey, EG&G

Cask TRA 077	TAN 647	1 mR/hr	11.0" dia. x 14.5" high	Stainless Steel, Carbon Steel & Lead	500	Dave Harvey, EG&G
Cask TRA 094	TAM 647	0.5 mR/hr	26.0" dia. x 62.5" high	Stainless Steel, Carbon Steel & Lead	14,200	Dave Harvey, EG&G
Cask PP #4	TAN 647	5 mR/hr	9.75" dia. x 12.75" high	Stainless Steel, Carbon Steel & Lead	330	Dave Harvey, EG&G
Cask Round	TAN 647	0.2 mR/hr	24.0" dia.	Stainless Steel, Carbon Steel & Lead	3,000	Dave Harvey, EG&G
Cask TRA 093	TAN 647	1 mR/hr	41.0" dia. x 63.0" high	Stainless Steel, Carbon Steel & Lead	22,000	Dave Harvey, EG&G
Cask TRA 099	TAN 647	0.5 mR/hr	24.0" dia. x 57.0" high	Stainless Steel, Carbon Steel & Lead	10,000	Dave Harvey, EG&G
Cask XMTR #5	TAN 647	0.5 mR/hr	12.75" dia. x 25.0" high	Stainless Steel, Carbon Steel & Lead	1,100	Dave Harvey, EG&G
Cask PBF 003	TAN 647	35 mR/hr	47" l. x 25" w. x 41" high	Stainless Steel, Carbon Steel & Lead	12,400	Dave Harvey, EG&G

Cask PBF 004	TAN 647	150 mR/hr	43" l. x 23" w. x 45" high	Stainless Steel, Carbon Steel & Lead	15,300	Dave Harvey, EG&G
Cask TRA 076	TAN 647	7 mR/hr	33.0" dia. x 83.0" high	Stainless Steel, Carbon Steel & Lead	28,000	Dave Harvey, EG&G
Cask HS #705	TAN 647	3 mR/hr	14" dia. x 25.875" high	Stainless Steel, Carbon Steel & Lead	1,800	Dave Harvey, EG&G
Cask PBF 005	TAN 647	unknown	27" l. x 19" w. x 30" high	Stainless Steel, Carbon Steel & Lead	4,250	Dave Harvey, EG&G
Cask HS #101	TAN 647	5 mR/hr	20.0" dia. x 47.1" long	Stainless Steel, Carbon Steel & Lead	5,851	Dave Harvey, EG&G
Cask TRA 100	TAN 647	0.3 mR/hr	28.0" dia. x 48.0" high	Stainless Steel, Carbon Steel & Lead	53,000	Dave Harvey, EG&G
Cask HS #308	TAN 647	500 mR/hr	20.0" dia. x 27.25" high	Stainless Steel, Carbon Steel & Lead	3,000	Dave Harvey, EG&G
Cask HS #104	TAN 647	0.5 mR/hr	20.0" dia x 48.5" high	Stainless Steel, Carbon Steel & Lead	5,300	Dave Harvey, EG&G

Cask HS #102	TAN 647	5 mR/hr	20.0" dia. x 47.1" long	Stainless Steel, Carbon Steel & Lead	5,620	Dave Harvey, EG&G
Cask AEC 720-1404	TAN 647	0.1 mR/hr	14.0" dia. x 45.0" high	Stainless Steel, Carbon Steel & Lead	1,200	Dave Harvey, EG&G
Cask CFA	TAN 647	2 mR/hr	28.0" dia. x 72.0" high	Stainless Steel, Carbon Steel & Lead	14,000	Dave Harvey, EG&G
Cask TRA DD1	TAN 647	70 mR/hr	216 cubic feet	Stainless Steel, Carbon Steel & Lead	2,500	Dave Harvey, EG&G
Cask TRA ATR 1 TX-4	TAN 647	800 mR/hr	80.5 cubic feet	Stainless Steel, Carbon Steel & Lead	1,200	Dave Harvey, EG&G
Cask TRA ETR Z TX-4	TAN 647	50 mR/hr	80.5 cubic feet	Stainless Steel, Carbon Steel & Lead	1,200	Dave Harvey, EG&G
Cask TRA ETR X TX-4	TAN 647	50 mR/hr	80.5 cubic feet	Stainless Steel, Carbon Steel & Lead	1,200	Dave Harvey, EG&G
Cask TRA ETR Y TX-4	TAN 647	175 mR/hr	80.5 cubic feet	Stainless Steel, Carbon Steel & Lead	1,200	Dave Harvey, EG&G

Cask ETR 1	TAN 647	6 mR/hr	42.0" dia. x 56.0" high	Stainless Steel, Carbon Steel & Lead	45,000	Dave Harvey, EG&G
Cask ETR 4	TAN 647	0.1 mR/hr	21.0" dia. x 94.0" high	Stainless Steel, Carbon Steel & Lead	30,000	Dave Harvey, EG&G
Cask ETR 3	TAN 647	30 mR/hr	42.0" dia. x 56.0" high	Stainless Steel, Carbon Steel & Lead	45,000	Dave Harvey, EG&G
	TAN 647	4 mR/hr	42.0" dia. x 56.0" high	Stainless Steel, Carbon Steel & Lead	45,000	Dave Harvey, EG&G
Cask FMRIC	TAN 647	0.1 mR/hr	1107.57 gal.	Stainless Steel, Carbon Steel & Lead	65,000	Dave Harvey, EG&G
Cask TSC 1A	TAN 647	0.1 mR/hr	111.0" dia. x 135.0" high	Stainless Steel, Carbon Steel & Lead	92,000	Dave Harvey, EG&G
Cask TSC 1C	TAN 647	0.1 mR/hr	111.0" dia. x 135.0" high	Stainless Steel, Carbon Steel & Lead	92,700	Dave Harvey, EG&G
Cask TRA 075	TAN 647	0.5 mR/hr	24" dia. x 28" w. x 144" l.	Stainless Steel, Carbon Steel & Lead	20,000	Dave Harvey, EG&G

Cask TRA 079	TAN 647	0.3 mR/hr	396.43 gal.	Stainless Steel, Carbon Steel & Lead	58,000	Dave Harvey, EG&G
Cask CFA	TAN 647	2 mR/hr	unknown	Stainless Steel, Carbon Steel & Lead	2,300	Dave Harvey, EG&G
				Total	2,233,126	

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