Summary of NCRP Report No. 141: Managing Potentially Radioactive Scrap Metal

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ABSTRACT

The National Council on Radiation Protection and Measurements (NCRP) recently published Report No. 141, *Managing Potentially Radioactive Scrap Metal*. The Report was prepared by NCRP Scientific Committee 87-4 after it concluded its 4 y deliberation on the subject of the disposition of potentially radioactive scrap metal (PRSM). PRSM has become an issue of social contention in the past few years. The objective of NCRP Report No. 141 is to provide guidance on the disposition approach and on the important radiation protection issues that are associated with the approach. Although the focus of the Report is on radiation protection, it also identifies other critical areas, such as cost and public perception. On the basis of its review and evaluation of the above areas as well as related factors, the Report concludes with five major findings on managing PRSM. First, the large quantities of PRSM generated in the United States from operations involving both man-made and naturally occurring radionuclides require a comprehensive management approach. Second, existing national guidance on pollution prevention forms a sound basis for PRSM management. Third, the current regulatory system lacks a comprehensive spectrum of viable disposition options. Fourth, there is an urgency to establish consistent national and international policies and standards. And fifth, concerns of the metal industry and public must be adequately addressed in developing policies and implementing standards. In accord with these findings, the Report also concludes with the following eight recommendations: (1) comprehensive and consistent national and international risk-based policies for managing PRSM need to be developed, (2) a set of uniform clearance standards to address national and international concerns needs to be developed, (3) the standards should include naturally occurring radioactive material (NORM) and technologically enhanced NORM (TENORM), (4) regulatory control over orphan sources must be improved, (5) the processes of clearance and intervention/interception should be harmonized, (6) the use of a licensed mill/brokerage as a “clearinghouse” for recycling should be encouraged, (7) new technologies and/or plant designs to reduce metal contamination should be developed, and (8) steps should be taken to enhance public understanding of the clearance process.

BACKGROUND

During World War II and the years that followed, numerous facilities were built in the United States and other parts of the world to develop nuclear weapons in support of military operations. This operations network includes the processes by which uranium is mined and extracted from ores, enriched, fabricated into nuclear fuel, fissioned in a nuclear reactor, removed, and reprocessed to recover the fissile components. After the war, it was recognized that nuclear energy and radioactive materials had many peacetime applications as well. Those applications include the use of nuclear energy to generate electricity and the use of radioactive materials in medicine, industry, research and agriculture. The network of operations developed to support nuclear applications, commonly referred to as the “nuclear fuel cycle,” primarily required the creation of numerous additional commercial and military defense facilities throughout the United States. Regulation of these facilities is covered under the Atomic Energy Act (AEA) of 1954 (Public Law [P.L.] P.L. 83-703, codified as amended 42 U.S.C. 2011-2297) and its subsequent amendments. AEA does not, however, govern activities that primarily involve contact with naturally occurring radioactive material (NORM), particularly technologically enhanced NORM (TENORM), as exemplified by industrial activities involving petroleum or phosphorous extraction. Nor are activities associated with operation of non-U.S. Department of Energy (DOE) particle accelerators covered by the AEA. Accelerator-produced radioactive materials (ARM), together with NORM, are usually referred to as NARM. NARM is not regulated by the U.S. Nuclear Regulatory Commission (NRC), but by individual states.

Quantities of metals will be generated primarily by decommissioning components used in the basic structure of the facilities that have been regulated by either AEA provisions or otherwise, maintaining the functionality and safety of support systems, and serving other purposes of the facility. Other sources of the scrap metal may be equipment, instruments, and scientific or engineering devices. The metals involved will include aluminum, copper, iron, steel, lead, nickel, stainless steel, zirconium, and other types of metals, including precious metals, with the specific types depending on the nature of the facility.

In light of the massive cleanup effort that is taking place at the nation’s nuclear weapons complex and related activities elsewhere, the National Council on Radiation Protection and Measurements (NCRP) established Scientific Committee (SC) 87-4 (under the NCRP Scientific Area of Waste and Mixed Waste) to address radiation protection issues associated with scrap metals that are expected to be recovered from such cleanup efforts. SC 87-4 began its deliberation in 1998 and concluded with a publication that was issued as NCRP Report No. 141, *Managing Potentially Radioactive Scrap Metal* (NCRP, 2002).

Disposition management

Developing a systematic approach to managing the disposition of potentially radioactive scrap metal (PRSM) is a challenging task in today’s regulatory environment. Although current regulations for the disposal of various types of well-characterized radioactive waste are firmly established, the provisions are not adequately formulated to address comprehensive disposition options for materials that do not fall within existing regulatory confines. In particular, the current regulatory system does not provide systematic options for releasing materials containing either very small amounts of contaminants or no contamination at all. Although there are provisions for *exempting* particular radioactive materials or categories from regulatory control, the threshold or other basis for *releasing* such materials has not been consistently or clearly specified. In the absence of clear standards and a systematic approach, PRSM and similar waste streams may be classified as radioactive waste, regardless of their actual content of radioactive material. The lack of a full range of options for such materials severely constrains facility operators in effectively managing the disposition of PRSM.

POTENTIALLY RADIOACTIVE SCRAP METAL

Since only a portion of the scrap metal will have been in contact with or in proximity to radioactive materials, it is expected that much of it will be free of contamination. Nonetheless, because it will have originated through the dismantlement of facilities that were associated with the use or processing of radioactive materials, it is referred to in this Report as “potentially radioactive scrap metal” (PRSM). In general, PRSM includes all suspect or contaminated metal within a facility, if it cannot be otherwise classified under existing laws or regulations.

Source and inventory

Estimating the inventory of PRSM is a rather challenging task. First, a systematic method of estimating the scrap metal inventory does not exist. Second, reporting on the scrap metal inventory has been sparse and has not been systemized for decommissioning activities. Third, very few comprehensive studies exist since “complexwide” decommissioning experience is so limited. Therefore, PRSM inventory information relies primarily on the following sources: (1) existing radioactive metal inventory studies, (2) estimates from ongoing decontamination and decommissioning projects, and (3) projections of future decontamination and decommissioning projects.

The amounts and types of scrap metal resulting from the decommissioning of the nation’s nuclear power plants [a total of 103 commercial power plants are currently operating (ANS, 2002)] depend primarily on the reactor type (pressurized water reactor or boiling water reactor). Appropriate scaling factors were used to adjust for different power ratings of the plant (EPA, 2001; NEI, 1991; 1993; Nieves *et al*., 1995) from inventories estimated for some reference plants (Bryan and Dudley, 1974).

Estimating the DOE inventory presents a particular difficulty. Unlike commercial power plants that share common design features, DOE weapons facilities encompass a wide spectrum of nuclear fuel-cycle operation capabilities; often, individual facilities were custom designed and built to serve a particular mission. Recent evaluations (DOE, 2001; EPA, 2001; Gresalfi, 1997; Hertzler *et al*., 1993; Lilly *et al*., 1992; Nieves *et al*., 1995) project that DOE’s PRSM inventory ranges from about 1 to 1.5 million metric tons (MT). Figures on DOE’s PRSM inventory are evolving and improving as better information becomes available.

Outside the nuclear industry, approximately one-third (*i.e*., three million metric tons) of the total PRSM inventory results primarily from industrial activities involving NORM or TENORM. Typically, NORM is brought to the surface with a natural resource product (such as petroleum or phosphate) and deposited on the extraction and processing equipment in the form of scale, in the equipment as sludge, or in the spoil from purification processes. In Table 1, information about NORM is based on U.S. Environmental Protection Agency’s (EPA) compilation of piping-scale data from the petroleum industry (Dehmel *et al*., 1992; EPA, 2001).

Table 1—*Estimated potential United States inventories of PRSM from various sources, by metal type (NCRP, 2002).*

	Mass (1,000 MT) by metal type					
Source	Aluminum	Copper	Lead	Nickel	Carbon Steel	Stainless Steel
Commercial nuclear power plants	12–287	11–643	3–730	0–17	536–3,210	135–199
DOE nuclear weapons facilities[a]	27–44	7–56	1	38–57	192–1,068	12–174
Military	—[b]	—	—	—	—	160
R&D reactors	—	—	—	—	2	2
NARM related activities	—[c]	—[c]	—	—	3,000[d]	—
Total United States	39–331	18–699	4–731	38–74	3,730–7,280	309–535

[a] Includes uranium enrichment facilities that have been privatized.
[b] "—" means less than 1,000 MT.
[c] While there are materials in these categories, there are no available data on quantities.
[d] In the United States, an estimated 3,000,000 tons of NORM-contaminated scrap metals (including piping, tanks, and equipment) was reported by EPA (2001) and Dehmel (1992). The reported NARM-related metals consist mainly of NORM-contaminated metals.

Radiological characteristics

The PRSM inventory can be classified by the expected concentrations of radioactive material (activity level) and the nature of contamination. Both factors depend on facility design, operating history, maintenance, decay time, and decommissioning strategy. For purposes of this Report, PRSM has been divided into four general categories (Nieves *et al*., 1995): (1) scrap metal that is suspected of being radioactive but could actually be clean (suspect radioactive), (2) metal with surface contamination that is removable (surface contamination—removable), (3) metal with surface contamination that is fixed in place (surface contamination—fixed), and (4) metal with in-depth contamination due to neutron or particle activation (activated).

It is important to note that the majority of the PRSM inventory is actually not contaminated; much of it is merely suspected to be contaminated. Estimates of the inventories by metal type for all U.S. commercial power plants are provided in Table 2. More than 75 percent of the total metal mass falls in the categories of suspect radioactive or removable surface contamination.

Metal availability

PRSM will become available as the various nuclear facilities are decommissioned and dismantled. Most commercial nuclear power plants were constructed during the 1970s and 1980s. Assuming an expected life span of 40 y plus about 10 y for idling time and planning, scrap metal availability from these facilities is expected to peak before the middle of this century. The Nieves *et al*. (1995) report estimates timelines of PRSM inventories from power plants in various regions of the world, assuming PRSM availability at 50 y following plant start-up (license renewal of some commercial power plants may extend the metal availability for up to 40 y).

Table 2—*Percentage distribution of scrap metals in various contamination categories for a reference pressurized water reactor (NCRP, 2002).*[a]

Metal Type	Distribution (percent of metal inventory)			
	Suspect Radioactive	Surface-Contaminated — Removable	Surface-Contaminated — Fixed	Activated
Aluminum	80	15	0	5
Copper	98	2	0	<1
Lead	100	0	0	0
Carbon steel and iron	70–80	10–20	0	10–15
Stainless steel	0	50	15[b]	35

[a] Based on a reference pressurized water reactor with 1,000 MW(e) power rating. Estimated metal inventory is 33,000.
[b] Primarily for a steam generator.

MANAGEMENT OPTIONS AND APPROACH

Objective of waste minimization

The disposition of PRSM presents a major challenge to the operators of facilities that are associated with the production of man-made radioactive materials. It presents a similar challenge to industries that are associated with NORM or TENORM. Above all, the goal should be to protect human health and the environment while minimizing waste as a means to prevent pollution. It is commonly accepted as good environmental and public health policy that the amount of waste that must be sent to disposal should be minimized. Observance of such practices has been strongly endorsed by the U.S. Congress in the Pollution Prevention Act of 1990 (P.L. 101-508, codified at 42 U.S.C. 13101-13109). The concept of waste minimization also has been the subject of specific guidance developed by EPA (1992; 1993). On the basis of this guidance, NCRP has recommended that approaches to managing PRSM be based on a comprehensive spectrum of viable options, ranging from disposal at a licensed radioactive facility to recycling for various end uses.

Disposition alternatives and strategy

On the basis of management considerations and past practices, a number of basic disposition options for PRSM have been identified are shown in Figure 1. All the options have been used in the United States to some extent, but with varying degrees of success. While some of the options remain within the regulated environment with radiological control, others entail the release from control by means of a concept such as clearance. In all cases, however, the primary decision that must dictate the selection of an option is that it must represent a means of disposition that can be accomplished with prudent protection of human health and the environment.

Disposal at licensed low-level radioactive waste facilities. Disposal of PRSM as low-level radioactive waste (LLRW) at a licensed burial facility can be a costly management option. PRSM has been routinely disposed of as LLRW when (1) it has elevated contamination levels or (2) other options are either not well developed or not available. For commercially generated LLRW, the Low-Level Radioactive Waste Policy Amendments Act of 1985 set milestones, penalties, and incentives for individual states or groups of states, called compacts, to site LLRW disposal facilities. (There are currently nine compacts, involving 42 states.) So far, the only licensed disposal facilities accepting wastes are in Barnwell, South Carolina; Richland, Washington; and Clive, Utah. DOE had, in the past, buried a certain quantity of its PRSM at burial cells on site. Smaller DOE facilities with limited on-site burial options have routinely shipped radioactive wastes for burial at other DOE-owned facilities.

On-site storage. For on-site storage, the option of holding for radioactive decay generally involves materials contaminated with radionuclides with relatively short half-lives or for which no practical decontamination methods are available. Such materials are usually generated through activation by a device such as a nuclear reactor or a particle accelerator. Typical radionuclides of concern include ^{54}Mn (half-life of 312.5 d) and ^{60}Co (half-life of 5.24 y). Questions regarding release standards would still remain after storage. DOE utilizes the on-site storage option while evaluating future options for reuse or recycling of materials such as the large inventory of valuable nickel recovered from gaseous diffusion plants (DOE, 1995).

Recycle for internal use. Since the early 1990s, much of DOE's focus relative to PRSM management has been on reuse or recycling for internal use. In 1996, DOE issued the "Recycle 2000" policy to encourage recycling of radioactively contaminated carbon steel into the certified M-series containers to be used for one-time disposal of LLRW. In 2001, DOE issued a department-wide directive to advocate internal reuse. The policy cited reasons of safety and cost-effectiveness, resource utilization, energy conservation, and pollution prevention (*i.e.*, reduction of mixed waste volume). Two major issues regarding internal reuse or recycling options are the levels of demand for the materials and the costs associated with requirements for controlled recycling (DOE, 2001). It is also unclear how PRSM can be recycled for use within industries outside the AEA regulations, such as the petroleum industry, whose scrap metals are frequently associated with NORM (or TENORM) contamination. A considerably wider market could be created if, for example, the scrap from petroleum industry or NRC licensed facilities could be recycled for a designated use in the DOE facilities, or vice versa.

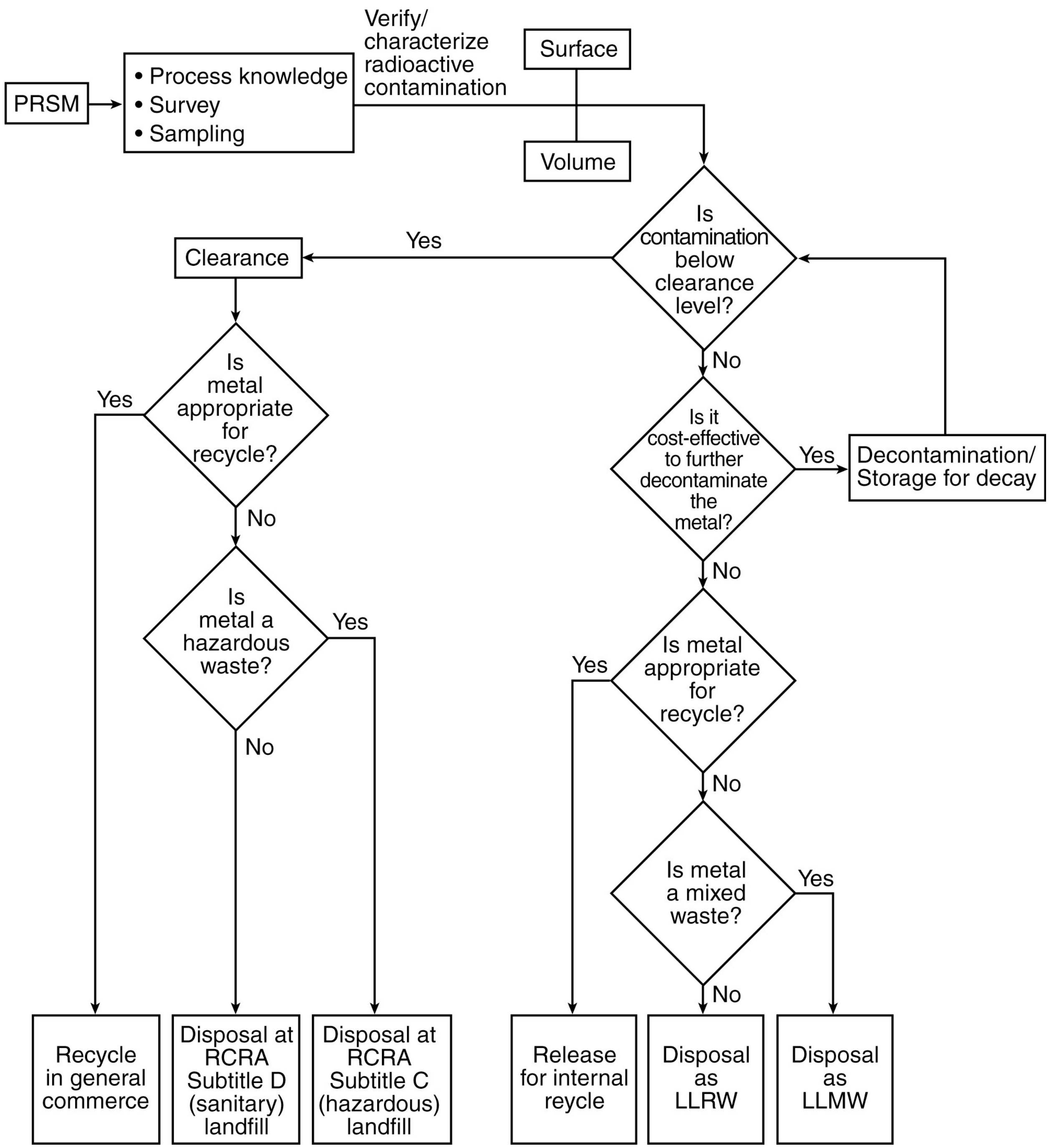

Fig. 1. Conceptual approach to PRSM disposition management decision (NCRP, 2002).

Disposal at Resource Conservation and Recovery Act landfills. PRSM has been disposed of, on a limited scale, at landfills permitted by EPA under the Resource Conservation and Recovery Act of 1976, Subtitle C (hazardous waste) and Subtitle D (industrial or municipal waste). The regulations of several states allow release for unrestricted use of all items and equipment that meet specific waste acceptance criteria. NRC has adopted a policy that allows "unimportant" quantities of source material to be disposed of as waste on a case-by-case basis with state concurrence (10 CFR Part 40). Many RCRA Subtitle C and D landfills have prohibitions against accepting any radioactive material. NRC has developed draft guidance that would allow an exemption for PRSM contaminated with source material, designating it as unimportant quantities of source material if the surface contamination was below certain levels. EPA is also considering development of standards that would allow low-activity LLRW, including PRSM, to be disposed of at a RCRA Subtitle C facility.

Release to general commerce. Although some PRSM has been released to general commerce in the past, those releases were primarily limited to metals with surface contamination and were based on the current guidance of NRC (1974) or DOE (1990). Release of PRSM that may contain volumetric contamination has been made on the basis of a case-by-case evaluation by DOE (Chen *et al*., 1999) and also NRC (in accordance with 10 CFR 20, Subpart 2002). The exact amounts of metal released in the past are unknown, although the estimated total quantity recycled from DOE facilities during 1993 to 2000 is on the order of 160,000 MT. That quantity includes both materials released to general commerce and those recycled for internal use. Much of the DOE metal originated from nonradiological areas or was surveyed or confirmed to be free of contamination prior to release. However, the public and the metal recycling industry have expressed strong opposition to any new rule or practice that allows release for recycling in general commerce of metals containing any residual radioactivity (MIRC, 1999).

Disposition strategy

Depending on the metal type, quality, radiological characteristics, cost constraints, or other factors, the options shown in Figure 1 and discussed above can be considered for disposition of PRSM. For example, for scrap metal with relatively high concentrations of radionuclides that are not easily removed or that cannot be removed at all, the proper choice for disposition would be a licensed radioactive waste disposal facility. For metals that contain radionuclides with relatively short half-lives or for those awaiting future decisions, the option to store them on site appears to be reasonable. For those containing some radioactive materials that can be safely recycled for use within the industry (or within the generator community for continued control), the option for internal recycling would be viable. (The internal recycling option should be explored to the fullest extent in light of public opposition to recycling PRSM in general commerce.) For metals that contain zero or minimal concentrations of radioactive materials but otherwise have no recycling value, the options would be disposal at hazardous waste landfills or sanitary landfills for nonhazardous municipal and industrial wastes. Yet another option would be storing them for radioactive decay until the metal qualified for recycling, or controlling the future use of the material (*e.g.*, recycling steel as sewer mains). For metals that have been determined to have met the clearance standards and for which the particular scrap metal might represent a valuable resource, release to general commerce for recycling might be a viable option. If the metal also contains hazardous materials, one consideration would be to treat and remove the hazardous characteristics (such as by chemical decontamination), leaving only the radioactive contents for consideration. Or it could be disposed of as low-level mixed waste.

Regulatory needs and recent policy-making activities

The disposition options available under current regulations are rather fragmented and do not form a comprehensive basis for sound PRSM disposition decisions. In particular, the lack of national release standards for materials containing very low levels of residual radioactive contents presents a major obstacle to a viable release option. The nation is in need of regulatory policies that address whether PRSM can be used for recycling in general commerce or disposed of as nonradioactive waste at EPA- or state-permitted burial facilities.

Such a need has long been recognized by regulators, the nuclear industry, and other industries associated with the production of radioactive materials. In fact, materials containing surficial residual radionuclides have been released routinely on the basis of existing guidance, including guidance issued by NRC in Regulatory Guide 1.86 (NRC, 1974) and similar guidance found in DOE Order 5400.5 (DOE, 1990). Such guidance, however, is limited to the release of materials with surface contamination. Furthermore, it is based largely on the detection capabilities of radiation instrumentation and bears little or no relationship to any established dose or risk criterion. Release of materials with volume contamination has been difficult because of the lack of guidance and can be conducted only on a case-by-case basis. As a result, there have been several attempts by regulatory agencies to establish consistent and uniform standards.

Such regulatory activities include NRC’s renewed effort to make rules for the release of solid materials from its licensed facilities (64 FR 35090, 1999a) and DOE’s effort to prepare a programmatic environmental impact statement regarding the disposition of scrap metal generated from its facilities (66 FR 36562, 2001). In addition, through the Conference of Radiation Control Program Directors, Inc., the states are in the process of establishing standards for the disposition of TENORM.

FRAMEWORK AND APPROACH TO DEVELOPING RELEASE STANDARDS

Radiation protection framework

Some disposition options, such as release for disposal at landfills or release for recycling in general commerce, as discussed above, involve the release of materials that are outside regulatory controls for radioactive materials. The primary goal in developing clearance criteria and procedures is to avoid unnecessary costs and avoid wasting resource materials that could have other beneficial uses within society. Developing such a program is based on the current national and international radiation protection framework, which is designed to protect humans against unnecessary exposures from radiation sources. Under this framework, three source categories have been defined (ICRP, 1991): (1) sources introduced by a practice, (2) existing sources requiring intervention, and (3) existing sources (*e.g.*, cosmic rays) for which no specific protection issues have been identified and for which no effective protection measures can be applied (it therefore has no bearing on the disposition issues of PRSM). The interrelationships among all three categories are depicted in the flow diagram shown in Figure 2.

Principles governing a practice include justification of practice, optimization of protection, and protection of individuals (ICRP, 1991). Disposition of PRSM therefore follows the principles of optimization and protection of individuals that are embedded in the original practices that apply to the source from which PRSM was generated. Principles governing intervention are justification of intervention and optimization of protection. Although disposition of PRSM bears no direct relationship with the intervention process, it is important to note that the steel industry has already instituted one form of intervention by installing sensitive radiation monitors to prevent the inadvertent introduction of "radioactive devices" (*i.e.*, "orphan sources") from entering the scrap metal pool, as discussed later. The development of release standards that apply to PRSM recycling, in particular, must take these types of intervention measures into account.

Concept of controlling releases

To avoid the imposition of excessive regulatory procedures, certain practices and/or radiation sources involving small quantities of radioactive materials are usually excluded from the scope of regulation because of their specific usage and because the associated social impacts have been determined to be insignificant. This exclusion process has been accomplished through

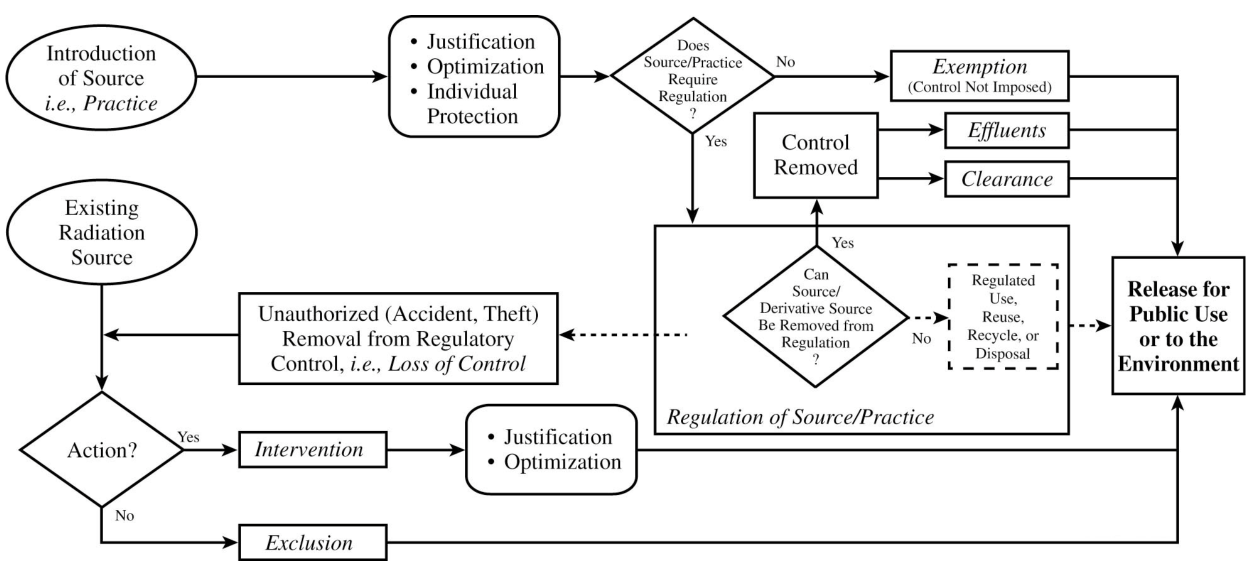

Fig. 2. Relationships among management concepts for radioactive sources (NCRP, 2002).

three approaches: (1) exemption—control was *not imposed* from the outset following a thorough deliberation [such as smoke detectors or other exempted radioactive materials (NRC, 2001)]; (2) clearance—control was subsequently *removed* from the existing practice by authorization (the process of clearance is analogous to effluent releases); or (3) *de minimis*—control was *deemed unwarranted* because the anticipated dose (or risks) were found to be trivial. All three approaches have been practiced in society resulting in various degrees of public awareness and success. They pertain to granting relief by not imposing or by removing regulatory control. Clearance and *de minimis* are the two approaches to be considered for the disposition of PRSM. Obviously, should the *de minimis* level be used as the criterion for developing clearance standards (a current trend favored by several national and international standards-developing bodies), then the two approaches will become indistinguishable.

Clearance as a form of controlled release of PRSM is analogous to the release of airborne or waterborne radioactive effluents from installations associated with the production and use of radioactive materials. Such releases are an integral component of routine operations. Examples of this type of regulation include two national standards developed by EPA: (1) national emission standards (40 CFR Part 61) to support the Clean Air Act and (2) environmental standards for the uranium fuel cycle (40 CFR Part 190, Part B) for controlling the planned discharges from nuclear fuel-cycle facilities. The Clean Air Act includes provisions to control radioactive releases to the atmosphere, and regulations under the Safe Drinking Water Act include limits on the concentrations of radioactive materials in drinking water.

Development of clearance standards—A risk-based approach

The term *clearance* refers to a process for certifying the removal of control from an existing practice when the potential dose levels to the critical group satisfy certain constraints or when authorized by the regulator. It is NCRP's view that a few tens of microsieverts per year to an average member of the critical group would be an appropriate dose criterion for setting clearance standards. This suggested dose level represents only a fraction of the recommended annual dose limit of 1 mSv and is well within the International Commission on Radiological Protection's (ICRP) recommended annual dose constraint of 0.3 mSv from a single source (ICRP, 1999). Should competent authorities opt to use an individual annual dose of 10 μSv as the criterion, development of clearance standards would be set at the "trivial dose" or the "negligible individual dose" (NID) level (NCRP, 1993) below which further effort to reduce the dose is considered unwarranted, and thus relieving its further consideration in the collective dose assessment. This dose level is one percent of the annual dose limit of 1 mSv and is about 0.3 percent of the average annual dose (*i.e.*, 3.0 mSv y^{-1}) received by a member of the public in the United States (NAS/NRC, 1990). An estimated annual individual risk level of 5×10^{-7} corresponds to a dose level of 10 μSv. The NCRP has recommended the use of this same dose constraint as the criterion to establish an exempt category for hazardous or radioactive wastes (NCRP, 2003). Note that using NID as the dose criterion for clearance will effectively render clearance standards to be developed at the *de minimis* level.

Clearance of PRSM that contains residual radioactive materials will require, through dose assessment, the establishment of activity concentrations for both surficial and volumetric sources. The clearance levels should be based on an analysis that includes plausible scenarios for unrestricted release. In practice, these scenarios can be described under the alternatives of reuse, recycle, or disposal.

Recent activities and remaining issues

Recent activities to develop clearance methods and standards have been conducted by the International Atomic Energy Agency (IAEA, 1996), the European Commission (EC, 2000), and the Health Physics Society Standards Committee for the American National Standards Institute (ANSI/HPS, 1999). These clearance standards are generally in agreement, such as using 10 µSv y^{-1} as the dose criterion, showing a distinct category aside from the LLRW (see Table 3). However, some differences do exist. The variations, in general, are not caused by the selection of dose criteria or fundamental approaches taken by the developing organizations. Rather, they originate from several sources of uncertainty based on institutional or technical judgments about the subject issues of various nations. Continued efforts are therefore essential in developing a set of uniform and consistent international clearance standards. It is imperative that the standards be carefully evaluated for incorporation by regulators in future rulemaking efforts. It is also important that such rulemaking efforts be conducted with the participation and consensus of national and international regulatory authorities, affected industries, workers, and the public.

ISSUES PERTAINING TO RADIOACTIVE SCRAP METAL RECYCLING

Four major potential sources of radioactive materials can be encountered during metal recycling: (1) naturally occurring radioactive residues, (2) radioactive materials intentionally introduced to measure refractory lining wear in blast furnaces, (3) controlled release of radioactive metals from radiologically regulated facilities, and (4) inadvertent or accidental introduction of radioactive devices (orphan sources) into the scrap metal. The common issues associated with these sources are that contamination may occur in metal products or the surrounding environment and that potential exposures to metal workers or members of the public may arise as a result. Among these sources, the inadvertent melting of sealed radioactive sources that have been lost or otherwise not under control (*i.e.*, orphan sources) is considered the most severe of all source types. Issues associated with orphan sources are further discussed below.

Distribution of radioactive material in the metal-melting process

Under certain conditions during the metal-melting process, some types of radioactive contaminant can be preferentially removed from the metal phase. This removal mechanism can also serve to further propagate the radionuclides to other surrounding media (such as metal products, baghouses, or the surrounding environment) that require attention. The mode of removal is a function of the chemistry of the furnace (acidic or basic), thermodynamics, and the chemistry of the impurities. Such a distribution mechanism is commonly termed “partitioning” or “fractionating.” Ranges of partitioning data for various radionuclides have been compiled on the basis of information on steelmaking furnaces (Cheng *et al*., 2000; EPA, 2001; NRC, 1999b;

Table 3—A sample comparison of published clearance standards and Class A LLRW limits for volume concentration of some radionuclides (NCRP, 2002).

Radionuclide[a] or Category	Concentration Limit for Class A LLRW ($Bq\ cm^{-3}$)[b]	Clearance Standards for Volumetric Contamination ($Bq\ cm^{-3}$)[c,d]		
		IAEA	EC	ANSI/HPS
C-14	3.0×10^4	840	280	280
C-14 in activated metal	3.0×10^5	2.4×10^3	790	790
Ni-59 in activated metal	8.1×10^6	—[e]	790	—
Nb-94 in activated metal	7.4×10^2	2.4	0.79	7.9
TC-99	1.1×10^4	840	28	280
I-129	3.0×10^2	84	2.8	28
Alpha-emitting transuranic nuclide with half-life greater than 5 y	3.7×10^3 ($Bq\ g^{-1}$)	—	—	—
Pu-241	1.3×10^5 ($Bq\ g^{-1}$)	30 ($Bq\ g^{-1}$)	10 ($Bq\ g^{-1}$)	10 ($Bq\ g^{-1}$)
Cm-242	7.4×10^5 ($Bq\ g^{-1}$)	—	3	—
Total of nuclides with less than 5 y half-life	2.6×10^7	—	—	—
H-3	1.5×10^6	8.4×10^3	2.8×10^3	2.8×10^3
Co-60	2.6×10^7	0.84	0.28	2.8
Ni-63	1.3×10^5	8.4×10^3	280	2.8×10^4
Ni-63 in activated metal	1.3×10^6	2.4×10^4	790	7.9×10^4
Sr-90	1.5×10^3	8.4	2.8	28
Cs-137	3.7×10^4	0.84	2.8	2.8

[a] Class A LLRW includes waste containing radionuclides beyond those listed here.
[b] Adopted from 10 CFR Part 61, Section 61.55.
[c] Adapted from IAEA (1996); EC (2000); ANSI/HPS (1999). (All standards are for all solid materials.)
[d] The published standards are presented in $Bg\ g^{-1}$. The values presented here are based on the assumption of the following waste densities: 7.9 $g\ cm^{-3}$ for radionuclides in activated metal (such as steel), and 2.8 $g\ cm^{-3}$ as a representative LLRW (Chen *et al.*, 1996).
[e] Dash means not available.

Nieves *et al.*, 1995). The data show the expected percentage of each radionuclide that partitions to the steel, slag, oxide fume, and other components. Consideration of such partitioning phenomena is important in developing the clearance standards discussed above.

Radiation protection considerations

Operations personnel have the potential for exposure to radioactive materials during activities involving metal processing. Exposure pathways would consist mainly of external radiation and inhalation, and, to a minor extent, direct ingestion (*e.g.*, ingestion of radioactive contamination on hands and fingers) and secondary ingestion (*e.g.*, ingestion of foods contaminated in the working environment). Consumers can also be exposed to metal products made from recycled scrap that contains radioactive materials.

In all related activities, radiation protection controls are not required, since the activities are conducted outside a regulated environment. The workers are generally those associated with metal recycling activities involving scrap handling, metal melting, slag collection, and baghouse operation. Potential exposures to the general public arise primarily from the use of consumer products made from metals containing radioactive materials. Exposure to the public is also possible from slag used for landscape filler and fertilizer and as a sub-base for athletic fields. Exposure through environmental releases is possible but has not been a significant concern. As discussed earlier, such exposure scenarios are key to the development of clearance standards.

Protection against orphan source contamination

Over the past two decades, potential contamination of scrap by radioactive materials has emerged as an issue of critical concern to the metal recycling and metal producing industries. This concern has developed primarily because of numerous reported events in which steel and aluminum mills accidentally melted discarded radioactive devices. The radioactive devices found in metal scrap, such as level or thickness measuring gauges, are usually orphan sources (*i.e.*, sources that were lost, abandoned, stolen, or improperly disposed of). They escaped institutional control and entered the public domain in an uncontrolled manner. Enormous costs to a metal manufacturing facility resulting from accidentally melting an orphan source have been reported; these typically range from $8 to $10 million (Lubenau and Yusko, 1995) and could reach as high as about $100 million (Sharkey, 1998). Such high costs result from plant shutdown, decontamination, and waste disposal following an accidental melt.

Source control issues

In the United States, about 800,000 devices containing sealed sources have been distributed under specific licenses by the NRC or agreement states, and 1,500,000 devices have been distributed under general licenses (Lubenau and Yusko, 2000). Problems arise when institutional controls are lost and the radioactive sources in the devices become “orphan” and can enter the public domain in an uncontrolled manner. Because disposal options are unavailable or expensive, an estimated 500,000 unwanted sources are being placed into long-term storage, thereby becoming vulnerable to loss of control (*e.g.*, unintentional improper disposal, theft, or abandonment of the facility). Annually, NRC receives about 200 to 400 reports of lost, stolen, or abandoned sources (Dicus, 2000; Lubenau, 2001). The figures are likely to be higher since there is a potential for underreporting.

Improvements in control measures

Recent history has shown that potentially grave consequences may result from inadequate management of radioactive sources. The metal industry, as well as members of the general public, are in need of a reasonable assurance that the economic losses and undue exposures caused by such events can be prevented. These are the preventive measures that are taken to reduce or avoid the potential events and the corrective measures that are used to rectify or mitigate the current approach and operations that govern the control of radioactive sources. [Since September 11, 2001, another urgent need has emerged for the nation, as well as across the world: to effectively control the spread of radioactive sources that may be used by terrorist groups as radiological dispersal devices (GAO, 2003a; 2003b).]

Preventive measures. First, the current licensing system needs to include a better justification for licensing radioactive sources and tighter regulatory control once the license is issued. Second, a comprehensive national tracking system for licensed sources should be developed. Currently there is no nationwide database on the inventory of sources permitted under either specific or general licenses. The recent changes to NRC's general license program (NRC, 2000) involve a registration program for certain sources, which will result in a better inventory of these sources. Third, a viable mechanism should be developed to facilitate collection and disposition of sources that are no longer in service. The options can include recycling, centralized storage, or disposal as waste. Although this problem has been partially addressed by DOE's Off-Site Sources Recovery Program, there is a need for a unified program for collection and disposition of all sources that are out of service. And fourth, there appears to be a need to impose financial surety as a licensing requirement. Imposing a financial surety requirement on possessors of sealed sources would help provide for continued institutional knowledge of the existence of a source; thus, better control and accountability might be obtained.

Corrective measures. First, the detection capability should be evaluated and improved. Although radiation detection systems have been widely used by private enterprises to screen the radioactive contents in scrap metal, the efforts have been conducted without regulatory input or guidance. The lack of a proper harmonization between instrumentation-based interception approaches would likely undermine the risk-based clearance approach discussed earlier. Second, there is a need to develop protocols for discovery, reporting, and transporting radioactive sources. The lack of standardized protocols has led to inconsistency in the ultimate disposition of the radioactive materials discovered. Lastly, national provisions need to be developed to enable prompt recovering and securing of sources found in metal scrap or elsewhere in the public domain without incurring costs to the finders. This also requires that sources having reached their end of service life be removed promptly to secured storage or disposal facilities.

Concerns of metal industry and the public on recycling of PRSM

Negative public perception. For years, radiation from man-made sources in general has struck fear in the public's mind (Slovic, 1979). Such a negative public attitude has manifested itself in the recycling of scrap metal that could have been contaminated with radioactive materials. Although such concerns are largely based on perception, it is important that they be fully understood, evaluated, and resolved by regulators in formulating a national policy on the disposition of PRSM.

Clearance of metals containing low levels of radioactive contamination, even if deemed acceptable by regulatory agencies, "…would undermine public trust in the safety of consumer and commercial products containing steel, nickel, and other metals" (MIRC, 1999). This concern was reinforced by a August 24, 1999 ABC television program, "World News Tonight," with Peter Jennings, that featured a segment titled *Dangerous Recycling*, and an article, "Nuclear

Spoons," by Anne-Marie Cusac in the October 1999 issue of *The Progressive* (MIRC, 1999). *The Washington Post* also carried a cartoon, "Boondocks," that addressed the potential for radioactive contaminated scrap to end up in consumer products. In addition, the American Iron and Steel Institute, a trade organization representing integrated steel producers, commissioned a poll of public opinion on this issue by the Wirthlin Group (December 16 to 19, 1999). The poll indicated that significant public opposition existed to the concept of clearance, even if governmental regulatory agencies declared the practice to be safe. In fact, opposition increased from 61 to 74 percent when those polled were told that a governmental agency had determined that such a practice posed no health risk (MIRC, 1999).

Residual liability to the metal industry. Within the metals industry, the opposition to recycling radioactive scrap metal comes from trade associations representing all carbon steel and stainless steel, nickel, copper, brass, and zinc producers in North America. The industry deems that the policy of clearance for metals "…would adversely affect consumer acceptance of products having a recycled metal content, even if radioactively contaminated metal was not actually used to produce the product." The concern is that the adverse perception would result in the public's "de-selecting" metals and products made of metals in their purchases. Such an action could have a devastating economic impact on the metals industry, as well as on those industries manufacturing products made of metals (MIRC, 1999). The potential burden of having to verify the acceptability (see Figure 3) of the radioactive contents in plant operations has also been viewed as excessive. One additional concern is that the metals industry has no guarantee that low-level contamination in dust and slag would not become subject to Superfund remediation in later years, or that a governmental agency would not eventually mandate a recall of metal products containing low-level concentrations of radioactive materials that were once considered "acceptable" (MIRC, 1999). These concerns are beyond the issues involved in the regulatory improvements discussed above.

FINDINGS AND RECOMMENDATIONS

Findings

1. **The management of PRSM will require a comprehensive and multifaceted approach.** An estimated amount of up to nine million tons of scrap metal of various types will be generated in the United States over the next few decades as a result of the decommissioning and dismantling of facilities associated with man-made radionuclides as well as NORM or TENORM. These metals will vary in condition, quality, quantity, nature of contamination, and market value but will otherwise share a common trait: much of the metal will only be suspected of radiological contamination and actually may not be contaminated at all. Disposition of such large quantities of PRSM will be a rather complex undertaking that will require a comprehensive national policy and multifaceted management approach.

Fig. 3. A portal truck monitoring system commonly used by steel mills to intercept incoming scrap metal. The view shows a truck approaching the monitor, which is located on the approach to the scale. Radiation detector panels are located on both sides and overhead (NCRP, 2002).

2. **National guidance on pollution prevention forms a sound basis for PRSM management.** It is commonly accepted as good environmental and public health policy that the amount of waste that must be sent to disposal should be minimized. Observance of such practices has been strongly endorsed by the U.S. Congress in the Pollution Prevention Act of 1990 (P.L. 101-508, codified at 42 U.S.C. 13101-13109). The concept of waste minimization also has been the subject of specific guidance developed by EPA (1992; 1993). This guidance states that approaches to managing PRSM should be based on a comprehensive spectrum of viable options, ranging from disposal at a licensed radioactive facility to recycling for various end uses.

3. **Current regulatory system focuses only on waste management.** Current United States regulatory provisions governing nuclear materials and radioactive wastes were derived from the AEA and its subsequent amendments. Because PRSM may contain very low concentrations of radioactive materials, it is generally classified as LLRW and must be

disposed of in accordance with regulations and procedures for LLRW, regardless of whether it actually contains radioactive content.

4. **There is an urgency to establish consistent national/international policies and standards**. Although the release of PRSM has been practiced in the past, no regulatory framework or basis has been developed to address such releases in a consistent and systematic manner, either in the United States or worldwide. Today, there is a consensus among regulatory agencies in the United States, as well as elsewhere, that risk represents a sound and acceptable basis for the establishment of protection standards (NCRP, 2003). Additionally, in view of the ever-increasing international trade in metals, there is an urgent need to develop an international consensus regarding the acceptable release of PRSM.

5. **Concerns of the metal industry and the public must be adequately addressed**. A primary concern to industry is the potential for systemwide radioactive material contamination of the metal recycling stream. This concern has been exacerbated by recent events in which lost licensed radioactive devices were accidentally melted at steel mills (Lubenau and Yusko, 2000). Consequently, any proposals to recycle PRSM within any type of consumer product have faced significant opposition. Compounding the problem is the widely held public fear of radiation. All of these concerns must be adequately addressed and factored into formulating a national policy pertaining to the disposition of PRSM, particularly for decisions that are associated with recycling in general commerce.

Recommendations

On the basis of the above discussion, eight recommendations are offered, all of which are designed to enhance the management and disposition of PRSM. These cover a number of interrelated issues that must be addressed in an integrated manner. Most importantly, the efforts leading to the resolution of these issues must involve regulators, representatives of the metal industry, the groups that generate PRSM, and other relevant stakeholders, especially the general public, in a highly innovative and cooperative manner.

1. **Comprehensive and consistent national and international risk-based policies for managing PRSM need to be developed.** The national policy related to PRSM needs to be consistent with all similar U.S. endeavors within the context of waste minimization measures designed to manage waste materials generated by other industries. In particular, there is an urgent need to develop a risk-based policy by which all viable disposition options can be fully developed to support the management of PRSM. Today, there is a consensus among regulatory agencies in the United States, as well as elsewhere, that quantification of the risks associated with the options represents a sound and acceptable basis for the establishment of such standards. This risk-based approach provides a structure for balancing the goal of protecting human health and environmental safety against the competing goal of minimizing waste.

2. **A set of uniform clearance standards to address national and international concerns needs to be developed.** These standards should complement the management strategy and must be developed on an international basis. In this regard, an appropriate dose criterion for setting clearance standards would be a few tens of microsieverts per year to an average member of the critical group. This would represent only a few percent of the primary dose limit of 1 mSv y^{-1} for exposure of the public to all controlled sources combined, which is currently recommended by NCRP and ICRP and is contained in standards of U.S. regulatory agencies. This value is also consistent with existing U.S. regulations for the control of residual radioactive releases, such as those from LLRW disposal facilities. A dose criterion of 10 μSv y^{-1} would be equivalent to what has been designated by the NCRP as NID (NCRP, 1993). As stated by NCRP, the NID defines a dose below which further efforts to reduce the dose to an individual member of the public are "unwarranted" (considering the potential excess risk of health effects).

3. **The standards should include NORM and TENORM.** It is estimated that about one-third of the PRSM that would ultimately be generated in the United States would be derived from industries associated with the handling or processing of NORM or TENORM. The most common type of PRSM originating from such sources is carbon steel. In the United States, regulation of TENORM generated by the commercial sector is currently within the jurisdiction of the individual states, and there are significant differences in the regulations being applied from state to state. Because TENORM is associated with the same radiation protection issues as those associated with man-made radioactive material, the NCRP recommends that EPA, NRC, and DOE, in concert with state regulators, develop a system for controlling the recycling of TENORM-contaminated scrap metals (both from domestic sources and from abroad). This is particularly important in light of the fact that the majority of the radioactive contamination detected at metal mills is attributable to NORM or TENORM.

4. **Regulatory control over orphan sources must be improved.** Up to 400 of the more than two million radioactive devices that have been distributed under the licensing programs of the NRC or individual states are reported as lost or stolen each year. On numerous occasions, such sources have been present in scrap metal that has been delivered to metal mills and foundries. Experience demonstrates that melting a source within a batch of steel can lead to significant economic impacts and public health concerns. Thus, eliminating the potential for occurrence of these types of events will, in part, alleviate the concerns of metal mill and foundry operators who oppose accepting recycled PRSM at their facilities. On this basis, consideration should be given to a careful reevaluation of current regulatory policy as well as implementation procedures in order to ensure better control of licensed devices. It is also essential that methods be developed to provide financial protection to metal mill and foundry operators against the inadvertent melting of orphan sources.

5. **The processes of clearance and intervention/interception should be harmonized.** United States reliance on imported scrap metal has been increasing over the past decade. Standards for release of contaminated scrap metal vary among countries, as does their enforcement. There is increasing evidence of a lack of control of radioactive

contamination in the PRSM that originates in some Eastern European countries, as well as in other parts of the world. Concerns regarding orphan sources and steel contaminated with man-made nuclides or TENORM have led the U.S. steel-making industry to install highly sensitive monitoring equipment at most facilities. The detection capabilities of current and future monitoring technology raise the possibility of conflicts with risk-based releases of materials. In consideration of these developments, it is recommended that efforts to harmonize the interception and clearance processes be increased. Without harmonization, the monitors may interfere with, or cause the unintended rejection of, cleared materials. If harmonization cannot be accomplished, it will be necessary to administer the clearance system as a certification process, bypassing the interception process.

6. **The use of licensed mills/brokerages as "clearing houses" for recycling should be encouraged.** Since commercial metal mills are not set up for radioactive material control, it may be best to restrict the recycling of PRSM to mills or brokerages specifically licensed and dedicated to this purpose. In cases where the licensed-mill approach would prove to be infeasible for economic or other reasons, the alternative may be the use of a licensed brokerage, by which rigorous requirements would be followed to ascertain compliance prior to the release of PRSM. This approach offers several advantages for administering the clearance process: (a) such entities could serve as clearing houses to certify the releases of PRSM; (b) since such entities would be licensed and approved by the regulators, there would be legal justification for any materials released; (c) this, in part, would lead to better acceptance of such operations by industry and the public; and (d) there would be assurance that proper sampling and monitoring had been conducted and that the materials met the regulatory requirements for release. Furthermore, the end-use of recycled metal from a licensed mill or brokerage can be better controlled. That is, depending on the level of residual radioactivity, the metal can be released either for restricted use (*e.g.*, used within the nuclear industry) or for unrestricted use.

7. **New technologies and/or plant designs to reduce metal contamination should be developed.** Examples include the proper selection of materials used and the application of special coatings to metal surfaces to reduce, if not completely eliminate, radioactive surface contamination. Incorporation of these characteristics into the design of nuclear facilities, which will facilitate their decommissioning, should also be considered. This approach has been increasingly adopted in the design of newer models for future commercial nuclear power plants. NRC took steps to address this issue in Subpart E to 10 CFR Part 20 regulations, added as part of its 1997 rulemaking on licensing termination. The licensing requirements include facility designs and procedures to minimize contamination, facilitate eventual decontamination, and minimize generation of wastes. It is recommended that new types of technology be exploited and that efforts to develop even better contamination reduction methodologies continue.

8. **Steps should be taken to enhance public understanding of the clearance process.** The lack of such understanding is a substantial impediment to releasing PRSM in general commerce. Information that should be made more widely known includes the following:

- PRSM is a by-product of practices that have been previously justified on the basis of issues such as national security; proper disposition of such material should be conducted through a responsible management approach. Managing PRSM is designed to control the propagation of radioactive pollution into the environment. The type of control required is exemplified in many existing laws that were established to limit the release of pollution into specific environmental media.

- The standards developed for clearing PRSM for release into the public domain should be based on criteria that are designed to stringently limit any accompanying impacts on either the environment or the public.

- Recycling of contaminated metals is routinely being practiced in other countries of the world. Development of international standards for the release of PRSM will ensure better and more stringent control of such materials both within the United States and in these other countries.

- As part of a phased approach for establishing a framework for PRSM disposition, proposed regulations may initially prohibit the recycling of PRSM into consumer products to avoid direct contact of PRSM with the general population. Only if the regulatory system proves to be practical and only if safety is assured for all potential uses would a lessening of these restrictions (toward fully instituting a clearance process) be considered.

Additionally, in view of the negative public attitude regarding the release of PRSM in general commerce, it is recommended that development of internal recycling activities take precedence over clearance. The commitment of this approach reinforces the commitment from PRSM generators to strictly enforce safe waste recycling procedures under continued regulatory control. Further, such a program, although it may differ from clearance in terms of release criteria or implementation procedures, can serve as a pilot effort to confirm the feasibility of recycling PRSM in the public domain. It also has the potential benefit of revealing issues that have not previously been identified. More importantly, continued dialogue in an open and constructive environment is greatly needed for any endeavor intended to formulate a consensus on an acceptable national policy on the subject issue.

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