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**DECONTAMINATION OF FAST (CPP-666) FUEL STORAGE AREA
STAINLESS STEEL FUEL STORAGE RACKS**

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Abstract

This purpose of this report was to identify and evaluate alternatives for the decontamination of the RSM stainless steel that will be removed from the Idaho Chemical Processing Plant (ICPP) fuel storage area (FSA) located in the FAST (CPP-666) building, and to recommend decontamination alternatives for treating this material.

Upon the completion of a literature search, the review of the pertinent literature, and based on the review of a variety of chemical, mechanical, and compound (both chemical and mechanical) decontamination techniques, the preliminary results of analyses of FSA criticality barrier contaminants, and the data collected during the FSA Reracking project, it was concluded that decontamination and beneficial recycle of the FSA stainless steel produced is technically feasible and likely to be cost effective as compared to burying the material at the RWMC. It is recommended that an organic acid, or commercial product containing an organic acid, be used to decontaminate the FSA stainless steel; however, it is also recommended that other surface decontamination methods be tested in the event that this method proves unsuitable. Among the techniques that should be investigated are mechanical techniques (CO_2 pellet blasting and ultra-high pressure water blasting) and chemical techniques that are compatible with present ICPP waste streams.

Summary

The identification of recyclable Department of Energy (DOE) radioactive scrap metal (RSM) is one of the primary objectives of the WINCO Metal Recycle program. Closely related to this objective are activities associated with the identification of decontamination and processing techniques that will expedite the beneficial reuse of both DOE and commercial RSM. The purpose of this report is to present alternatives for the decontamination of the RSM stainless steel that will be removed from the Idaho Chemical Processing Plant (ICPP) fuel storage area (FSA) located in the FAST (CPP-666) building, and to recommend decontamination alternatives for treating this material.

The results of an analysis of the dispositioning alternatives developed during the reracking studies lead to the conclusion that it is cost effective to decontaminate and recycle the FSA RSM, as compared to burial with or without size reduction. While the costs associated with this activity cannot be estimated at this time (the nature of the contamination, the decontamination technique to be used, and the end-uses of the material are not known), it is clear that the least cost effective alternative is to bury the racks without size reduction and that burying the material after size reduction is not significantly more cost effective because the cost of the size reduction activities almost entirely consumes the cost savings resulting from the reduced burial costs.

During an analysis of the cost effectiveness of using RSM for the fabrication of dry storage fuel canisters, it was shown that a cost savings of \$32,000 per canister would be realized by using RSM, as compared to using steel purchased on the open market. While this analysis was based on the use of melt refining as the decontamination technique, the costs associated with using a different decontamination technology should not cause much more than a three-fold increase in the decontamination costs as compared to melt refining (based on estimated costs for melt refining as compared to decontamination by a traditional technique).

Further, it is recommended, based on the information reviewed during this activity, that the FSA surface-contaminated stainless steel be decontaminated by treatment with an organic acid chemical technique that is compatible with ongoing ICPP process streams, and that decontamination be performed prior to size reduction. If it is not possible to size reduce prior to decontamination, then the material should be stored, as contaminated material, until its end-use is determined. Any activities that result in the conversion of surface contamination into volumetric contamination should be avoided until the end-use of the material is known.

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I. Introduction

The identification of recyclable Department of Energy (DOE) radioactive scrap metal (RSM) is one of the primary objectives of the WINCO Metal Recycle program. Closely related to this objective are activities associated with the identification of decontamination and processing techniques that will expedite the beneficial reuse of both DOE and commercial RSM. The purpose of this report is to present alternatives for the decontamination of the RSM stainless steel that will be removed from the Idaho Chemical Processing Plant (ICPP) fuel storage area (FSA) located in the FAST (CPP-666) building, and to recommend decontamination alternatives for treating this material.

The FAST basins predominately contain spent naval fuels. The fuels are stored under water on stainless steel racks (Figure 1), with additional hardware in place to guarantee criticality control. The water in the basins is monitored for radionuclide content and treated to maintain the desired purity. Recently, a program that addressed reracking of the fuel in the storage basins was undertaken. As part of this program, the costs associated with four disposal options for the rack materials were compared. These options are: (1) burial at the Radioactive Waste Management Complex (RWMC) without size reduction (demolition); (2) size reduction at the ICPP and disposal at the RWMC; (3) size reduction and decontamination at a remote site (private contractor) with some material becoming the property of the contractor and some material returning to the INEL for burial at the RWMC; and (4) shipping to a private contractor, who would take title to the material and all subsequent processing wastes, for casting shielding blocks for sale to another DOE facility and disposal of the wastes incident to processing.¹

As the purpose of this document is to address the decontamination of ICPP FSA stainless steel fuel storage racks, generalized discussions of a variety of decontamination technologies for the surface decontamination of stainless steel will be presented, followed by discussion of the recommendations made during the FSA Reracking Project - Conceptual Design study performed by Fluor-Daniel, Inc. Conclusions drawn from the alternatives discussed and recommendations based on the conclusions will also be presented and discussed. Before these issues are addressed, however, the small amount of available information regarding the type of contamination present on the FSA stainless steel will be presented.

II. Type of Contamination on FSA Racks

Preliminary investigations have identified, in little more than a qualitative sense, the type of contamination present on stainless steel components removed from the FAST FSA basins. During the initial stages of the reracking activities, criticality barriers, which are stainless steel structural units attached to the fuel racks that help ensure non-critical geometries, were removed from the basin and sampled.

Note: Dimensions are nominal, consult design drawings for details.

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Stainless Steel Fuel Storage Racks Type RK-SF-900

Figure 1

The samples were removed from one of the barriers by mechanical means.^a The pieces, assigned sample descriptors R-2-1, R-2-2, R-2-3 and R-2-4, were gamma scanned at the Remote Analytical Laboratory (RAL); the analyses detected two radionuclides, Co-60 and Cs-137, present in each of the samples at the concentrations 5.81, 9.77, 6.42 and 10.2 disintegrations per second per gram (d/s/g) for Co-60, and 0.210 d/s/g, 0.115 d/s/g, below detection and below detection for Cs-137, respectively.^b Sample R-2-1 was subsequently leached in 88 mL of aqua regia until slightly more than 50 w/o was dissolved. Gamma scans of the remaining metal subsequent to the aqua regia treatment identified no radionuclides above background.² The leaching information is important because it shows that the FSA stainless steel is almost certainly not volume contaminated.

These results are of paramount importance because they elucidate the types and quantity of contamination that might be present on the FSA rack material. If it is assumed that each sample has a surface area of 1 inch², the analytical results may be converted to per unit area values. The values would be: 16.0, 51.6, 35.7 and 56.1 disintegrations per second per cm² (d/s/cm²) for Co-60, and 0.577 d/s/cm², 0.608 d/s/cm², below detection and below detection for Cs-137, respectively. To understand the significance of these quantities, a comparison of these quantities the free-release criteria from NRC Reg. Guide 1.86 would be helpful.³

In June, 1974, the U. S. Atomic Energy Commission released Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors. In this document, surface contamination criteria for free release of RSM were established. The "acceptable surface contamination levels" for free release were 0.833, 2.50 and 0.167 d/sβγ/cm² for average, maximum and removable contamination,^c respectively. As both Co-60 and Cs-137 are βγ emitters, a DF of 336 would render the material present in R-2-4 releasable assuming the only contamination present was that detected during the γ scan. As it is not likely that the contamination on the FSA stainless steel is smearable, a DF of 70 would probably be sufficient to produce material that met the "average" criteria based on the

a. R. L. Demmer cut four pieces, approximately 1 inch², respectively, from one of the barriers using a hacksaw.

b. All surfaces of each sample were scanned; the tabulated values are those from the surface of each sample that resulted in the greatest number of counts.

c. "Measurements of average contamination should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each subject object.

The maximum contamination level applies to an area of not more than 100 cm².

The amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped." (see U.S.AEC Regulatory Guide 1.86).

assumption stated above. These results suggest that decontamination of this material to free release levels should be possible.

III. Decontamination Technologies

A wide variety of decontamination technologies have been developed and demonstrated for the surface decontamination of RSM, and a variety of review articles describing these technologies are available.^{4,5,6,7,8,9} These techniques may be nominally partitioned into three groups: chemical methods, mechanical methods and compound methods (which utilize chemical and mechanical methods in tandem). Included in the chemical methods grouping are: rinsing with water (to solubilize surface contamination), acid washing/dipping, electropolishing, and other methods that remove surface contamination by means of chemical reactions. The mechanical techniques include abrasive grit blasting, CO₂ pellet blasting, high and ultra-high pressure water blasting (in which water is used as an abrasive), scrubbing, and ultrasonics. The compound techniques include laser ablation,^d electrohoning,^e and high pressure washing, scrubbing, or ultrasonic treatments in combination with corrosive solutions.

Decontamination methods such as electrorefining, melt refining and slagging are not addressed for the removal of surface contamination because these are best suited for the removal of volume decontamination. When these techniques are applied to surface contaminated materials, there is a high probability that the surface contamination will become volume contamination. As there are no "free release" criteria for volume contaminated materials, it would be extremely undesirable to convert surface contamination to volume contamination (in the unlikely event that the free release criteria of NRC Reg. Guide 1.86 are implemented for the disposal of DOE RSM) if there are no identifiable end-uses for volumetrically-contaminated material.

III.A. Chemical Methods

Chemical methods include those in which the decontamination agent reacts chemically with the contaminants, and possibly the surface to which the contamination is attached, and removes the contaminants 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 would include complexants and/or acids or bases. A variety of other chemicals have also been

d. The mechanical aspects are related to the ablation or thermal mechanical shock that causes material to fracture and depart the surface of the contaminated item; the chemical aspect of this technique is the vaporization that occurs due to surface heating by the laser.

e. Literature on this topic may also be found by searching the term "electrohorning" because of an error in the title of one paper on the subject.

utilized for surface decontamination of stainless steels. As it will not be possible to address all of the reagents in detail, only acids, commercial products, metal ion solutions, and electropolishing will be discussed in detail.

III.A.1. Acids

Acids are more corrosive than water. Often organic acids, especially citric and oxalic, are used for surface decontamination because they are less corrosive than mineral acids. They also are easily decomposed, resulting in less downstream corrosion (during in-situ decontamination in operating facilities).^f

A commonly-used technique for decontaminating pressurized water reactor (PWR) cooling loop components involving weak acids is the two step, alkaline permanganate ammoniated citric acid (APAC) process. The first step is the oxidation of the contaminated surface by alkaline (pH = 14) permanganate at 60°C, which causes the surface oxide coating to become embrittled; the second is decontamination in a chelating acidic bath (citric and oxalic acids), that removes the contamination layer and prohibits redeposition of contamination; a corrosion inhibitor may also be present in the acid bath.¹⁰ This technique has been used successfully at the ICPP for a variety of applications involving surface-contaminated stainless steel processing equipment and lines.¹¹

Another multistep chemical process is the four-step CONAP process. The first step is an alkaline pretreatment of the contaminated surface, followed by oxidation of the surface with acidic potassium permanganate, dissolution and complexing of the contamination with a complexant, and last, a rinsing step to remove process solutions from the surface of the decontaminated item. Decontamination factors of greater than 10,000 have been measured during routine decontamination activities involving reactor primary cooling components. Metal processed by this scheme has been melted and caste into shielding blocks.¹²

The use of aqueous 2.5 w/o glycolic acid-2.5 w/o citric acid mixtures for the 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 specimens (actual material from the hot leg of the reactor cooling system) that were suspended in the decontamination solutions. Decontamination factors⁹ have been measured as a

f. Oxalic and formic acids can be oxidized to H₂O and CO₂ under sufficiently oxidizing conditions.

g. The "decontamination factor" (DF) is a measure of the decontamination efficacy of a reagent and is calculated using the expression

$$DF = (\text{activity of untreated surface})/(\text{activity of treated surface}).$$

function of treatment time, with a maximum DF of 6.9 being attained for 48 hour treatments.¹³

A relatively recent application of a multiple acid method is the very soft (VS) process. This is a two-step process. The first step involves treatment of the surface with a permanganic acid-chromic acid mixture, followed by a solution that is mainly oxalic acid. This technique has been used for decontamination of PWR, BWR and HTGR components with varying degrees of success, with mean DFs as high as 400 for the HTGR components and 150 for the BWR components.¹⁴

Strong mineral acids are not generally used for decontamination due to corrosion problems (with halide-containing acids, especially HCl), passivation problems (HNO₃), and safety concerns related to hydrogen gas generation; however, these solutions have been shown to be quite effective for removing some types of surface contamination from stainless steels.¹⁵

The aggressive chemistry of the chloride ion in HCl(aq) has also been exploited in mixtures for surface decontamination of stainless steel. Mixtures of HCl and hydroxylamine hydrochloride (NH₂OH·HCl) and HCl and AlCl₃, respectively, have been shown to be effective for performing bulk dissolution as a means of surface decontaminating stainless steel. Hydrochloric acid alone was also effective; however, as expected, it caused extreme pitting of the decontaminated surfaces. In these studies, up to 0.5 cm/day was removed from the surface of 316 stainless steel samples during batch dissolution studies with the NH₂OH·HCl/HCl mixtures. As the contamination-containing oxide layer on stainless steel is usually about 0.0005 cm thick, this technique could be useful for the surface decontamination of reactor cooling loop components.¹⁶

Mixtures of aggressive acids have also been investigated for surface decontamination of RSM stainless steels. Dilute solutions of nitric acid, 0.5 to 1.0 weight percent (w/o), and hydrofluoric acids, 0.05 w/o, have been shown effective for surface decontaminating stainless steel fuel baskets for free release in Canada.^h These studies also included the development of an cation exchange system for regeneration of the decontamination solutions that could lead to considerable volume reductions during full-scale operation of the process.¹⁷ Other workers have also examined solutions of mixed acids that have shown promising results as well.^{18,19}

While there are, at this time, free release criteria for surface contaminated RSM in place, current practices throughout the DOE complex disallow free release of material with contamination above background levels. If free release cannot be

h. The target level for the final product was 0.1 $\mu\text{Ci}/\text{m}^2$ of β - γ contamination; this treatment resulted in levels below this target level.

achieved in the future, melt refining could be used to recycle material into useful products for applications in a controlled environment.

While there are, at this time, free release criteria for surface contaminated RSM in place, current practices throughout the DOE complex disallow free release of material with contamination above background levels. If free release cannot be achieved in the future, melt refining could be used to recycle material into useful products for applications in a controlled environment.

III.A.2. Commercial Products

A variety of commercial decontamination solutions are available for use and the efficacies of sixteen of these solutions were compared to one another and to that of 10 w/o oxalic acid, which is commonly used for the surface decontamination of 304L stainless steel coupons. The contaminated coupons were prepared by baking an aqueous suspension of Savannah River Plant waste tank sludge onto the surface of the 304L coupons. The decontamination solutions were prepared as directed in literature provided by the manufacturers. The chemical compositions were not published in the open literature (most are proprietary), but short descriptions of the most effective are presented below.

Turco Decon 4521 and Turco Decon 4518 are oxalic acid-based solutions designed to decontaminate stainless steels. Turco Decon 4306D is a powder and does not etch stainless steel; it is low in chloride and fluoride and contains bisulfite salt(s). Atomic Products Radiacwash is a noncorrosive, nonalkaline, biodegradable solution that contains no phosphate, chromate, silicate, borate, carbonate, aluminate or halide salts. It decontaminates by dissolving contaminant ions from the surface and complexing them. Nutek 750C is a noncorrosive, biodegradable solution of nearly neutral pH and is marketed as a calcium sulfate scale remover. Nutek 75C/2X is a nonacidic, biodegradable solution that dissolves inorganic coatings from stainless steel surfaces. Research Products International Lift-Away is a noncorrosive, nonacidic, biodegradable solution that contains no phosphate, chromate, borate, carbonate or halide salts.

The results showed that four of these commercial solutions, Turco Decon 4521, Turco Decon 4518, Turco Decon 4306D and Atomic Products Radiacwash, had infinite DFs for the removal of the simulated contamination (as did the 10 w/o oxalic acid), while Nutek 75C/2X, Nutek 750C and Research Products International Lift-Away had DFs of 72, 13.7 and 8.83, respectively.²⁰

III.A.3. Metal Ion Solutions

Metal ion-containing reagents for the surface decontamination of stainless steel are well known. A variety of studies have been performed to investigate the

effectiveness of reagents employing metal ions that attack surface contamination.^{21,22,23,24,25} These reagents may be conveniently partitioned into two groupings, low oxidation state transition metal ions (LOMI) and high oxidation state metal ions.

The LOMI reagents that have shown effectiveness for surface decontamination of stainless steel include those containing V(II)(aq) and Cr(II)(aq). Low pH solutions of acid and LOMI are effective for surface decontamination because the high acidity keeps the LOMI and dissolved contaminant metal ions in solution. Solutions of higher pH, with organic complexants added to increase the solubility of both the LOMI and contaminant metal ions, are also effective. Decontamination occurs because the LOMI reduce the metal ions in the surface contamination, destabilizing the contaminant layer, which subsequently dissolves in the acidic solution. Complexants added to the high pH solutions also tend to stabilize the dissolved product, promoting dissolution and retarding redeposition.²⁶

Vanadium(II) picolinateⁱ has been shown effective in removing Magnox reactor boiler deposits²⁷ and Steam Generating Heavy Water Reactor primary cooling loop contamination.²⁸ The effectiveness of this reagent for the removal of iron oxide deposits is not completely surprising as the Fe(III)/Fe(II) reduction potential, 0.771 v, is much more positive than that for the V(III)/V(II) couple, -0.255 v.²⁹ This vanadium reagent is not, however, effective for the removal of high chromium deposits (often found in the primary cooling systems of boiling water reactors). This ineffectiveness is not surprising because the reduction of uncomplexed aqueous Cr(III) by V(II) picolinate is not thermodynamically favorable.

A variety of Cr(II) aqueous complexes have, however, been found effective for removing the high-Cr deposits in BWR primary cooling systems. The effectiveness of these reagents is believed to be due to both the stability of the complexed aqueous Cr(III) species and the regeneration of Cr(II) aqueous species by each reaction of a Cr(II) complex with Cr(III) in the contamination.³⁰

Solutions of high oxidation state cerium, Ce(IV), in sulfuric, hydrochloric and nitric acid, respectively, have been investigated for use as stainless steel decontamination reagents. Although all three have shown effectiveness, only the sulfuric and nitric acid solutions have been used extensively.^j The effectiveness of the sulfuric acid/Ce(IV) solution is primarily dependant on the Ce(IV) concentration³¹ and in preliminary studies it has been shown to be superior to the Ce(IV)/nitric acid reagent. Decontamination factors, from 24 hour treatments of

i. Picoline is a monosubstituted methyl-pyridine with the methyl substituent at the 2,3, or 4 position.

j. This is most likely due to the fact that chloride-containing solutions are quite corrosive to and cause pitting of stainless steel surfaces.

similar specimens of actual contaminated stainless steel, for 1.3 millimolar (mM) Ce(IV) in 0.25 M H_2SO_4 at 80°C and 5 M Ce(IV) in 0.5 M HNO_3 at 90°C were 460 and 4.3, respectively.³² The difference between the two DFs may be due at least in part to the relatively low nitric acid concentration. The effectiveness of the Ce(IV)/nitric acid solution is a function of both the concentration of ceric ion and the nitric acid, with nitric acid concentrations in the range 0.5 - 4 M resulting in maximum effectiveness.³³

A proprietary Ce(IV) process has been developed that is purported to utilize a "cerium acid" as the active ingredient.³⁴ In this reagent, the cerium is also present as ceric ion, but the concentration of Ce(IV) is much lower than in other Ce(IV)-containing decontamination solutions.

III.A.4. Gels

A recent chemical decontamination development is the use of gels that contain traditional (or other) decontamination reagents. The advantages of gels, as compared to traditional recirculated aqueous solutions, are that they require lower volumes of decontamination solutions and have longer contact times with the contaminated surface; subsequently, they tend to produce reduced waste volumes as well. During decontamination tests involving the CO_2 cooling system on the French gas-cooled G2 reactor, DFs of about 500 were obtained by a multi-step process. The first step was an alkaline gel treatment (3 M NaOH in a gelling agent), followed by rinsing, treatment with an acidic gel (3 M H_3PO_4 , 3 M H_2SO_4 , silica and Cemusol) and a second rinse.³⁵

III.A.5. Electropolishing

The electropolishing decontamination technique has been extensively used for the surface decontamination of metals and alloys. The item to be decontaminated, which acts as the anode of the electrolytic cell, is placed in a bath containing the decontamination solution. The bath is generally a phosphoric acid solution, or a phosphoric acid/sulfuric acid solution. A stainless steel mandrill is present in the solution to act as the cathode. As electric current is passed through the cell, oxidation of the anode causes the surface of the anode to be removed. The thickness of surface layer removed is usually 5 to 50 μm during an operating period of 3 to 30 minutes. The surface contamination is consequently removed as the surface of the anode is etched; representative operating conditions are 8 to 12 volts (DC) and 5 to 20 amperes per square decimeter (A/dm^2).

This technique is quite versatile. It has been used in the batch mode for disassembled components and also in the in-situ mode. Among the items decontaminated by this technique are: tools of various sizes and dimensions,

stainless steel animal cages, fission product storage containers, laboratory ware, ducting, pipe and a variety of valves.³⁶ During decontamination in the batch mode, the electrolyte solution is constantly mixed by recirculating the solution through an external loop. The solution may be filtered or chemically treated during recirculation to remove contaminant material and/or to regenerate the electrolyte solution.

While electrolytic decontamination is usually performed with an acidic decontamination solution, it is sometimes advantageous to use a basic solution to ensure compatibility with downstream processes involving the decontamination electrolyte. One such basic electrolyte is an aqueous solution 2.35 M in sodium nitrate, 0.052 M in sodium tetraborate decahydrate, 0.015 M in sodium oxalate, and 0.060 M in sodium fluoride. The boron-containing compound is present for criticality protection (when decontaminating items with fissile-material contamination), as well as to raise the pH to 8.5 to 8.9 range. The oxalate anion is present to increase the bulkiness of the metallic ions that may later be separated by precipitation and the fluoride ion is present to complex contaminant ions (specifically plutonium).^k The application of this method to plutonium-contaminated stainless steel has been successfully demonstrated. Decontamination factors of 7×10^6 were attained during the treatment of a variety of stainless steel items.³⁷

A third permutation of the electrolytic technique is the use of an alternating-current (ac) voltage. This technique may employ an acidic or neutral solution; sodium nitrate is a commonly-used neutral electrolyte. The alternating current technique often provides superior decontamination because the alternating current causes the surface contamination to be alternately oxidized and reduced, thus resulting in the removal of oxide coatings, where the bulk of surface contamination is held, when standard anodic decontamination techniques alone are not effective.³⁸

The alternating anodic and cathodic electrolysis can effectively decontaminate a metal surface, even with oxides present. For example, during carbon steel decontamination tests, it is believed that the alternating electrolysis removes the surface oxide in the three step process by the cathodic reduction of the $\text{Fe}_3\text{O}_4(\text{s})$ surface oxide: (1) the oxide layer is reduced to produce an amorphous surface layer primarily consisting of FeO , followed by (2) dissolution of the iron contained in the surface layer, and finally (3) the ionic reactions in the aqueous solution. The first step is the removal of an oxide ion from the surface film, with an accompanying reduction of ferric ion to ferrous ion or elemental iron, to form the amorphous layer. The second step is the dissolution of ferrous ion and oxide ion, and/or elemental iron, from the amorphous layer. The third step is the formation of ferrous

k. The concentrations were computed from the published results of Childs and Long, Nuclear Technology, 54, p. 209 (1981), which were reported in grams per liter of each compound. The molar masses of each compound were taken from: CRC Handbook of Chemistry and Physics, 64th edition, R. C. Weast, editor-in-chief, CRC Press, Inc., Boca Raton, FL (1983).

hydroxide and water by reaction of ferrous and oxide ions, with hydroxide and hydrogen ions, respectively. It is believed that the diffusion of the ferrous and oxide ions through the amorphous surface layer are the rate determining processes.³⁹

III.B. Mechanical Methods

There are a variety of abrasive methods that may be implemented to surface decontaminated RSM. These range from fairly unsophisticated methods, such as scrubbing with brushes, to the more sophisticated, which include CO₂ pellet blasting, honing and ultrasonic vibration. Abrasive scrubbing with brushes is effective for some application, such as the removal of surface contamination that is loosely held to the surface. For more tightly bound contaminants, ultrasonic vibration with abrasive materials, abrasive grit blasting, or CO₂ pellet blasting would be more effective.

One of the major drawbacks to these decontamination techniques, except for CO₂ pellet blasting, is the production of secondary wastes. Using water or non-volatile solids for the abrasive material results in a waste that contains non-radioactive materials. In the case of water, the solutions may be evaporated, but this activity requires a facility. Carbon dioxide pellet blasting eliminates the production of large volumes of waste that include nonradioactive materials because the CO₂ sublimates at normal operating temperatures, leaving only the radioactive contaminants to be dispositioned.

Hard machining, in tandem with less abrasive mechanical or chemical techniques, has been one of the traditional methods utilized for surface decontamination of the interior of BWR primary cooling components prior to maintenance activities. The less abrasive technique is first applied to remove the outer layer of "soft crud" contamination that is usually composed of hematite, followed by the machining to remove the "hard crud" deposits composed mainly of magnetite. The less abrasive techniques, such as vibratory finishing, brush cleaning, and high pressure water cleaning, all lead to large volumes of secondary wastes. The recent application of CO₂ pellet blasting to the removal of the "soft crud" has shown it to be a promising technique because of high effectiveness and because the production of secondary waste is nearly negligible.⁴⁰

Abrasive honing is a technique that is well suited for the surface decontamination of the inside surface of long lengths of pipe. The Flex-hone, which is commercially available,¹ is a set of abrasive honing stones attached to nylon strands that acts as a brush; the "brush" can be rotated at high rates of speed (up to 1800 rotations per minute). Decontamination factors in the range 100 to 300 were achieved during

I. The Flex-hone (trademark owned by Brush Research Manufacturing, Inc) is a commercial device.

experimental investigations on carbon and stainless steel pipe. This abrasive technique produces considerably less waste than abrasive grit blasting techniques because the same stones can be used for a long periods of time (as opposed to using large volumes of abrasive grit with a carrier solution).⁴¹

III.C. Compound Methods

Electro-honing decontamination is a concatenation of two well-known techniques: electrolytic decontamination and mechanical (abrasive) decontamination. This technique is most applicable for large, flat surfaces. The apparatus developed for this application may be operated remotely. The operational portion of the apparatus consists of two rotating cylinders, that act as the cathodes, with a solution circulation system that introduces the electrolyte solution to the abrasive cylinders where the electrolyte contacts the surface of the workpiece through openings in the surface of each abrasive cylinder; surface removal is performed by the two rotating, abrasive cylinders. Development work has been performed with both acid and neutral salt solutions; however, no DFs were reported.⁴²

There are a variety of other combinations of techniques that are also available for use. High pressure washing can be performed with alkaline or acidic solutions; it is also possible for complexants to be present as well. These techniques are improvements over water blasting with regard to decontamination factors; however, the wastes are sometimes more difficult to manage.

One such example for which the waste management is not an extraordinary problem is the use of hot oxalic acid in tandem with ultrasonic and mechanical scrubbing. This technique was used on pipe weld specimens from the Monticello BWR with great success. Decontamination factors of 70,000 for β - γ contamination and 100,000 for α contamination were realized using this tandem technique, followed by chemical wipedowns of the decontaminated surfaces, and electropolishing of hot spots.⁴³

Another compound method is laser ablation decontamination; this technique causes the fracture of contaminant coatings with simultaneous vaporization of the contaminants from the surface being decontaminated. Although a patent application for this technique was submitted in the early 1980's,⁴⁴ this technology is by no means mature; it does, however, show some promise for reducing worker exposures, because it can be operated remotely, and for the reduction of waste, as compared to traditional methods, because it does not employ solvents or carriers. Laboratory scale studies have demonstrated that a 100 watt Kerf eximer laser can remove about 1 μ m of a 430 stainless steel surface per laser pulse at pulse frequencies of about 300 Hz; the area of the surface ablated is dependant on the focussing of the laser beam.⁴⁵ This technique also can be used to destroy organic coating that are present with radionuclide contamination.

III.D. Comparison of Decontamination Methods

Comparison of alternative decontamination schemes for the FSA stainless steel could reasonably be based on the following criteria: contamination level and type present on the RSM stainless steel, technical sophistication of the method, desired contamination level of the product, volume of waste generated, the availability of facilities in which to perform these activities, and total cost. An attempt to discuss and address these concerns is presented below.

The most important of these criteria is the contamination level and type present on the RSM stainless steel. This criteria is most important because the amount and type of contamination present on the contaminated material impacts the other criteria. Different types of contamination require different decontamination techniques and facilities in which to perform the activities, and each decontamination technique may have other unique characteristics as well.

The preliminary knowledge pertaining to the contamination present on the FSA stainless steel suggests that the material is surface contaminated, with Co-60 being the primary contaminant. It is unlikely that compound methods will be necessary to decontaminate this material, so the reasonable choices for decontamination techniques are chemical and mechanical techniques. One of the prime considerations when making the final choice should be ease of operation, which quite often translates into savings of both time and money. Another, and maybe the most important consideration, is waste generation, which is also closely related to cost.

The chemical techniques reviewed in this document included both mature and new techniques, and it is likely that almost any of the chemical techniques would be appropriate for decontaminating the FSA RSM. It is not clear if this contamination is "hard crud" or "soft crud". Most of the non-machining mechanical methods will not remove "hard crud" surface contamination, so it is not known if a mechanical technique will be appropriate for this application.

It is also not clear what level of contamination is acceptable for the decontaminated material; this requirement is somewhat dependant on the end-use of the material. It is reasonable to expect, however, that materials that do not meet the "free release" criteria of NRC Reg. Guide 1.86 would be unacceptable for processing by facilities in the private sector. For this reason, it is supposed that the decontaminated material should meet the "free release" criteria of Reg. Guide 1.86.

The volume of waste generated, the availability of facilities and the total costs associated with this activity are not quantified at this time. Preliminary information

is available, however, for the four alternatives addressed by the Fluor-Daniel reracking report, and that information is presented and discussed below.

IV. FSA Rack Decontamination/Dispositioning Alternatives^{m,46,47}

Reracking of the basins at the FAST facility (CPP-666) was proposed as part of the FDP upgrade project. The conclusions, with regard to the waste disposal of RSM produced during reracking, can be summarized by the following four alternatives:

1. Bagging and burying the racks as-is at the RWMC. This alternative would involve removing the racks from the basins, bagging and boxing them on-site without any size reduction, and burying them at the RWMC.
2. Demolition on-site and burial at the RWMC. This alternative would involve size reducing the racks on-site, bagging and boxing the resulting material, and burying the resulting material at the RWMC.
3. Shipping the racks off-site for demolition, decontamination and subsequently dispositioning of the resulting waste and decontaminated metal. This alternative would involve bagging and boxing the racks on-site and shipping them to an off-site contractor where the racks would be demolished and decontaminated. The off-site contractor would take title to some of the material (which would be decontaminated well enough to be free-released as stainless steel scrap), and the remainder of the material would be returned to the INEL for disposal at the RWMC.
4. Shipping the racks off-site to a foundry. This alternative would involve bagging and boxing the racks on-site and sending them to a foundry where the stainless steel would be melted and cast into shielding blocks for use elsewhere in the DOE complex. No material would be returned to the INEL for disposal at the RWMC.

IV.A. Comparison of Alternatives

The first alternative would produce, by far, the greatest amount of waste because the racks are quite bulky. It is estimated that 56,368 ft³ of waste, at a total cost of \$2,740,079,ⁿ would be buried at the RWMC if this disposal scheme were implemented. This alternative would include no decontamination of the material.

m. The cost information and descriptions of alternatives presented in this section was abstracted from the Fluor-Daniel, Inc. "Rack D&D Conceptual Design Report" and "FSA Rack Reconfiguration Project Plan Title I" report.

n. This total cost includes: \$2,480,192 for disposal costs at the RWMC (based on the rate of \$44/ft³ for disposal at the RWMC), and the balance for other costs that include materials, storage and transportation.

The second alternative would result in an estimated 14,848 ft³ of waste, at a total cost of \$2,584,138,^o for burial at the RWMC, at an overall volume reduction of 3:1 as compared to disposal without size reduction. The metal would not be decontaminated prior to disposal.

The third alternative would result in a volume reduction slightly greater than 10:1 as compared to the first alternative, which would result in 4480 ft³ of waste being disposed of at the RWMC at a total cost of \$2,360,776.^p A portion of the metal would be decontaminated for free release by the off-site contractor. The material that could not be free released would be returned to the INEL for disposal at the RWMC. Decontamination techniques would probably include chemical dipping and/or electro-polishing.

The last alternative is considerably less expensive than the other three, primarily because the metal, once decontaminated, would be reused rather than dispositioned to a waste facility. The material would be melt-refined at a total cost of \$1,231,527,^q with the processor disposing of the contaminated by-products that result from processing. The volume reduction would be about 90:1 as compared to the as-is disposal alternative.

V. Conclusions

The results of an analysis of the dispositioning alternatives developed during the reracking studies lead to the conclusion that it is cost effective to decontaminate and recycle the FSA RSM, as compared to burial with or without size reduction. While the costs associated with this activity cannot be estimated at this time (the nature of the contamination, the decontamination technique to be used, and the end-uses of the material are not known), it is clear that the least cost effective alternative is to bury the racks without size reduction and that burying the material after size reduction is not significantly more cost effective because the cost of the size reduction activities almost entirely consumes the cost savings resulting from the reduced burial costs.

During an analysis of the cost effectiveness of using RSM for the fabrication of dry storage fuel canisters,⁴⁸ it was shown that a cost savings of \$32,000 per canister would be realized, as compared to using steel purchased on the open market, by

o. This cost includes: \$1,600,335 for demolition, \$653,312 for burial at the RWMC and the balance for other costs that include materials, storage and transportation.

p. This cost includes: \$2,040,309 in off-site contractor costs, which corresponds to \$3.23/pound, associated with demolition and decontamination, \$197,120 for burial at the RWMC, and the balance for other costs that include materials, storage and transportation.

q. This cost includes: \$276,747 for transportation, \$757,440 for off-site contractor costs (which corresponds to \$1.20/pound), with the balance of the costs attributable to packaging and storage.

using RSM. While this analysis was based on the use of melt refining as the decontamination technique, the costs associated with using a different decontamination technology should not cause much more than a three-fold increase in the decontamination costs as compared to melt refining.^r

It would be most expedient to decontaminate the material as it was removed from the FSA basins because storage costs for contaminated RSM are much greater than those for clean material. This decontamination should be performed prior to size reduction if possible because the common size reduction techniques, especially plasma arc cutting, will likely result in the production of volumetrically-contaminated materials, which will probably require burial.^s Decontamination by melt refining immediately upon removing the RSM from the FSA basins would limit the subsequent uses of the material to a DOE/NRC-controlled environment because there are no volume release criteria for RSM. Using a surface decontamination technology would allow the decontamination of the RSM as it left the FSA basins, as opposed to decontamination just prior to fabrication while not limiting the options for end-uses of the RSM.

The cost estimated by Fluor-Daniel, for the third alternative (destruction and decontamination at a private contractor facility with the contractor free releasing some of the material and returned the undecontaminated material to the ICPP for burial at the RWMC), was based on chemical dipping or electropolishing being used for the decontamination of the RSM. These two techniques would seem to be among the logical chemical techniques for the decontamination of this material; mechanical techniques, such as CO₂ pellet blasting, could be applicable if it is determined that this contamination is "soft crud."

Recently, a draft review and evaluation of decontamination technologies was compiled by the Decontamination and LLW Development Group.⁴⁹ In this evaluation, the applicability of various techniques for loose and fixed contamination removal, the technical status and limitation of each technique, and a rating of each technique based on effectiveness and availability (highly recommended, recommended or not recommended) were presented. The highly recommended techniques that could decontaminate to free release levels were: grit blasting, organic acids, inorganic acids REDOX treatments (metal ion treatments), and complexants; the recommended techniques that could decontaminate to free release levels were: ultra-high pressure water blasting (35,000 psi or greater),

r. Off-site contractor costs for melt refining, \$757,440, are about three times smaller than those associated with traditional methods, \$2,040,309. These figures were taken from the "Comparison of Alternatives subsection of the "FSA Rack Decontamination/Dispositioning Alternatives" section of this report.

s. Alternative 3 from the **FSA Rack Decontamination/Dispositioning** section of this report predicted the production of waste that could not be decontaminated. This was probably hypothesized because it is likely that the result of plasma arc cutting or other size reduction would be the conversion of some of the material into volumetrically-contaminated stainless steel.

various CO₂ blasting techniques, ice blasting, laser ablation, chemical gels, fluoboric acid, caustic treatment, ultrasonic treatment, and vibratory finishing. From this listing, it is clear that there are a variety of techniques that could be successfully implemented for the decontamination of FSA RSM.

VI. Recommendations

It is recommended that the FSA surface-contaminated stainless steel be decontaminated as soon as possible upon its removal from the FSA, and that decontamination be performed prior to size reduction. If it is not possible to size reduce prior to decontamination, then the material should be stored, as contaminated material, until its end-use is determined. Any activities that result in the conversion of surface contamination into volumetric contamination should be avoided until the end-use of the material is known.

Chemical decontamination using an organic acid or a commercial product containing an organic acid is the recommended technique for the decontamination of FSA RSM; however, because it is not possible to guarantee that this technique will be successful, it is recommended that more than one additional chemical technique, at least two mechanical decontamination techniques, and laser ablation be tested for decontamination efficiencies as well. The chemicals should be selected from the large variety of commercial and other traditional reagents that have been demonstrated effective for decontaminating stainless steel RSM and that are likely to be compatible with ongoing ICPP waste treatment operations. This may eliminate many reagents from consideration, but compatibility with ongoing activities at the ICPP is essential from a cost effectiveness perspective.

The mechanical techniques investigated should include CO₂ pellet blasting and ultra high pressure water blasting, but not abrasive grit blasting. The concern with the abrasive grit blasting is that this material may not be compatible with ongoing waste management activities; this should not be a problem with the carbon dioxide and water processes.

The third recommendation is continued investigation of laser ablation. This technique is probably not applicable for the FSA decontamination activity, but this technology could well have widespread application for a variety of organic-RSM mixed waste problems, as well as for traditional surface RSM decontamination.

VII. References

1. Fluor-Daniel, Inc., Advanced Technology Division, FSA Reracking Project - Conceptual Design, Rack Decontamination, Demolition and Disposal Study (SOW 3.2.2), work performed under DOE Contract DE-AC07-90ID12680, p. E-1, May 1992.
2. "Information Only" Report of Analytical Results for Sample Log Number 080411, August 04, 1993.
3. "Regulatory Guide 1.86 Termination of Operating Licenses for Nuclear Reactors," in U.S. Atomic Energy Commission Regulatory Guide, Directorate of Public Standards, June, 1974, pp. 1.86-1 - 1.86-5.
4. H. W. Arrowsmith and R. P. Allen, "New Decontamination Techniques for Exposure Reduction," in Proceedings of the U.S. Department of Energy Environmental Control Symposium, Volume 2, Nuclear Energy and Transportation, report no. DOE/EV-0046 (or CONF-781109-vol.2), 1979.
5. R. P. Allen, Overview of Nonchemical Decontamination Techniques, Pacific Northwest Laboratory, Richland, WA, 1984, report no. PNL-SA--12562.
6. G. L. Copeland, Decontamination Effectiveness for Metallic Low-Level Waste, Oak Ridge National Laboratory, Oak Ridge, TN, report no. ORNL/HFW-81/34.
7. R. P. Allen, "Nonchemical Decontamination Techniques," **Nuclear News**, June 1985, p. 112.
8. R. P. Allen, L. K. Fetrow and M. W. McCoy, PNL Size Reduction and Decontamination Facilities and Capabilities, Pacific Northwest Laboratory, Richland, WA, 1983, report no. PNL-SA--11416.
9. R. P. Allen, K. J. Schneider, G. J. Konzek and R. I. Smith, "Decontamination Technology Assessment," in International Topical Meeting on Nuclear and Hazardous Waste Management: Spectrum '88, American Nuclear Society, La Grange Park, IL, 1988, p. 511.
10. J. P. Gauchon, F. Bregani, W. Ahlfaenger and M. Lasch, Composition of Contamination Layers, report no. EUR-9474, and references within.
11. J. E. Johnson and A. G. Westra, ICPP Decontamination Manual, Allied Chemical Company, Idaho Falls, ID, report no. ICP-1172, January, 1979, p. II-1.2.
12. P. Hebrant, "Lending Piping a New Lease of Life," **Nuclear Engineering International**, 34(414), p. 48 (1989).

13. E. F. Hill, J. M. Lutton and H. P. Maffei, "Removal of Radioactive Isotopes from LMFBR Components Using the Glycolic--Citric Acids Process," in Second International Conference on Liquid Metal Technology in Energy Production, NTIS, U.S. Department of Commerce, Springfield, VA, 1980, p. 8-13.
14. E. Schenker, E. Buchley, H. P. Alder, W. Francioni, W. Heess and A. Conrath, "VS-decontamination Process," in Water Chemistry of Nuclear Reactor Systems 5. Proceedings of the International Conference, British Nuclear Energy Society, London, 1989, p. 186.
15. J. P. Gauchon, F. Bregani, W. Ahlfaenger and M. Lasch, Composition of Contamination Layers, report no. EUR-9474.
16. D. A. White, "Development of Reagents for the Decontamination of Stainless Steel Plant Scrap by Bulk Dissolution," in Proceedings of the Institute of Mechanical Engineers International Conference Decommissioning of Major Radioactive Facilities, Mechanical Engineering Publications, Bury St. Edmunds, UK, 1988, p. 111.
17. A. Husain, "A Process for Decontaminating Stainless Steel to Release Limits," **Nuclear Technology**, 85, p. 66 (1989).
18. A. Agostinelli, F. Bregani, R. Pascali and C. Ronchetti, Vigorous Decontamination Tests of Steel Samples, 1982, report no. CONF-821005.
19. H. Crossley and J. R. Wakefield, "Development of Techniques to Decontaminate the WAGR Heat Exchangers," in Decommissioning of Nuclear Installations, Proceedings of an International Conference, report no. EUR 12690, October 1989, p. 567.
20. E. A. Shurte, "Evaluation of Commercially Available Decontamination Chemicals," in Waste Management '88, Waste Processing, Transportation, Storage and Disposal Technical Programs and Public Education, Volume I, Arizona Board of Regents, 1988, p. 725.
21. T. Swan, M. G. Segal, W. J. Williams and M. E. Pick, LOMI Decontamination Reagents and Related Preoxidation Processes, Electric Power Research Institute, Palo Alto, CA, 1987, report no. EPRI NP-5522M.
22. M. T. Wang, Effect of LOMI Decontamination and Preoxidation Processes on Stainless Steel-Clad Low-Alloy Steel, Electric Power Research Institute, Palo Alto, CA, 1990, report no. EPRI NP-6730.
23. L. A. Bray, Development of a Chemical Process Using Nitric Acid-Cerium(IV) for Decontamination of High-Level Waste Containers, Pacific Northwest Laboratory, Richland, WA, 1988, report no. PNL-6567.

24. T. Suwa, N. Kuribayashi and E. Tachikawa, "Development of Chemical Decontamination Process with Sulfuric Acid-Cerium(IV) for Decommissioning, Single Step Process to Dissolve Chromium-Rich Oxides," **Journal of Nuclear Science and Technology**, 23(7), p. 622 (1986).
25. T. Suwa, N. Kuribayashi and E. Tachikawa, "Development of Chemical Decontamination Process with Sulfuric Acid-Cerium(IV) for Decommissioning, System Decontamination Process with Electrolytic Regeneration of Ce^{4+} from Ce^{3+} ," **Journal of Nuclear Science and Technology**, 25(7), p. 574 (1988).
26. T. Swan, M. G. Segal, W. J. Williams and M. E. Pick, LOMI Decontamination Reagents and Related Preoxidation Processes, Electric Power Research Institute, Palo Alto, CA, 1987, report no. EPRI NP-5522M, p. 2-1.
27. D. Bradbury, C. Kirby, M. G. Segal and W. J. Williams, "Decontamination of Magnox Boilers," in Proceedings of the Institution of Mechanical Engineers Conference on Decommissioning of Major Radioactive Facilities, Mechanical Engineering Publications, Bury St. Edmunds, UK, 1988, p. 133.
28. T. Swan, M. G. Segal, W. J. Williams and M. E. Pick, LOMI Decontamination Reagents and Related Preoxidation Processes, Electric Power Research Institute, Palo Alto, CA, 1987, report no. EPRI NP-5522M, p. 2-7.
29. W. M. Latimer, The Oxidation States of the Elements and Their Potentials in Aqueous Solutions, Second Edition, Prentice-Hall, Inc., Englewood Cliffs, NJ, pp. 340-348 (1952).
30. T. Swan, M. G. Segal, W. J. Williams and M. E. Pick, LOMI Decontamination Reagents and Related Preoxidation Processes, Electric Power Research Institute, Palo Alto, CA, 1987, report no. EPRI NP-5522M, p. 2-11.
31. T. Suwa, N. Kuribayashi and E. Tachikawa, "Development of Chemical Decontamination Process with Sulfuric Acid-Cerium(IV) for Decommissioning, Single Step Process to Dissolve Chromium-Rich Oxides," **Journal of Nuclear Science and Technology**, 23(7), p. 631 (1986).
32. T. Suwa, N. Kuribayashi and E. Tachikawa, "Development of Chemical Decontamination Process with Sulfuric Acid-Cerium(IV) for Decommissioning, Single Step Process to Dissolve Chromium-Rich Oxides," **Journal of Nuclear Science and Technology**, 23(7), p. 625 (1986).
33. A. P. Murray, "A Chemical Decontamination Process for Decontaminating and Decommissioning Nuclear Reactors," **Nuclear Technology**, 74(3), p. 326 (1986).

34. A. P. Murray, "A Chemical Decontamination Process for Decontaminating and Decommissioning Nuclear Reactors," **Nuclear Technology**, 74(3), p. 324 (1986).
35. M. Montjoie, J. R. Costes and F. Josso, "An Example of Power Reactor Cooling Circuit Decontamination," Proceedings of the Institute of Mechanical Engineers International Conference Decommissioning of Major Radioactive Facilities, Mechanical Engineering Publications, Bury St. Edmunds, UK, 1988, p. 127.
36. R. P. Allen and H. W. Arrowsmith, "Radioactive Decontamination of Metal surfaces by Electropolishing," **Materials Performance**, November, 1979, pp. 21 - 26.
37. E. L. Childs and J. L. Long, "Electrolytic Decontamination of Stainless Steel Using a Basic Electrolyte," **Nuclear Technology**, 54, pp. 208 - 214 (1981).
38. T. Izumida, K. Kato, F. Kawamura and H. Yusa, "Electrolytic Decontamination of Surface-Contaminated Metal by Alternating Electrolysis Using Square-Wave Current in a Neutral Salt Electrolyte," **Nuclear Technology**, 70(2), pp. 249 - 253 (1980).
39. T. Izumida, K. Kato, F. Kawamura and H. Yusa, "Electrolytic Decontamination of Surface-Contaminated Metal by Alternating Electrolysis Using Square-Wave Current in a Neutral Salt Electrolyte," **Nuclear Technology**, 70(2), pp. 249 - 253 (1980), and references within.
40. T. Oguchi, "Using Ice to Blast Off Crud," **Nuclear Engineering International**, January 1989, p. 49.
41. M. Takeuchi, T. Morisue, Y. Hasegawa, T. Takahar and A. Ishihama, "Decontamination of Steel Pipe by Honing," in Waste Isolation in the U.S. and Elsewhere, Technical Programs and Public Communications. Volume 1, General, The University of Arizona, Tucson, AZ, 1982, p. 421.
42. S. Sakamoto, H. Iida and M. Wada, "Development of Electro-horning Decontamination Technique," in Low and Intermediate Level Radioactive Waste Management, Volume 1, pp. 223 - 227 (1989). An alternative source for this citation is report number: CONF-891006, p. 223.
43. T. W. Oliver and J. E. Le Surf, "Recent Pacific Nuclear Decontamination Experience," in Water Chemistry of Nuclear Reactor Systems 5. Proceedings of the International Conference, British Nuclear Energy Society, London, 1989, p. 171.
44. T. A. Wojcik, H. E. Ferree and W. H. Kasner, "Laser Decontamination

Method," Patent: European Pat. Appl.: EP 91646 A1, date 831019, Application: EP 83103326 (830406), *US 368075 (821019).

45. H. M. Pang, R. J. Lippert, Y. M. Hamrick, S. Bayrakal, K. Gaul, B. Davis, D. P. Baldwin and M. C. Edleson, "Laser Decontamination: A New Strategy for Facility Decommissioning," report no. IS-M--730 (1992).

46. Fluor-Daniel, Inc., Advanced Technology Division, FSA Reracking Project - Conceptual Design, Rack Decontamination, Demolition and Disposal Study (SOW 3.2.2), work performed under DOE Contract DE-AC07-90ID12680, May 1992.

47. Fluor-Daniel, Inc., Advanced Technology Division, FSA Rack Reconfiguration Project - Existing Fuel Storage Rack Decontamination and Disposition Plan (SOW 3.2.2, Title I Design), work performed under DOE Contract DE-AC07-90ID12680, May 1992.

48. S. D. Wahnschaffe, Investigation of Using RSM in Dry Storage Canisters, letter SDW-1-93 to B. J. Frazee, dated July 10, 1993.

49. J. L. Gutterud, Decontamination Technologies for Fuel Reprocessing Facilities, letter JLG-12-93 to J. B. Colson, dated June 17, 1993.

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