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MARTIN MARIETTA

Decontamination of Surfaces by Blasting with Crystals of H_2O and CO_2

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-12911

Chemical Technology Division

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EXECUTIVE SUMMARY

A major mission of the U.S. Department of Energy during the 1990s is site and environmental cleanup. In pursuit of this mission, numerous remediation projects are under way and many others are being planned at Oak Ridge National Laboratory (ORNL). A key component of the remediaton work is cooperative endeavors with commercial firms to adapt, demonstrate, and evaluate the vendor's equipment and processes during the decontamination of ORNL facilities. The vendor can use the demonstration results for improving his equipment and processes and in marketing them to others. ORNL can benefit by having its facilities, equipment, or materials decontaminated by the demonstrations.

In this report, tests using two proposed methods for decontaminating surfaces — one using water ice crystals [Crystalline Ice Blast (CIB)],* the other using dry ice crystals (CO_2 Cleanblast™)† — are described. Both methods are adaptations of the commonly used sand-blasting technology. In this technology, sand particles are entrained in a high-velocity air stream and impacted on the surface to be cleaned. While cheap and effective in use, this technology can lead to complications and expense because of the destruction of the surfaces; the increased volume of waste to be handled when the sand, sand fines, substrate, and contaminants are mixed together; and the disposal problems that result when the recovered fines contain Resource Conservation and Recovery Act materials and are defined as mixed wastes (e.g., in this case, lead compounds mixed with radioactive isotopes).

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*Applied Radiological Control, Inc., Kennesaw, GA 30144.

†Environmental Alternatives, Westmoreland Industrial Park, Route 12, Westmoreland, NH 03457.

Both the Crystalline Ice Blast and the CO_2 Cleanblast™ processes have advantages that could be superior to those offered by the conventional methods for decontaminating items in the nuclear field. The two methods tested differ from sand blasting in that the particles are not particularly abrasive and do not accumulate as particles in the wastes. They differ from each other in that the CO_2 particles sublime during and after impact and the ice particles melt. Thus, the two demonstrations provide important information about two strong candidate decontamination methodologies. Each process was tested at ORNL using contaminated lead bricks and contaminated tools and equipment.

Demonstrations with the prototype Crystalline Ice Blast and the CO_2 Cleanblast™ systems showed that paint, grease, and oil can be removed from metal, plastic, asphalt, and concrete surfaces. Furthermore, removal of contamination from lead bricks was highly effective. Both processes were found to be less effective, under the conditions tested, with contaminated tools and equipment that had chemically bonded contamination or contamination located in crevices since neither technology abrades the substrates or penetrates deeply into crevices to remove particulates. Some process improvements are recommended.

1. INTRODUCTION

Oak Ridge National Laboratory (ORNL) is a multipurpose research and development facility operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy (DOE). Since its establishment in the early 1940s, ORNL has operated numerous facilities for pursuing its many research, development, and demonstration missions. As an undesired by-product of DOE's research and development activities, many DOE facilities became contaminated with radioactive isotopes. The contamination is found within facilities such as the research reactors, radiochemical pilot plants, radioisotope production facilities, and the many research and development laboratories, as well as in piles of wastes and in the environment.

A major mission of DOE during the 1990s is site and environmental cleanup. In pursuit of this mission, numerous remediation projects are under way and many others are being planned at ORNL. A key component of the remediation work is cooperative endeavors with commercial firms to adapt, demonstrate, and evaluate the vendor's equipment and processes during the decontamination of ORNL facilities. The vendor can use the demonstration results for improving his equipment and processes and in marketing them to others. ORNL can benefit by having its facilities, equipment, or materials decontaminated by the demonstrations. These projects present opportunities for ORNL to develop the expertise needed for addressing site or environmental problems at other DOE or commercial sites.

The Radiochemical Technology Section of the ORNL Chemical Technology Division has formed a group whose primary mission is to develop and demonstrate decontamination technologies. The objectives of the Decontamination Technology Development Group within the Radiochemical Technology Section are (1) to design and test new kinds of equipment for decontamination work, (2) to adapt and test existing technologies for novel applications to decontamination activities, and (3) to test and evaluate equipment and processes through decontamination demonstrations, either alone or in cooperation with industrial vendors.

This report describes tests conducted by the Decontamination Technology Development Group using two proposed methods for decontaminating surfaces — one using water ice crystals [Crystalline Ice Blast (CIB)],[1] the other using dry ice crystals (CO_2 Cleanblast™).[2]

Both methods are adaptations of the commonly used sand-blasting technology. In this technology, sand particles are entrained in a high-velocity air stream and impacted on the surface to be cleaned. The surfaces are often severely eroded during sand blasting, and the recovered sand also contains the contaminant, the eroded substrate materials, and the sand fines. While cheap and effective in use, this technology can lead to complications and expense because of the destruction of the surfaces; the increased volume of waste to be handled when the sand, sand fines, substrate, and contaminants are mixed together; and the disposal problems that result when the recovered fines contain Resource Conservation and Recovery Act (RCRA) materials and are defined as mixed wastes (e.g., in this case, lead compounds mixed with radioactive isotopes).

Contaminated tools and equipment are kept at ORNL, waiting for decontamination for reuse or disposal. Some of the contaminated items are intrinsically valuable and could be reused or sent to surplus sales if they could be decontaminated in a nondestructive way. Others represent scrap values and could be returned to the economy if they could be decontaminated to levels "below regulatory concern." Others are wastes that could be disposed of at less cost and/or with

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[1]Applied Radiological Control, Inc., Kennesaw, GA 30144.

[2]Environmental Alternatives, Westmoreland Industrial Park, Route 12, Westmoreland, NH 03457.

less use of scarce burial ground space if they were reduced to levels "below regulatory concern," which at this time is only a conceptual value.

Likewise, large amounts of radioactive lead are stored at ORNL for eventual recycle. The lead is stored for two reasons. In the first place, this material has value and should be recovered and recycled. Secondly, if the lead were simply disposed of as waste, it would have to be classified as a hazardous mixed waste. Since there is no currently approved method of disposal for hazardous mixed wastes, this type of waste must be stored on-site. The current methods for the decontamination of lead use either corrosive chemicals and/or abrasive techniques and generate significant quantities of mixed secondary wastes. A new method for decontaminating lead would be very useful throughout the field of nuclear energy if such a method could prevent the generation of mixed secondary wastes.

Both the CIB and the CO_2 Cleanblast™ processes have advantages that could be superior to those offered by the conventional methods for decontaminating items in the nuclear field. The two methods tested differ from sand blasting in that the particles are not particularly abrasive and do not accumulate as particles in the wastes. They differ from each other in that the CO_2 particles sublime during and after impact and the ice particles melt. Thus, the two demonstrations provide important information about two strong candidate decontamination methodologies. Each process was tested at ORNL using contaminated lead bricks (2 × 4 × 8 in., each weighing about 28 lb) and contaminated tools and equipment. Each process demonstration is described in a separate section; the two processes are then compared.

The results of the tests can be better understood with a little background in the measurement of radioactivity and the calculation of the decontamination factor (DF). Defining a DF as the ratio of the radiation readings before treatment to the readings after treatment, one may estimate the effectiveness of the removal process. A higher DF indicates that more cleaning has occurred. In general, the closer the DF is to 1.0, the less successful the treatment. However, it should be noted that DFs become less meaningful as a means of describing the effectiveness of the process for cleaning the surfaces as the detection limits, or release limits, are approached. For example, if the divisor approaches a constant value (the detection limit), the ratio becomes a fixed number. If the divisor becomes less than the release limit, the ratio becomes indeterminate — at best a minimum value can be specified. When checking for "Green Tag" tolerances (i.e., in connection with releasable items), it is customary to quantify the measurements of radioactivity *only* if they are above the release limits. Many, but not all, of the items were found to be below the release limits after going through the cleaning process; consequently, the measured DFs for these items are presented as lower limits of this measure of decontamination effectiveness.

The ORNL release limits, according to the ORNL Environmental, Safety, and Health Procedure,[3] are any direct probe readings less than 1000 dpm $\beta\gamma$ and less than 300 dpm α. The release limits for transferable activity (smear results) are any values less than 200 dpm $\beta\gamma$ and less than 20 dpm α on a smear paper. For measurement and reporting convenience, the standard definition of a smeared area of 100 cm^2 is used, even though the test piece (e.g., a screwdriver) may not have that much surface area. A lead brick, smeared diligently, could yield a smeared area of as much as 900 cm^2. Furthermore, it should be noted that the ORNL release limits do not correspond to the *hypothetical* level "below regulatory concern," mentioned previously.

[3]*ORNL Health Physics Manual*, Radiation and Contamination Control (Sect. 2.0).

2. DEMONSTRATION OF THE CIB PROCESS

2.1 BACKGROUND

The process of cleaning surfaces by blasting them with high-velocity ice particles has been studied by several groups.[4] These pioneers fed crushed ice into a modified sand blaster and observed the results. As might be expected, they found that ice was less abrasive than sand and therefore not as effective or as cheap as sand for the purposes studied. In 1984, the Canadian Defense Research Establishment Pacific of the Canadian Department of National Defence Laboratory asked a multidisciplinary Canadian research and development laboratory to reevaluate the economic feasibility of ice blast cleaning in light of its advantages — a dust-free process and a more easily handled waste stream. These advantages might command a premium in the coming years as concern for worker health and the environment begin to take precedence over simple economics. Today, we recognize the additional advantage of a reduction of total waste volume and the potential for elimination of additional waste streams.

Ice blast technology was originally developed as a dust-free coating-removal technique for confined spaces such as ship interiors and machine rooms. As research and development progressed, it was evident that the nonabrasive property of ice particles produced a uniquely different effect in blast cleaning: it was possible to fracture the bond between a permanent coating and the host material without causing any significant substrate damage. This finding opened up a whole new area of application. The crystalline ice blast technology was ideal for sensitive activities such as removing the paint from aircraft surfaces to look for evidence of cracks and other defects — a job that had required solvents in the past.

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[4]References to pioneers in ice-blasting technology.

A series of tests by researchers at Applied Radiological Control, Inc., was performed to develop a commercial process for using ice in air as a blast cleaning medium. Their findings include the following: (1) Ice is not abrasive and therefore should not be applied where abrasive erosion is required. (2) Ice is not free-flowing; therefore, its transport should be precisely controlled from the source to the mixing nozzle. (3) Ice melts as temperature or pressure increases and therefore should be handled and transported with a minimum of force or friction. Designing a system capable of addressing these issues required a substantial engineering effort and a thorough understanding of high-velocity impact phenomena on surfaces. The present ice blast process evolved from these basic requirements into the prototype ice blast system used in these demonstration tests. Ice crystal velocities as high as 1800 ft/s at relatively low nozzle pressures ($\leq$200 psig) can be delivered with this system.

2.2 DESCRIPTION OF THE CIB SYSTEM

The system to produce, size, fluidize, meter, transport, and mix ice with high-velocity air operates as an integrated process (Fig. 1). The major components of the system are as follows: a refrigeration module, an ice generation and handling module, an air-handling module, an ice transport system, and a mixing (blast) nozzle. The ice-handling module includes an ice maker with its refrigeration module; an ice crusher and sizer; an ice fluidizer; an overflow ice receptacle to catch the fluidized ice product when the blast system is not operating; and the regulators, control valves, and logic circuits needed to provide the proper crystalline ice feed rates to the ice transport system. The ice-handling module incorporates design features to provide the proper ice particle size distribution and precision ice and transport fluid metering to prevent ice jams.

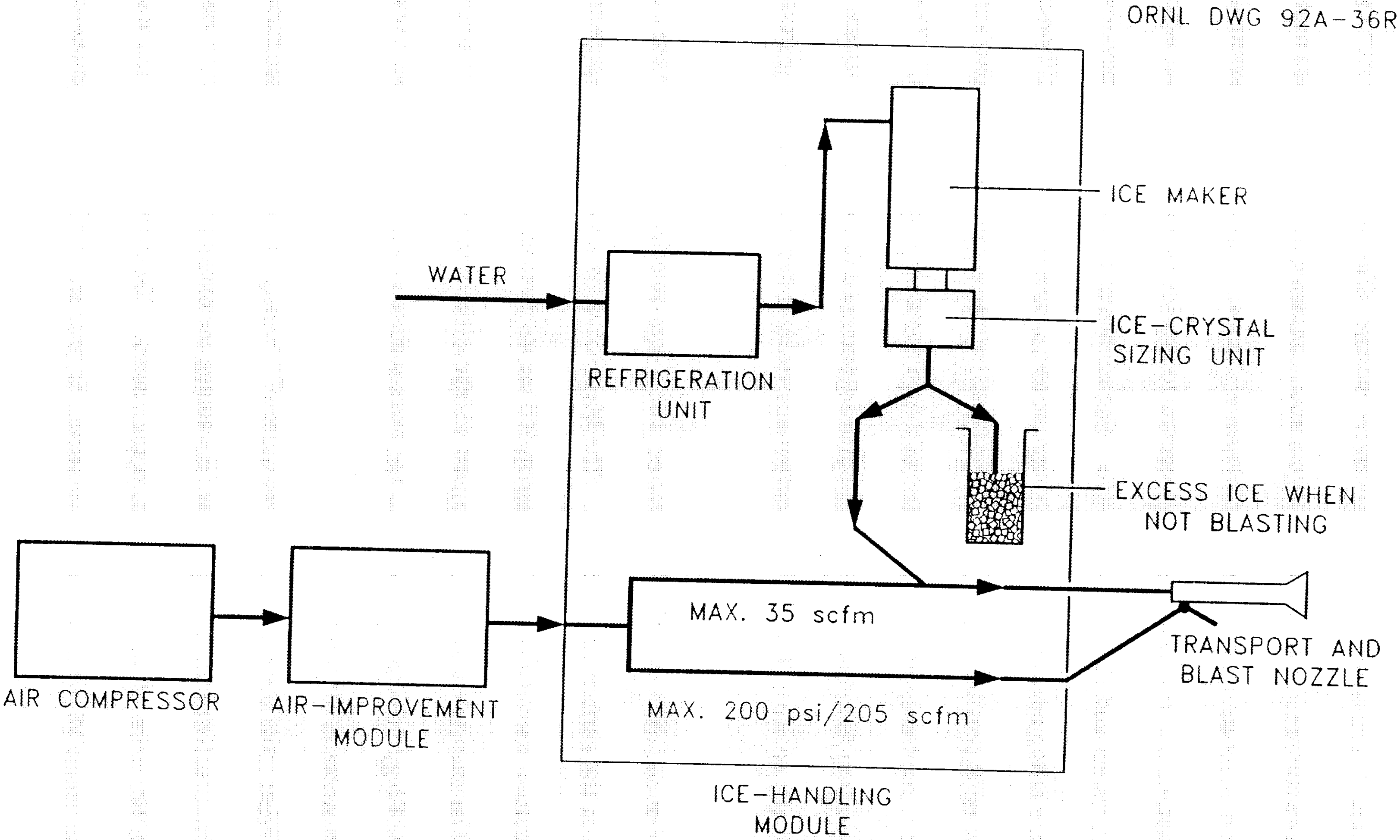

Fig. 1. Flow diagram of the Crystalline Ice Blast system.

The air-handling module consists of an industrial air compressor, rated at 500-scfm capacity and 250 psig and an air-improvement module. The inlet air passes through particulate filters. The compressed air passes through a train, consisting of a water-cooled heat exchanger; a condensed water separator; a refrigerated heat exchanger to cool the compressed air stream; and the regulators, control valves, and logic circuits to provide the proper airflow rates to (1) the ice transport system and (2) the blast nozzle. The maximum air pressure is controlled by a safety relief valve at the inlet point of the air-improvement module. All hoses and fittings are rated to withstand burst pressures higher than those allowed by the automatic safety relief valve.

The ice transport system consists of a tube containing low-velocity air. The fluidized ice crystals coming from the ice-handling module are entrained in the passing air steam to carry them to the blast nozzle. The design incorporates features that minimize ice particle attrition or melting.

The entrained ice crystals are mixed with a high-velocity air stream in the blast nozzle and directed at the surface to be cleaned. The blast nozzle is a proprietary design that maximizes energy transfer between the air blast stream and the ice particles.

The integrated system is designed to allow the nozzle operator to stop and start the delivery of high-velocity ice crystals to the work surface at will. This is accomplished by using a deadman switch at the nozzle.

When operating at maximum pressure of 200 psig to the nozzle, maximum air volume is 205 scfm directly to the mixing nozzle. By adding the maximum of 35 scfm for delivery of ice, a total of 240 scfm of air is delivered to the nozzle. Operating at these maximum conditions produces about 15 gal of wastewater an hour. In practice, surface decontamination efforts often do not require operating at maximum capabilities to successfully clean the surfaces; therefore, smaller volumes of air are used and smaller amounts of wastewater are generated per hour.

2.3 PROCEDURE FOR CIB CLEANING TESTS

The development tests were performed in three phases. Phase 1 consisted of cold tests to check out the systems, train the operators, and set the initial operating parameters to be used for the hot tests. Phase 2 consisted of hot tests using contaminated tools and manipulator parts that had resisted decontamination by conventional means. Phase 3 consisted of cleaning studies using contaminated lead bricks (2 × 4 × 8 in.). These studies were particularly interesting because conventional decontaminating methods yield a mixed waste (i.e., RCRA and radioactive materials mixed together). At the present time, mixed wastes present difficult handling and disposal problems. All materials used in Phases 2 and 3 had been contaminated during use at ORNL.

2.3.1. Cold Testing

The initial operating parameters for the future decontamination tests were set by studying the effectiveness of removal of nonradioactive coatings (e.g., paints) from cinder block, concrete, fiberglass, and metal surfaces. The tests were performed to determine the effect that positioning of the blast nozzle (i.e., angle of attack and distance from surface), traverse speed, and other operating conditions (e.g., nozzle operating pressure and ice feed rate) had on the rate and completeness of removal of the coatings.

The cold tests were conducted in the shop area at the Radiochemical Development Facility (RDF) at ORNL, known locally as the Building 3019 Complex. The tests were performed in a customized glove box inside a clear Plexiglas enclosure to permit observation under sealed conditions (Fig. 2). The customized glove box allowed for (1) free movement of the ice blast nozzle into and out of the box, (2) a heated base to facilitate the melting of spent ice, (3) collection of the melted ice as a liquid for analysis, and (4) adequate ventilation to maintain negative pressure during the tests.

The enclosure was fitted with a ventilation system having a capacity of 1000 scfm to provide an adequate margin of safety in controlling the anticipated 200 ft^3/min from the blasting operations. The enclosure was operated within a regulated negative pressure range of −1.5 to −2.0 in. water gauge to ensure containment of the particulate matter released by the blasting action. The ventilation air was passed through a bank of roughing and high-efficiency particulate absolute (HEPA) filters before it was released to the atmosphere. The spoils of this demonstration (mainly water and flakes of coatings) were collected using a vacuum cleaner and then also fitted with roughing and HEPA filtration and saved for analysis.

The cold tests demonstrated the basic capabilities of the CIB process and equipment, provided operator training, and helped set the initial parameters for the tests with contaminated items. The coatings were successfully removed from cinder block, concrete, fiberglass, and metal surfaces with no visual damage to the substrate. For removing these coatings, a nozzle distance of about 4 to 6 in. from the surface appeared to be optimal. The proper angle for the ice to strike the surface is 90°. Removal rates decrease as the angle deviates from 90°. The entire series of tests was accomplished within a run time of about 2 h. About 11 gal of wastewater was recovered from the box interior.

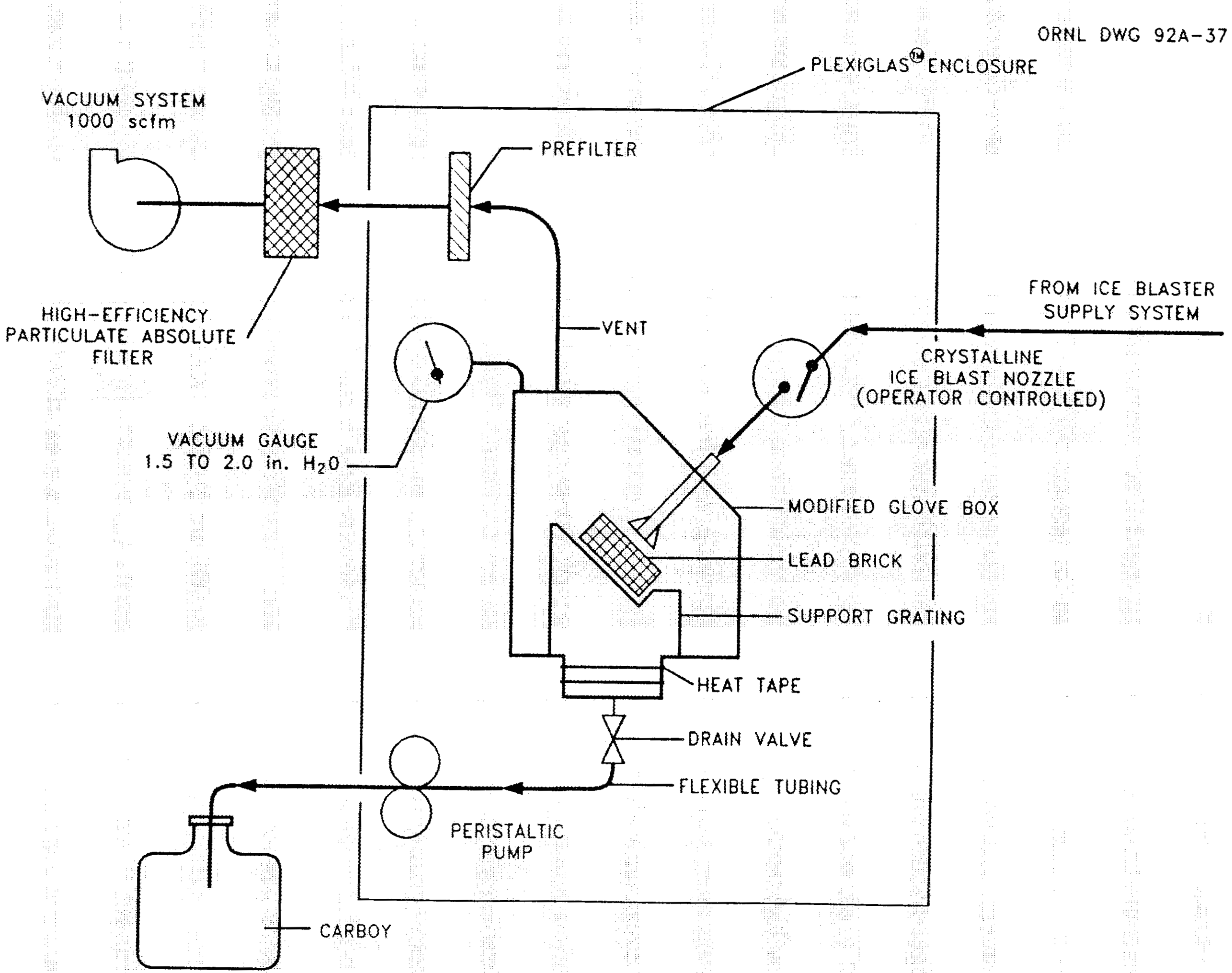

Fig. 2. Flow diagram showing glove-box operation of the Crystalline Ice Blast system.

2.3.2. Tests Using Partially Decontaminated Tools and Manipulator Parts

Phase 2 of the demonstration was performed to evaluate this technology for general use in decontaminating tools and equipment. None of the items treated in Phase 2 was initially below the ORNL release tolerances. (See Sect. 1.)

2.3.2.1 Description of Tools and Equipment Decontaminated in Phase 2

The contaminated parts obtained for testing in Phase 2 were tools (screwdrivers, forceps, pliers, hammers, and wire cutters), manipulator slave-end gear assemblies, and radiation detector probe (Geiger-Müller tube) heads. A lead brick was also tested in this phase. With the exception of the lead brick and the radiation detector probe head with the highest readings, all items tested in this phase had been subjected to decontamination at least one time before, using hand scrubbing with cleaning agents and/or pressure washing with hot 1000-psig water sprays. Contamination levels remained high after these hand cleaning endeavors, with both alpha (α) and beta-gamma (βγ) radiation present as fixed (direct probe readings, which includes any transferrable activity) and transferable (smear readings) present on most parts (Table 1).

Direct (probe) readings ran from tens of thousands of disintegrations per minute (dpm) to >500 mR/h of βγ radiation and from below release limits (≤300 dpm) to tens of thousands of disintegrations per minute of α radiation. Transferable contamination levels ranged from below release limits (≤200 dpm) to over 500,000 dpm of βγ radiation. Likewise, the transferable α radiation ranged from below release limits (≤20 dpm) to over 80,000 dpm, based on counting smear papers and reported on an assumed surface area of 100 cm^2, even if the object itself did not have a surface area that large.

Table 1. Tabulated data from Crystalline Ice Blast (CIB) treatment of hand tools and manipulator parts

	After handwipe decontamination				After CIB decontamination				Decon factor (probe)	
	Max probe (dpm)		Max smear (dpm/100 cm²)		Max probe (dpm)		Max smear (dpm/100 cm²)			
	α	β,γ	α	β,γ	α	β,γ	α	β,γ	α	β,γ
Clip, electric	1,000	130,000	21	867	<300	4,800	<20	<200	>3.3	27.1
Forceps	400	130,000	<20	80,000	<300	<1,000	<20	<200	>1.3	>130
Gear, manipulator	30,000	7,000,000	200	5,600	4,800	1,250,000	<20	<200	6.3	5.6
Gear, manipulator	15,000	80,000	<20	<200	1,000	20,000	<20	<200	15.0	4.0
Gear manipulator	12,000	7,000,000	28	460	1,600	50,000	<20	<200	7.5	>200
Gear, manipulator	1,600	40,000	<20	<200	800	20,000	<20	<200	2.0	2.0
Gear, manipulator	1,200	60,000	<20	460	<300	35,000	<20	<200	>4	1.7
Gear, manipulator	<300	2,000,000	<20	847	<300	550,000	<20	<200	*a*	3.6
Hammer	1,000	100,000	21	3,200	<300	15,000	<20	<200	>3.3	6.7
Hand, manipulator	40,000	100,000	25	<200	16,800	25,000	<20	<200	2.4	4.0
Lead brick	<300	250,000	<20	4,500	<300	15,000	<20	<200	*a*	16.7
Mallet	1,000	100,000	20	500	<300	<1,000	<20	<200	>3.3	>100
Pliers, needlenose	400	30,000	20	1,000	<300	<1,000	<20	<200	>1.3	>30
Pliers, snapring	<300	170,000	<20	2,500	<300	24,000	<20	<200	*a*	7.1
Probe head, GM	2,000,000	>250,000,000	81,000	576,000	20,000	20,000,000	700	8,000	100	>12
Probe head, GM	10,000	>12,000,000	48	3,000	4,000	7,000,000	<20	218	2.5	>1.7
Screwdriver	14,000	2,500,000	300	6,000	1,600	42,000	25	<200	8.8	>200
Screwdriver	4,000	180,000	28	1,000	400	12,000	<20	<200	10.0	15.0
Screwdriver	500	20,000	30	235	<300	<1,000	<20	<200	>1.7	>20
Screwdriver	<300	25,000	<20	<200	<300	10,000	<20	<200	*a*	2.5
Wire cutters	12,000	110,000	100	2,700	<300	5,000	<20	<200	>40	22.0

[a]Value is indeterminate.

2.3.2.2 Procedure for Phase 2 Demonstrations: Decontaminating Tools and Other Items

Because of the radiation and contamination levels present on the test pieces, it was necessary to perform the Phase 2 demonstrations in a controlled area — the Manipulator Rebuild Shop, Building 3074. The room had special ventilation and provided secondary containment for these operations. One of the glove boxes in the Manipulator Rebuild Shop was modified to handle the blast nozzle and test pieces for Phase 2. One glove port was modified to install the blast nozzle in a rigid nozzle support. The operator used the other glove port for hand-positioning the contaminated items in front of the blast nozzle. In other respects, it was very similar to the layout shown in Fig. 2.

The optimum distance for removing paint (as determined in the cold tests), about 4 to 6 in. between the blast nozzle and the surface, was too great for decontamination purposes. Visible surface cleaning was much improved at a distance of 1.5 to 2 in. from the surface, and the apparent removal rates of the surface films were increased by more than 50% as well. The test piece was held at approximately 90° to the blast nozzle and moved by hand as needed to expose all of the surfaces to the cleaning action.

The initial operating conditions for the CIB tests were as follows:

- air supply — 185 scfm (120 psig),
- nozzle orifice diameter — 0.30 in.,
- particle velocity at the nozzle — 1712 ft/s (calculated), and
- gallons of melted ice collected — about 11 gal/h.

The final decontamination operating conditions for the CIB tests were as follows:

- air supply — 205 scfm (205 psig),

- nozzle orifice diameter — 0.25 in.,
- particle velocity at the nozzle — 1814 ft/s (calculated), and
- gallons of melted ice collected — about 11 gal/h.

The test items were introduced into the glove box. The CIB equipment was started and adjusted to the test conditions. The operator moved the test piece to within 1.5 to 2 in. of the nozzle and exposed all surfaces to the blasting action. This procedure was repeated until it appeared that all surfaces had been cleaned. The next piece was then taken through the process. Typically, a tool took about 3 to 5 min to process. The cleaned items were removed from the glove box and surveyed for residual contamination.

The used ice and detritus removed from the surfaces were collected on the bottom of the glove box, melted, and recovered by vacuuming.

2.3.2.3 Results of the CIB Decontamination Tests of Tools and Equipment

The decontamination process did not provide any noticeable erosion or damage to the surfaces.

With the exception of the two radiation detector probe heads, all pieces came out of the cleaning operation with no transferable activity above the control limits of <200 dpm/100 cm^2 for $\beta\gamma$ radiation and <20 dpm/100 cm^2 for α. For these pieces, the divisor used in determining the DF became an indeterminate value (i.e., a value less than 200 or 20). Assuming these values as maximum value constants provided simple DFs for transferable radioactivity ranging from *more than* 1.7 to *more than* 200 for $\beta\gamma$ and from *more than* 1.3 to 100 for α.

For fixed contamination, all of the tools and equipment came out of the treatment with smaller readings than before, but only 4 of the 21 pieces tested were below the release limits (<1000 for $\beta\gamma$ and <300 for α.) Some items were given a second decontamination treatment without significant improvement in results.

The tests produced a minimal amount of waste, with no indication of airborne contamination. The collected liquids were easily filtered to remove the particulates that were blasted from the surfaces of the contaminated tools and equipment. The clarified liquid was discharged directly down the hot drain.

2.3.2.4 Discussion of Results of CIB Decontamination Tests of Tools and Equipment

The tests with the tools and equipment demonstrated the importance of impact force for effective removal of radioactive contamination. The transferable activity was reduced to levels below the release limits by the CIB treatment for all the pieces tested. It was less effective for fixed contamination. Only 4 of the 21 pieces were reduced to levels below the release limits for fixed contamination (Table 1). This could be explained on the basis of two factors — crevices that are difficult to clean,[5] and contamination bonded to the surfaces of the items.

Pieces with complex surface geometries (e.g., gears) or crevices (e.g., pliers) naturally took longer to process than simpler ones (e.g., forceps), and the cleaning process was generally less effective. The CIB process can only remove materials that are exposed to the blasting action, and it is at least conceptually possible that the blasting action could drive some of the contaminated particles deeper into the interstices of the tools.

In the second case, the CIB process would not be expected to be very effective. If the radioactive materials were bonded to the surface, perhaps by exposure to aggressive reagents during usage or during prior decontamination attempts, a gentle method (in terms of low abrasiveness) for cleaning surfaces would not remove them.

The waste was disposed of as a liquid low-level waste.

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[5]The smear technique does not sample the contamination inside crevices or joints.

2.3.3 Tests Using Contaminated Lead Bricks

In Phase 3 of the CIB tests, almost 1 ton of lead (66 bricks) was put through the decontamination process. The test objectives were, first, to demonstrate the ability of the ice blast system to successfully remove transferable (smearable) and nontransferable (fixed) radioactive contamination from lead, and, second, to determine if this could be accomplished without creating a hazardous mixed waste.

2.3.3.1 Description of the Lead Bricks

The lead bricks used in this demonstration had been previously decontaminated via hand scrubbing with surfactants to remove the bulk of the loose contamination. Only one of the bricks had transferable α contamination above the release limit, and this level of contamination was only 21 dpm/100 cm^2. Thirty-two bricks had transferable $\beta\gamma$ contamination before the CIB treatment. These levels of contamination ranged from 204 to 3825 dpm/100 cm^2, with an average value of 514 dpm/100 cm^2 and a median value of 275 dpm/100 cm^2. The other 34 lead bricks were below the release rates (<200 dpm/100 cm^2, $\beta\gamma$) for transferable radioactivity. The complete data are presented in Appendix A.

For fixed activity, ten bricks were above the release limits for α contamination. These ranged from 350 to 1800 dpm α, with an average of 855 and a median of 700 dpm α. After the hand scrubbing, all the bricks were above the $\beta\gamma$ release limits, ranging from 1100 dpm to 11 mR/h! Omitting the five most highly contaminated bricks (i.e., those having initial readings in the range of milliroentgens per hour,[6] the average was 53,000 dpm $\beta\gamma$, and the median was 15,000 dpm $\beta\gamma$.

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[6]No easy conversion is available from milliroentgens per hour to disintegrations per minute.

The "before treatment" data from the βγ probe, presented in Appendix A, were grouped by radiation levels, as shown in Table 2. The last five bricks, all having radiation levels in the range of milliroentgens per hour, were arbitrarily assigned a radiation reading of 1,000,000 dpm, although there is no simple way to convert from milliroentgens per hour to disintegrations per minute.

The grouped data are plotted in Fig. 3. The radiation reading is presented on the y axis on a logarithmic scale. The cumulative number of bricks having less than a given radiation reading is plotted on the x axis on a linear scale. Thus, for example, 27 of the 66 bricks had a radiation reading less than 10,000 dpm βγ at the start of the tests. Also, none of the bricks were below the release limit at the start.

2.3.3.2 Procedure for CIB Tests with Lead Bricks

The customized ventilated glove box, designed and installed in the Plexiglas enclosure in the shop area of the RDF (Building 3019) and used in the cold tests described previously, was used for the lead brick decontamination tests (Fig. 2). The handling procedure for the lead bricks was similar to that described for the contaminated tools and equipment tests.

As with the previous CIB tests, several preliminary tests were conducted to determine the optimum conditions to use.

The operating conditions used for the CIB tests of lead bricks were the same as those used for the tools and equipment described in Sect. 2.3.2.2. The bricks were introduced into the glove box in batches. The CIB equipment was started and adjusted to the test conditions. The operator moved the brick to within 1.5 to 2 in. of the nozzle and blasted each surface facing the nozzle with a sweeping motion. The brick was rotated again and again and blasted until it appeared that all surfaces had been cleaned. The brick was replaced in the holder, and the next brick was taken

Table 2. Grouped data for $\beta\gamma$-contaminated lead bricks before CIB treatment

Number of bricks	Cumulative number	Radiation level (probe, dpm)
10	10	1,001-2,000
10	20	2,001-5,000
7	27	5,001-10,000
8	35	10,001-20,000
10	45	20,001-50,000
5	50	50,001-100,000
8	58	100,001-200,000
3	61	200,001-500,000
5	66	500,001-1,000,000

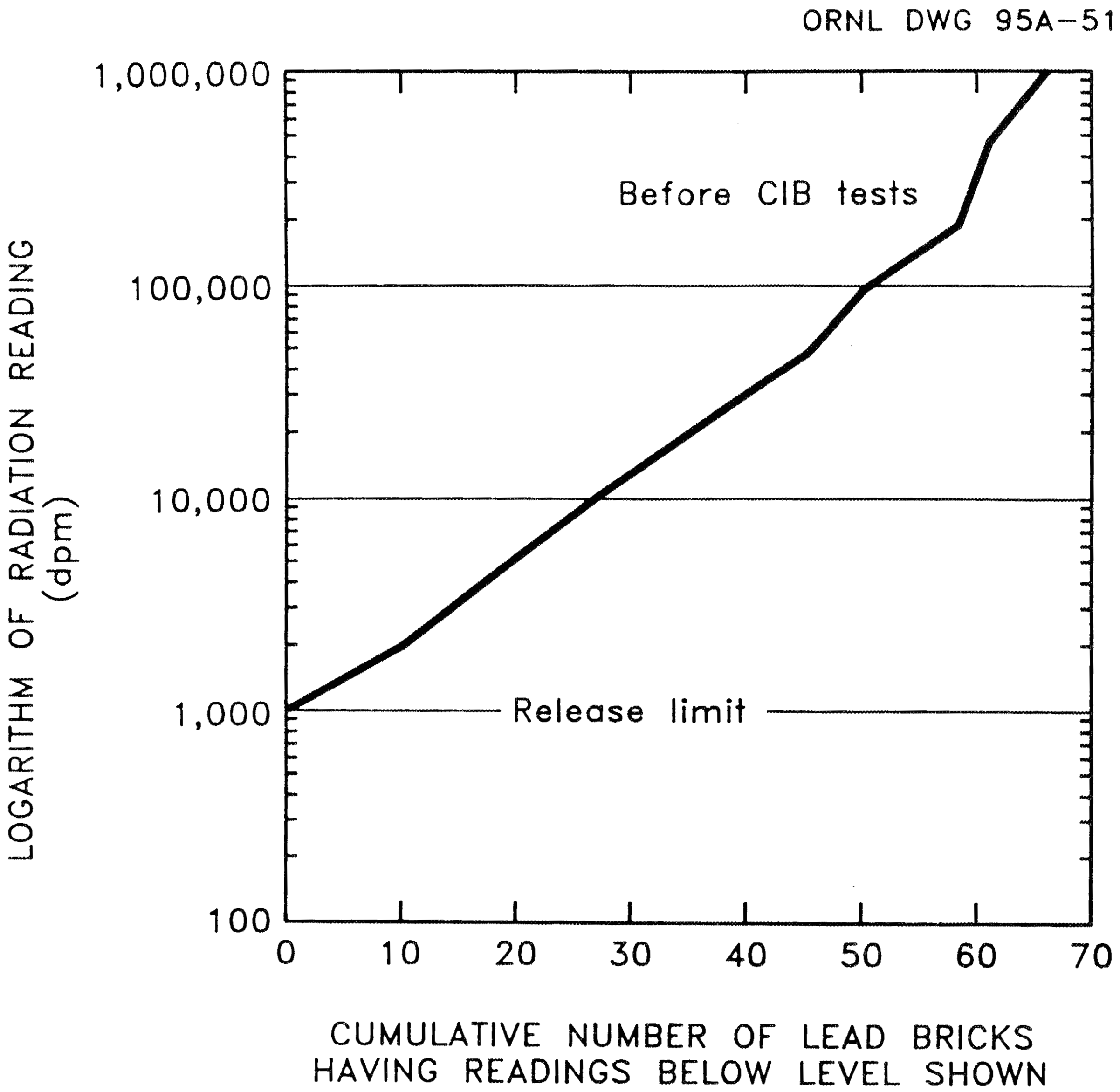

Fig. 3. Radiation levels before CIB decontamination tests.

through the process. Typically, each brick took between about 5 and 10 min to process. The cleaned bricks were removed from the glove box and surveyed for residual contamination. The process was repeated until all bricks had been treated.

The used ice and detritus removed from the surfaces were collected on the bottom of the glove box, melted, and recovered by vacuuming.

2.3.3.3 Results from the Tests Using Lead Bricks

Of the 66 lead bricks used in these tests of the CIB process, 62 were decontaminated to a point below ORNL's release limits. Five lead bricks remained contaminated upon termination of the demonstration. (See Appendix A.) Thirteen bricks were treated a second time. This second cleaning was required primarily because of an operator error in procedure, usually an incomplete cleaning of one surface of a brick due to an oversight. Five bricks were treated a second time to determine if the smear or probe readings could be reduced further. Excluding the same five bricks mentioned in Sect. 2.3.3.1, $\beta\gamma$ decontamination factors ranged from *greater than* 1.1 to *greater than* 400. The starting bricks had no significant α contamination.

The final probe results have been plotted in the same manner as the pretest data (Fig. 4). The curve for the pretest data is reproduced in this figure to show the success of the decontamination efforts graphically. As noted in the graph, 61 of the 66 bricks were below the release limit.

A total of 60 gal of liquid waste was generated for the total demonstration of the decontamination of lead bricks — about 1 gal per brick by this technique. Samples of the five containers of this liquid waste were analyzed for lead and radionuclides to determine if the containers could be emptied down the radioactive waste drain. The concentration of lead in the liquid must be less than 5 ppm (5 mg/L) for the waste to avoid being characterized as a hazardous (and therefore a mixed) waste.

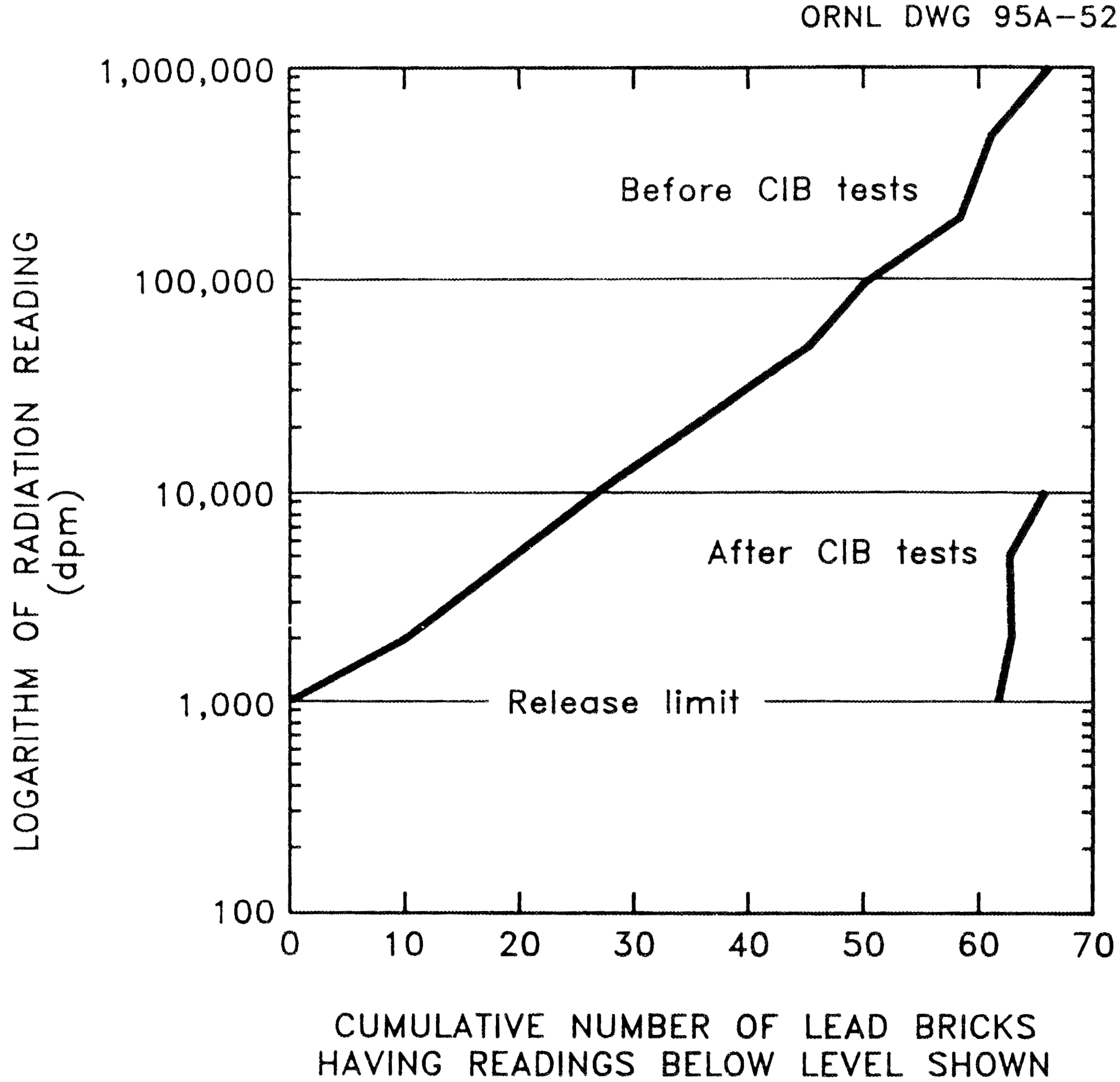

Fig. 4. Radiation readings after the CIB decontamination tests.

Analytical data from the five samples are provided in Table 3. All samples were significantly lower than the mandated 5-ppm release limit for lead. The lead concentrations ranged from <0.1 (presumed to be 0.0 ± 0.15 mg/L) to 0.68 ± 0.02 mg/L, with a median concentration of 0.30 ± 0.15 mg/L. The median concentration of ^{137}Cs was 0.05 ± 0.02 Bq/mL. The concentration of ^{60}Co was below 0.08 Bq/mL. These radioactivity levels correspond to those of liquid low-level waste.

Several items of equipment in the system were surveyed or analyzed. The inside of the modified glove box was probed and smeared for radioactivity after the tests.[7] The corners of the box had the highest probe readings, ranging from about 66,000 to about 180,000 dpm $\beta\gamma$, the maximum reading. The sump (drain) probed some 80,000 dpm $\beta\gamma$. A new brick rack (i.e., one not previously contaminated) was installed for this job. Afterwards it probed less than 3000 dpm $\beta\gamma$, and some of this could have come from "shine" from the corners. Smears of the brick rack showed no values above the smear tolerances (<20 dpm α and <200 dpm $\beta\gamma$). If the brick rack provides a better estimate of the quantities of radioactive materials deposited from these tests than the corners of the box do, one could conclude that very little radioactivity was released to the atmosphere in the box by the CIB process.

The roughing filter was analyzed for radioactive contamination and for inorganic elements to determine the displacement of the contamination and to characterize it for waste acceptance. The filter housing in the vicinity of the roughing filter probed <300 dpm α and 5000 dpm $\beta\gamma$. The smear results were below the smear tolerance values mentioned previously. A single portion of the filter material was submitted for analysis. The total weight of the filter was not measured;

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[7]The box was contaminated prior to use, but the initial levels of contamination were not known.

Table 3. Analytical results from the recovered liquids obtained with Crystalline Ice Blast

Sample no.	Cs-137 (Bq/mL)	Co-60 (Bq/mL)	Lead (mg/L)
1	0.06 + 0.02	<0.08	0.30 + 0.15
2	0.06 + 0.02	<0.06	<0.01
3	0.05 + 0.02	<0.05	0.18 + 0.08
4	0.03 + 0.01	<0.06	0.54 + 0.24
5	<0.05	<0.05	0.68 + 0.02

therefore, the sample results cannot be related quantitatively to the entire filter. The analytical values of interest to these tests are as follows: gross α, 68 Bq/g; gross β, 65 Bq/g; ^{137}Cs, 106 Bq/g; and lead, 10% by weight. The high value for lead content is surprising, but may be partially explained by additional lead contamination caused by removal of a lead-based paint from the glove box interior prior to the sampling and analysis of the roughing filter media. Since it was taken from a single sample, it may also be a nonrepresentative value.

2.3.3.4 Discussion of Results for Lead Bricks

The lead bricks were uniform in size and shape, but varied in the degree of surface roughness, the thickness of their oxide layers, and their levels of contamination, either as fixed or as transferable radioactivity. It is likely the life history of the individual lead bricks, rather than their individual contamination levels just prior to the tests, determined the rate of decontamination and the success of the decontamination effort. The more pitted the surface was, such as might occur after repeated exposure to corrosive chemicals, the harder it was to clean. On the other hand, the oxide layer on older lead bricks was found to be helpful. An oxide layer, in and of itself, is not an indicator that radioactive contamination is present, but removal of the oxide layer has been found to be a simple indicator that the removable radioactive contamination has also been most likely removed. When all the oxide layer had been removed by using the CIB (or the Cleanblast™) process, the operator could confidently interrupt the cleaning process to make measurements of the residual activity. (It is more efficient to remove the oxide layer before measuring the completeness of the cleaning since it takes much more time to perform the radiological surveys than it does to decontaminate a brick.) Radioactivity that remained after this treatment was usually found to be impervious to further similar treatments if the operator had done a thorough job the first time.

The CIB treatment was effective for decontaminating lead bricks. As mentioned previously, about 92% of the bricks were cleaned below release limits even though the initial level of contamination was quite high. Five bricks (about 8%) remained contaminated, even after a second pass through the CIB treatment.

At the conclusion of the CIB lead decontamination tests, surveys of the box and its equipment were made to pinpoint where the displaced contamination was deposited. The vast majority of contamination was found on the floor and in the sump of the glove box. Only minor additional amounts of radioactive materials were found in the recovered water or on the HEPA filters, confirming that the melting of the ice through impaction upon the substrate does indeed limit the release of airborne contamination to the air. The analysis of lead on the filters was confounded by the removal of lead-based paint from the inside of the glove box before the filters were analyzed. This removal process may have added an unknown amount of lead to the filter, making it impossible to determine how much lead on the filter came from the lead brick cleaning operations. If one assumes that the lead removed from the bricks can be modeled after the behavior of the radioactive contamination removed from the bricks, one can say the displaced lead compounds, like the radioactive contamination, were collected in a well-defined area (i.e., they were not dispersed into the air in an uncontrolled manner). If this is found to be generally the case, the easy collection and cleanup of the lead and the removed radioactive materials would provide a useful selling point for the CIB process.

The tests produced about 60 gal of other liquid wastes. This represents about 1 gal of liquid per brick decontaminated by this process. The collected liquids were easily filtered to remove the particulates that were blasted from the surfaces of the contaminated lead bricks. The filtrate was analyzed and found to be disposable simply as liquid low-level waste (i.e., it did not need to be disposed of as a liquid mixed waste). (See Table 3.)

2.4 PERFORMANCE OF THE CIB EQUIPMENT

The operation of the CIB equipment is generally user friendly. Several operational problems should respond to design improvements. Reducing the physical size of the CIB unit would improve its operability. The refrigeration unit tended to freeze up internally and stop the CIB processing until it could be thawed out. Another process limitation was the drain system in the glove boxes. Operating in an enclosure limited the rate at which the used ice could be melted, and the drain tended to clog, stopping operation. A special heater was added to help alleviate this problem.

One major problem experienced with the CIB system is the noise it generates while in use. Noise levels were such that even when the operator wore earplugs under earmuffs, the working time was limited, based on Occupational Safety and Health Administration (OSHA) criteria for protection against hearing loss. Use of the CIB process requires some way to prevent the overexposure of the operators to OSHA-mandated hearing-conservation limits.

In all cases, the operator is required to make a judgment in determining when enough cleaning has been done. In the cold tests it was easy to see when the coatings had been removed. Similarly, the lead bricks that had oxidized layers gave a relatively clear indication when the cleaning could be stopped. With the contaminated tools and equipment, the operator had no such clear evidence.

2.5 CONCLUSIONS FROM THE CIB CLEANING TESTS

For several important classes of contaminated items, the use of ice as a blast medium offers some significant operational advantages. Blasting with small ice crystals is not an abrasive cleaning process and generates no abrasion product wastes. Ice produces a liquid phase after impacting the surface and traps the released particulates; in general, the water is easily separated from the removed solid materials (if they are not soluble). Furthermore, water is readily available, and ice-making technology is well established. The cost of the CIB process appears to be reasonable when compared to "cradle-to-grave" costs of competing decontamination processes with similar applications.

Demonstrations with the prototype system show that paint, grease, and oil can be removed from metal, plastic, asphalt, and concrete surfaces. This process would work just as well for removing coatings that are contaminated with radioactive species. In like manner, removal of contamination from lead bricks was highly effective and added no significant quantities of lead metal to the detritus solids. (Lead oxides and carbonates were removed but were essentially insoluble in the water recovered from the melted ice.)

The CIB process was found to be less effective, under the conditions tested, with contaminated tools and equipment that had chemically bonded contamination or contamination located in crevices. These items were not effectively decontaminated since the CIB technology does not abrade the substrates or penetrate deeply into crevices to remove particulates.

One process attribute could limit the application of this technology: the noise levels at the operator's working position were very high. These levels must be reduced to provide adequate operator working times if the CIB technology is to be acceptable. Alternatively, the process could be made automatic (e.g., with robot arms and feedback controls).

3. DEMONSTRATION OF THE CO_2 CLEANBLAST™ PROCESS

3.1 BACKGROUND

The CO_2 Cleanblast™ equipment is based on a Lockheed patent. High-velocity CO_2 pellets are used to clean surfaces. Upon impact, these cold (−78.5°C) pellets sublime (i.e., change from a solid to a gas without passing through a liquid phase) and provide a novel cleaning action. The cleaning dynamics can best be described as the combined effects of high-velocity particle impacts (blasting) followed by a lifting action (flushing) caused by the generation of gas in the interface between the surface and the layer being removed. The cleaning action is not considered abrasive to most surfaces tested. The CO_2 pellets change to a nontoxic and noncorrosive gas, and, in principle, must only be filtered to be released to the atmosphere. The gas is, however, incapable of supporting life, and the operating environment must be monitored to ensure an adequate concentration of oxygen for breathing. The operating parameters of the system (e.g., pellet size, hardness, velocity, rate of delivery) can be modified to provide a wide range of cleaning capabilities.

3.2 DESCRIPTION OF THE CLEANBLAST™ PROCESS SYSTEM

The carbon dioxide blasting system consists of six major components: liquid CO_2 tank, pelletizer, air compressor, air dryer, pressure hose, and blasting nozzle. The system is illustrated in Fig. 5. Liquid carbon dioxide is stored in a special tank at 200-300 psig. The liquid CO_2 is transported to the pelletizer, where it is converted to solid CO_2, which is compressed and extruded as pellets. The control system of the pelletizer operates at the factory settings. These are as follows: CO_2 inlet pressure—170 psig, air transport air pressure—40 psig, control air pressure—90 psig, and discharge air pressure—0 (variable up to 250 psig). A drive air pressure

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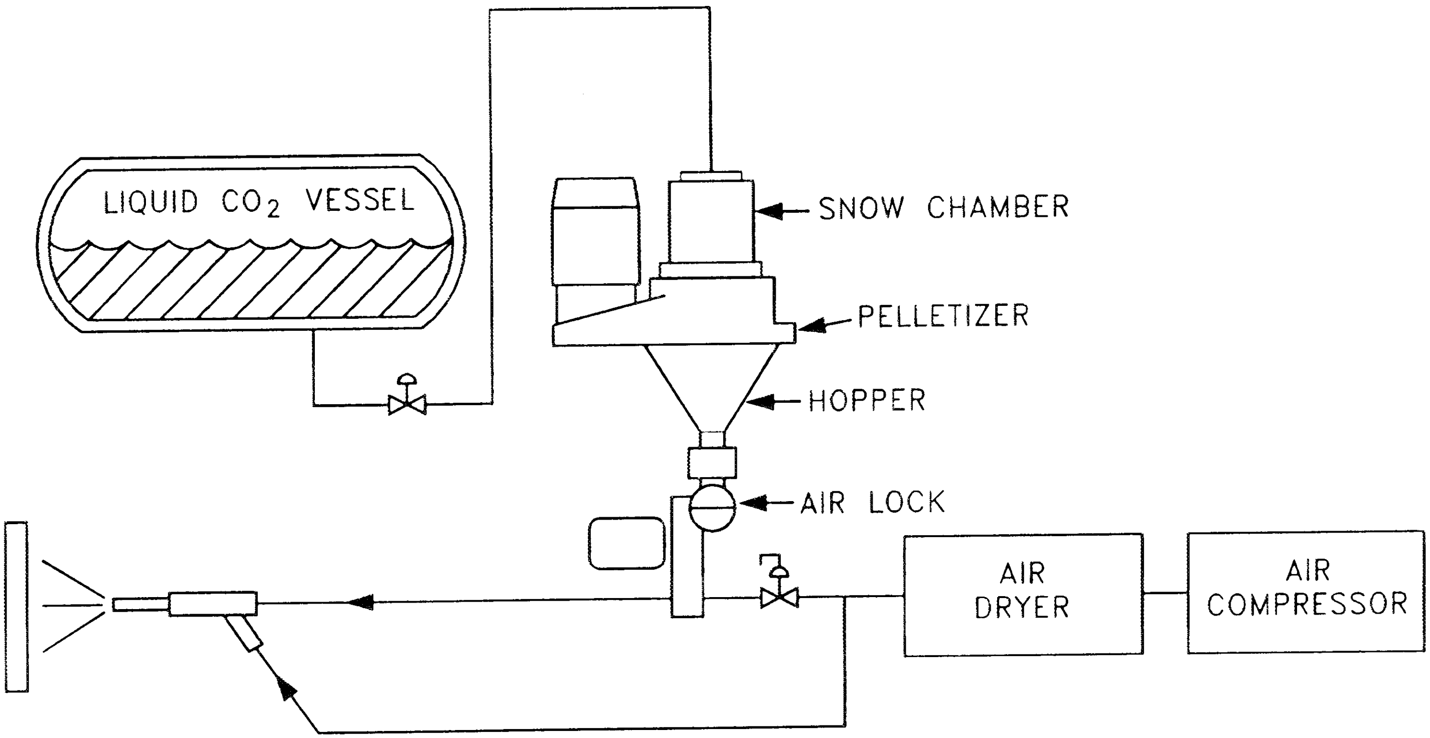

Fig. 5. Cleanblast™ process system.

of 125 psi (about 270 scfm) was determined to be the optimum setting for removing the contamination encountered during the demonstration.

The pellets are fluidized and transported via a low-pressure airstream to the blasting nozzle. A second air stream provides air at higher pressure to the eductor jet in the blast nozzle. In the nozzle, the CO_2 pellets are drawn into the high-velocity airstream by the venturi effect and propelled at the target surface. The pellet velocity is determined by the supply air pressure and is preselected for the application being performed. The typical range of velocities lies between 750 and 1000 ft/s.

The time required to remove the contamination will vary as a function of the material to be removed and the drive air pressure.

3.3 PROCEDURE FOR THE CLEANBLAST™ PROCESS TESTS

All demonstration activities were conducted in the clear Plexiglass enclosure (see Fig. 2) in the shop area of the RDF (Building 3019 Complex at ORNL). The clear enclosure permitted the CO_2 blasting operation to be observed without exposing the observer to the contaminated environment. The ventilation system used for the CIB tests was supplemented with a second system having a capacity of 2000 scfm (total capacity was 3000 scfm) to ensure a specified differential pressure of −1.5 to −2.0 in. water gauge in the enclosure. This is an adequate differential pressure to prevent the release of radioactive materials or CO_2 from the box into the room environment. (A high level of CO_2 in the room air would be hazardous to the worker's health.) The combined ventilation system provided a differential pressure of about −3.0 in. water gauge under all operating conditions tested. The glove box exhaust was protected with a bank of roughing and HEPA filters.

The test items were introduced into the glove box and placed in the rack in the center of the glove box. The CO_2 Cleanblast™ equipment was started and adjusted to the test conditions. It takes about 15 min for all temperatures and flows to stabilize. Then operator moved each piece to within 1.5 to 2 in. of the nozzle and blasted the surfaces facing the nozzle with a sweeping motion. The piece was rotated again and again and blasted until it appeared that all surfaces had been cleaned. The piece was replaced in the rack, and the next piece was taken through the process. The cleaned items were removed from the glove box and surveyed for residual contamination.

3.3.1 Cold Tests

The initial demonstration was centered around the removal of permanent coatings from a variety of materials (cinder block, concrete, fiberglass, and metals). These demonstrations verified the settings and provided training for the operators. The coatings were successfully removed with no visual damage to the substrates. The waste generated from the cleaning process was the flakes of the removed coatings. The flakes were collected on off-gas filters or picked up from the surfaces and floor of the glove box using a HEPA-filtered vacuum cleaner. Similar tests were performed with surfaces coated with greasy substances (described in Sect. 3.3.4).

3.3.2 Decontamination of Tools and Equipment

A selection of contaminated tools and equipment from the manipulator shop was subjected to the cleaning process.

3.3.2.1 Description of Tools and Equipment

The contaminated parts obtained for testing were tools (hammers, pliers, and screwdrivers) and equipment (manipulator slave-end gear assemblies.) All items tested in this phase had been subjected to decontamination at least one time before, using hand scrubbing with cleaning agents and/or pressure washing with hot 1000-psig water sprays. Contamination levels remained high after these hand cleaning endeavors, with both α and βγ radiation present as fixed (direct probe readings, which includes any transferable activity) and transferable (smear readings) present on most parts (Table 4).

Direct (probe) readings ran from 3000 dpm to 70,000 dpm of βγ radiation and from below release limits (≤300 dpm) to 18,000 dpm of α radiation. Transferable contamination levels ranged from below release limits (≤200 dpm) to 235 dpm of βγ radiation. The transferable α radiation was below release limits (≤20 dpm). The transferable activity readings were based on counting smear papers and reported on an assumed surface area of 100 cm^2, even if the object itself did not have a surface area that large.

3.3.2.2 Procedure for Decontaminating Tools and Equipment

The general procedure is described in Sect. 3.3.

3.3.2.3 Results of Decontaminating Tools and Equipment

The radiological data following the conventional decontamination and the data after CO_2 blast decontamination are presented in Table 4. The tools and equipment appeared to be cleaned as well as possible between about 3 and 5 min. No significant change was observed with longer treatments or additional treatments.

The DFs obtained in removing the fixed contamination range from about 1 (no decontamination) to about 12. None of the cleaned tools or equipment were below the release limits. The resulting waste from this activity was collected primarily by the HEPA filter with a limited amount of activity on the interior surface of the glove box.

Table 4. Tabulated data from CO_2 blast treatment of hand tools and manipulator parts

	After handwipe decontamination				After CO_2 blast demonstration				Decontamination factor (max probe)	
	Max probe (dpm)		Max smear (dpm/100 cm^2)		Max probe (dpm)		Max smear (dpm/100 cm^2)			
	α	βγ	α	βγ	α	βγ	α	βγ	α	βγ
Channel locks	<300	14,000	<20	<200	<300	2,000	<20	<200	*a*	7.0
Gear, manipulator	<300	6,000	<20	<200	<300	5,000	<20	<200	*a*	1.2
Gear, manipulator	18,000	50,000	<20	<200	13,000	50,000	<20	<200	1.4	1.0
Gear, manipulator	1,300	30,000	<20	<200	2,000	7,000	<20	<200	0.7	4.3
Gear, manipulator	<300	29,000	<20	<200	<300	20,000	<20	<200	*a*	1.5
Gear, manipulator	<300	3,000	<20	<200	<300	3,000	<20	<200	*a*	1.0
Hammer	360	70,000	<20	235	<300	6,000	<20	<200	*a*	11.7
Hammer	<300	10,000	<20	<200	<300	2,000	<20	<200	*a*	5.0
Pliers	<300	5,000	<20	<200	<300	1,800	<20	<200	*a*	2.8
Screwdriver	<300	14,000	<20	<200	<300	5,000	<20	<200	*a*	2.8
Screwdriver	490	38,000	<20	<200	700	8,000	<20	<200	0.7	4.8

[a]Indeterminate ratio.

3.3.2.4 Discussion of Results of Decontaminating Tools and Equipment

The CO_2 Cleanblast™ process was not effective in decontaminating the tools and equipment used in these tests. It is likely that the operating service conditions or the previous decontamination treatments had fixed the contamination to the surfaces, and the "gentle" cleaning action was not sufficient to abrade the surfaces. It was apparently not effective in removing or dislodging any fixed materials from crevices either.

3.3.3 Decontamination of Lead Brick

The CO_2 Cleanblast™ process was applied to the decontamination of lead brick to demonstrate the ability of the CO_2 blast system to successfully decontaminate transferable (smearable) and nontransferable (fixed) contamination from lead surfaces.

3.3.3.1 Description of the Contaminated Bricks

The lead brick used in this demonstration had been previously decontaminated via hand scrubbing with a surfactant to remove loose contamination. A summary of predecontamination levels of *fixed* (probe readings) $\beta\gamma$ contamination is shown in Table 5. The complete data set presented in Appendix B has been grouped for this table. The grouped data in this table are presented in Fig. 6.

3.3.3.2 Procedure for Decontaminating Lead Bricks

The procedure for decontaminating lead bricks is the same as that presented in Sect. 3.3.

3.3.3.3 Results of the Decontamination Tests of Lead Bricks

The bricks were decontaminated in several batches. Average times of between about 5 and 12 min per brick were recorded for each batch. The overall average cleaning time was 8.7 min per brick and agreed well with the overall median time of 8.9 min.

Table 5. Grouped data for βγ-contaminated lead bricks before treatment

Number of bricks	Cumulative no.	Radiation level (probe reading, dpm)
1	1	= 1,000
14	15	1,001-2,000
9	24	2,001-5,000
8	32	5,001-10,000
10	42	10,001-20,000
7	49	20,001-50,000
7	56	50,001-100,000
4	60	100,001-200,000
1	61	200,001-500,000

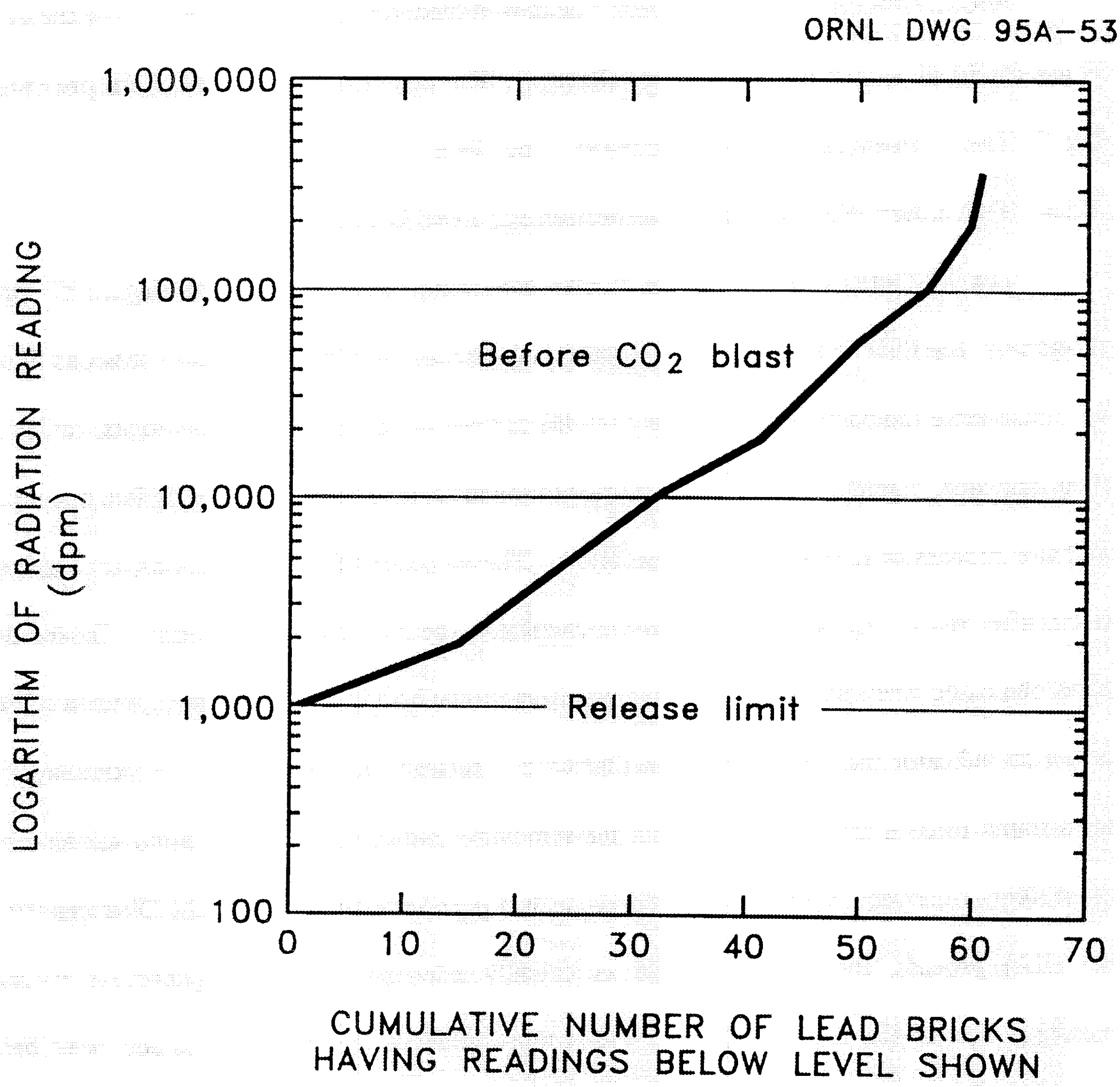

Fig. 6. Radiation readings before CO_2 Cleanblast™ decontamination.

About 92% (56 of 61) of the lead bricks were decontaminated to levels below the control limits for fixed contamination (probe readings.) The decontamination results are presented in Fig. 7. The complete results are presented in Appendix B.

3.3.3.4 Discussion of Results of Decontaminating Lead Bricks

The lead bricks were uniform in size and shape, but varied in the degree of surface roughness, the thickness of their oxide layers, and their levels of contamination, either as fixed or as transferable radioactivity. It is likely the life history of the individual lead bricks, rather than their individual contamination levels just prior to the tests, determined the rate of decontamination and the success of the decontamination effort. The more pitted the surface was, such as might occur after repeated exposure to corrosive chemicals, the harder it was to clean. On the other hand, the oxide layer on older lead bricks was found to be helpful. An oxide layer, in and of itself, is not an indicator that radioactive contamination is present, but removal of the oxide layer has been found to be a simple indicator that the removable radioactive contamination has also been most likely removed. When all the oxide layer had been removed by using the Cleanblast™ (or the CIB) process, the operator could confidently interrupt the cleaning process to make measurements of the residual activity. (It is more efficient to remove the oxide layer before measuring the completeness of the cleaning since it takes much more time to perform the radiological surveys than it does to decontaminate a brick.) Radioactivity that remained after this treatment was usually found to be impervious to further similar treatments, if the operator had done a thorough job the first time.

The CO_2 Cleanblast™ process was effective for decontaminating lead bricks. As mentioned previously, about 92% of the bricks were cleaned below release limits even though the initial level of contamination was quite high. Five bricks (about 8%) remained contaminated, even

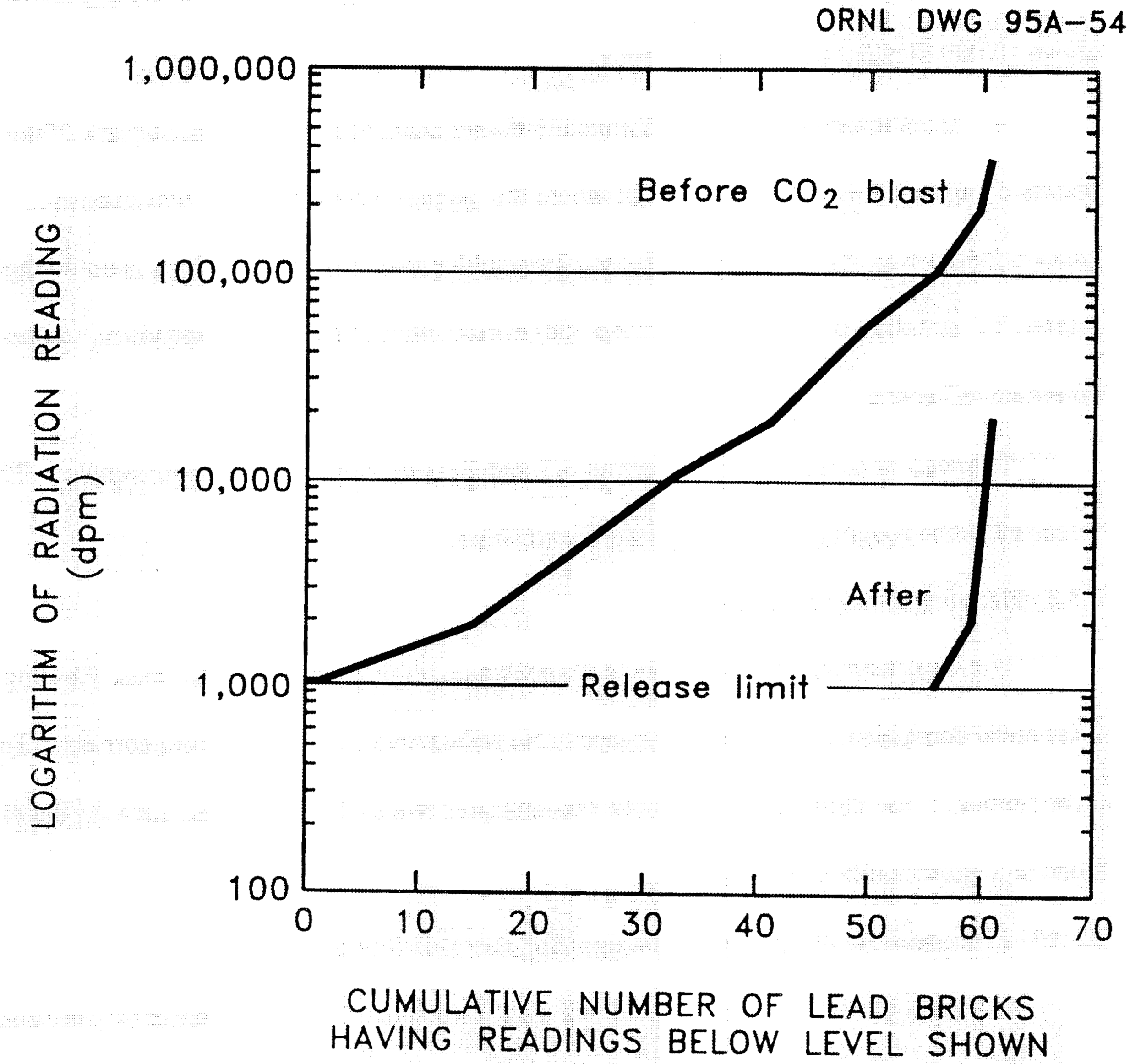

Fig. 7. Radiation levels after CO_2 Cleanblast™ treatment.

after a second pass through the CO_2 Cleanblast™ process. Only one of the remaining bricks was above 10,000 dpm $\beta\gamma$ (measured by probe).

At the conclusion of the CO_2 Cleanblast™ lead decontamination tests, surveys of the box and its equipment were made to pinpoint where the displaced contamination was deposited. The contamination was found on the surfaces of the glove box and on the filters, confirming the release of airborne contamination to the glove box atmosphere. The analytical results are presented in Table 6.

The lead concentrations were about 3.3 and 21% by weight for the two samples. These values make the roughing filters hazardous mixed waste.

3.3.4 Cleaning of Oily Surfaces

The final activity was designed to demonstrate the efficiency of CO_2 blast cleaning on sheet metal contaminated with oily substances. No radioactive contamination was present. These tests simulated the cleaning of ductwork contaminated with oils and PCBs, such as might be found at a gaseous diffusion plant.

3.3.4.1 Procedure for Preparing and Analyzing the Test Surfaces

Nine galvanized sheet metal coupons (300 mm square) were subjected to mechanical abuse (hammering, bending, etc.), which distorted their shape and fractured the galvanized coating. Several oily or greasy substances (B. G. lube oil, crayon, grease pencil, and high-temperature silicone vacuum grease) were applied to the test areas and allowed to cure before being subjected to the CO_2 blasting. Following the CO_2 Cleanblast™ application, the samples were placed in protective containers and taken to the laboratory to be inspected.[8]

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[8]The "before treatment" samples were not analyzed.

Table 6. Analysis of the roughing filters after the CO_2 Cleanblast™ tests

Sample no.	Cs-137 (Bq/g)	Gross α (Bq/g)	Gross β (Bq/g)	Lead ($\mu g/g$)
1	13.2 ± 0.23	0.88 ± 0.37	22.8 ± 1.6	$3.28 \pm 0.04 \times 10^4$
2	28.0 ± 2.7	1.87 ± 0.53	53.7 ± 2.5	$2.06 \pm 0.00 \times 10^5$

By using remote-sensing infrared spectroscopy (i.e., 75° specular reflectance), it was possible to measure the residual organic layers on the surfaces and obtain an estimate of the cleaning effectiveness of the CO_2 Cleanblast™ system. The technique can be used with flat or convex specimens with no limit to their size. Typical detection limits were on the order of 1 mg/m^2 based on the stretching band for light mineral or silicone oils. The detection limits were approximately doubled for severely hammered surfaces. At levels of >10 times the detection limits, it was possible to identify the chemical identities of the organic materials. Typical levels of oil contamination after vigorous attempts to wipe them dry with clean tissues were about 100 times greater than the detection limits. Marking pen inks were typically 1000 times greater than the detection limits.

3.3.4.2 Results of the CO_2 Cleanblast™ Tests for Removing Oily Substances

The results are presented in Table 7. Residual hydrocarbon layers ranged from about 3 to 6 mg/m^2. Silicone oil residues ranged from about 1.5 to 18 mg/m^2. The peripheral areas of sample no. 8 had levels of 118 mg/m^2 of a silicone material similar to Dow Corning high-vacuum grease.

3.3.4.3 Discussion of Results with Oily Substances

As with the removal of radioactive contamination, it is important that the contaminant to be removed be exposed to direct contact by the CO_2 Cleanblast™ agent. Because the original samples were not analyzed before treatment, it is possible only to estimate the decontamination success. Assuming that the original levels were the same as those found on the vigorously wiped surfaces used in testing the analytical methodology (i.e., 100 times the detection limits, or 100-200 mg/m^2), one can make some very conservative estimates of DFs. (The unwiped levels would certainly be many times higher than 100 times the detection limit.) For the samples with

Table 7. Infrared analyses of galvanized sheet metal

Sample no.	Sample description	Residual silicone (mg/m^2)	Residual hydrocarbon (mg/m^2)
0	Control (new duct cleaned with pine oil)	1.5	1.1
1	BG oil, hammered	1.5	3.4
2	BG oil, hammered	1.5	4.5
3	BG lube 0.1, hammered	1.5	3
4	BG lube 0.1, hammered	3.1	4.5
5	High-temp vacuum grease, hammered	1.5	3
6	Grease pencil, hammered	2.2	4.5
7	Grease pencil	1.5	3.5
8	High-temp vacuum grease	17.5	6
9	Crayon	4.3	3.7
10	Back side of sample no. 8		4.6

predominantly nonsilicone contaminants (i.e., 1-4, 6, 7, 9, and 10), the DF averaged 25. For silicone-based contaminants (5, 8) the DF was *more than* 5. Cleaning organics with the CO_2 Cleanblast™ process removes the bulk of the organic materials, but it is not clear whether the process alone is adequate for bringing the sheet metal surfaces below the limit of regulatory concern.

3.4 SUMMARY OF RESULTS FROM THE CLEANBLAST™ PROCESS TESTS

Results indicate that 56 of 61 lead bricks employed in testing were decontaminated to a point below ORNL's release limits. The DF obtained for the five lead bricks that remained contaminated upon termination of the demonstration ranged from 0 to 175 for nontransferable contamination.

The waste generated was limited to the material removed from the brick and was contained within the glove box. The airborne activity and detritus were removed via the filter system. All elements of the system were surveyed or analyzed to determine the displacement of the contamination and to evaluate for waste acceptance. The roughing filter, which was placed between the glove box and the HEPA filter, was analyzed to determine the radionuclide and lead content. Data from the analysis are provided in Table 6. The roughing filter is identified as a mixed hazardous waste, based on these analyses. The waste is all solid waste, and its volume is limited to the size of the filter and the small amount of material remaining in the glove box. The waste was disposed of as hazardous mixed waste.

3.5 DISCUSSION OF THE RESULTS OF THE CO_2 CLEANBLAST™ PROCESS

It is important to know the history of the contaminated items. Repeated treatments with harsh chemicals either in service or during decontamination can limit the effectiveness of the CO_2 Cleanblast™ process. This is especially true for lead bricks that have been melted and recast.

The demonstration indicated that the optimum angle for decontamination was 90° to the contaminated surface. In all cases, the operator is required to make a judgment to determine when enough cleaning has been done. In the cold tests it was easy to see when the coatings had been removed. Similarly, the lead bricks that had oxidized layers gave a relatively clear indication when the cleaning could be stopped. With the contaminated tools and equipment, the operator had no such clear evidence. Removing the oxidized layer from a typical lead brick took an average of 8.7 min. Somewhat shorter times were observed for cleaning the tools and equipment (about 5 min per item).

The CO_2 Cleanblast™ process resulted in successful decontamination of 92% of the lead bricks to below the release limits. Although it provided some decontamination of tools and equipment, it was not effective in decontaminating those items to levels below the release limits.

In all of the demonstrations, the waste generated was limited to the spoils removed from the surface. The contamination was spread on the inside surfaces of glove box and on the ventilation roughing and HEPA filters. There was no additional secondary waste.

3.6 PERFORMANCE OF THE CLEANBLAST™ EQUIPMENT

The CO_2 Cleanblast™ equipment operated well during the tests and was easy to control. No equipment malfunctions or operational difficulties occurred during these tests. The system was rather large and would benefit from a reduction in the size and number of pieces.

The cold temperatures involved require consideration in the design of the enclosures and other equipment to avoid failure as a result of brittle fracture or the effects of formation of frost on the cold pieces of equipment. Care must be taken to protect the operating personnel from contact with the cold surfaces or gas stream.

The major concern for this process is containment, both of radioactive species and of the CO_2 gas. The large volumes of gas produced must be filtered to prevent the spread of contaminated particulates. The operator's work space must be monitored to avoid harm resulting from oxygen deprivation by displacement of the air. Maximum concentrations of CO_2 were measured to be 2300 ppm in the general shop area and 8300 ppm in the enclosure.

A secondary problem experienced with the CO_2 Cleanblast™ system is the noise it generates while in use. The maximum noise level was measured to be 122.4 dBa in the work area when using a blast nozzle pressure of 125 psig. Even with the operator wearing earplugs under earmuffs, the working time was limited to 30 min per 8-h shift, based on OSHA criteria for the protection against hearing loss. At the demonstration processing rate, this would correspond to about 3 or 4 bricks per person per shift.

3.7 CONCLUSIONS FROM THE TESTS OF THE CO_2 CLEANBLAST™ PROCESS

The CO_2 Cleanblast™ decontamination process was demonstrated to be an effective method for removal of radiological contamination from lead bricks. The blast media is noncorrosive and nonabrasive and would make an excellent method for decontaminating the surfaces of electrical or other sensitive components. It would also appear to be an effective method for removing contaminated coatings (such as paint or grease) without generating a secondary liquid waste stream. It was not effective for removing contamination that had been chemically bonded to surfaces of tools or equipment during service or during prior decontamination attempts.

The waste volume is small; cleanup is confined to the process of collecting the removed coatings and residues and the ventilation filters for disposal.

The CO_2 Cleanblast™ Process is an effective method for removing surface coatings and loosely adherent surface contamination without significant harm to the surfaces being cleaned. It offers an attractive alternative to traditional cleaning methods for some items.

4. COMPARISON OF THE TWO METHODS FOR DECONTAMINATING TOOLS, EQUIPMENT, AND LEAD

The two processes (CIB and CO_2 Cleanblast™) provide similar decontamination results. Both processes require some operational improvements such as better noise control and a reduction in the total size of the processing equipment train.

While both methods require containment structures to prevent the spread of the released contamination, the CO_2 Cleanblast™ process presents a significantly greater challenge in containing radioactive particulates and in handling larger gas volumes. The CO_2 Cleanblast™ process liberates more radioactivity into the off-gas stream than the CIB process. The Cleanblast™ process requires protection of the operating personnel from exposure to excessive concentrations of CO_2 gas.

The CO_2 Cleanblast™ process has a unique attribute: the dry ice creates low temperatures. Stringent design and operating requirements must be followed to protect against equipment failure due to high pressures and/or low temperatures. The operating personnel must be protected against frostbite.

The CIB process generates a secondary waste, the meltwater, which may contain any soluble radioactive or substrate materials. The CO_2 Cleanblast™ process generates no liquid wastes (unless there is significant frost production and melting).

The CO_2 Cleanblast™ process has an advantage in that its cleaning medium is noncorrosive and could be used on delicate electronic surfaces, whereas the water-based CIB process cannot be used where contact with water would attack the surfaces in a destructive manner. This may be less of a consideration if there is no need to reuse or recycle the items.

The operating and equipment costs for the CO_2 Cleanblast™ process are higher (by about a factor of 2) than those for the CIB process.

5. CONCLUSIONS AND RECOMMENDATIONS

The factors that must be considered in determining which decontamination process to use will depend on the requirements of the decontamination tasks to be undertaken. These include the nature of the surfaces to be cleaned; the need to recycle or reuse the items; whether there are any restrictions imposed by the operating facility; the life-cycle capital and operating costs; and the costs for collecting, handling, and disposing of the waste streams. Either process could have some combination of these requirements that would make it the process of choice for certain applications.

In these tests, the CIB process demonstrated three advantages over the CO_2 Cleanblast™ process. It uses a less expensive reagent (water versus CO_2), it operates at more moderate temperature conditions, and it uses less expensive equipment. ORNL has submitted a proposal for a cooperative research and development agreement to develop the CIB system for use in decontaminating metals and concrete in DOE facilities. The proposed program will develop the equipment, fixtures, and procedures for demonstrations to decontaminate equipment and facilities at DOE sites.

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Appendix A

CRYSTALLINE ICE BLAST DATA FOR LEAD BRICKS

Table A.1. Crystalline Ice Blast (CIB) data for lead bricks

Brick no.	After handwipe decontamination: Max probe (dpm) α	After handwipe decontamination: Max probe (dpm) β,γ	After handwipe decontamination: Max smear ($dpm/100\ cm^2$) α	After handwipe decontamination: Max smear ($dpm/100\ cm^2$) β,γ	After CIB decontamination: Max probe (dpm) α	After CIB decontamination: Max probe (dpm) β,γ	After CIB decontamination: Max smear ($dpm/100\ cm^2$) α	After CIB decontamination: Max smear ($dpm/100\ cm^2$) β,γ	Decon factor (probe) α	Decon factor (probe) β,γ
1	<300	30,000	<20	439	<300	<1,000	<20	<200	*a*	>30
2	<300	25,000	<20	908	<300	<1,000	<20	<200	*a*	>25
3	<300	43,000	<20	214	<300	<1,000	<20	<200	*a*	>43
4	<300	20,000	<20	337	<300	<1,000	<20	<200	*a*	>20
5	<300	10,000	<20	214	<300	<1,000	<20	<200	*a*	>10
6	<300	100,000	<20	347	<300	<1,000	<20	<200	*a*	>100
7	<300	20,000	<20	224	<300	<1,000	<20	<200	*a*	>20
8	<300	50,000	<20	204	<300	<1,000	<20	<200	*a*	>50
9	<300	5,000	<20	<200	<300	<1,000	<20	<200	*a*	>5
10	<300	50,000	<20	214	<300	<1,000	<20	<200	*a*	>50
11	<300	48,000	<20	214	<300	<1,000	<20	<200	*a*	>48
12	<300	2,500	<20	<200	<300	<1,000	<20	<200	*a*	>205
13	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>105
14	<300	1,200	<20	<200	<300	<1,000	<20	<200	*a*	>1.2
15	<300	4,500	<20	255	<300	<1,000	<20	<200	*a*	>4.5
16	<300	2,400	<20	<200	<300	<1,000	<20	<200	*a*	>2.4
17	<300	5,000	<20	214	<300	<1,000	<20	<200	*a*	>5
18	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
19	<300	20,000	<20	275	<300	<1,000	<20	<200	*a*	>20
20	<300	1,200	<20	<200	<300	<1,000	<20	<200	*a*	<1.2
21	<300	4,200	<20	<200	<300	<1,000	<20	<200	*a*	>4.2
22	<300	7,000	<20	<200	<300	<1,000	<20	<200	*a*	>7
23	<300	8,000	<20	<200	<300	<1,000	<20	<200	*a*	>8
24	<300	4,000	<20	<200	<300	<1,000	<20	<200	*a*	>4
25	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
26	<300	10,000	<20	<200	<300	<1,000	<20	<200	*a*	>10
27	<300	1,100	<20	255	<300	<1,000	<20	<200	*a*	>1.1
28	<300	1,200	<20	<200	<300	<1,000	<20	<200	*a*	>1.2
29	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
30	<300	1,300	<20	<200	<300	<1,000	<20	<200	*a*	>1.3
31	<300	15,000	<20	224	<300	<1,000	<20	<200	*a*	>15
32	<300	300,000	<20	224	<300	<1,000	<20	<200	*a*	>300
33	<300	3,600	<20	<200	<300	<1,000	<20	<200	*a*	>3.6
34	<300	2,100	<20	<200	<300	<1,000	<20	<200	*a*	>2.1
35	<300	1,200	<20	<200	<300	<1,000	<20	<200	*a*	>1.2
36	<300	10,000	<20	<200	<300	<1,000	<20	<200	*a*	>10

Table A.1 (continued)

Brick no.	After handwipe decontamination: Max probe (dpm) α	Max probe (dpm) β,γ	Max smear (dpm/100 cm²) α	Max smear (dpm/100 cm²) β,γ	After CIB decontamination: Max probe (dpm) α	Max probe (dpm) β,γ	Max smear (dpm/100 cm²) α	Max smear (dpm/100 cm²) β,γ	Decon factor (probe) α	Decon factor (probe) β,γ
37[b]	<300	90,000	<20	<200	<300	<1,000	<20	<200	*a*	>90
38	<300	140,000	<20	245	<300	<1,000	<20	<200	*a*	>140
39	<300	12,000	<20	520	<300	<1,000	<20	<200	*a*	>12
40[b]	<300	500,000	<20	3,825	<300	2,000	<20	<200	*a*	250
41	<300	45,000	<20	<200	<300	<1,000	<20	<200	*a*	>45
42[b]	<300	13,000	<20	<200	<300	<1,000	<20	<200	*a*	>13
43	<300	6,000	<20	<200	<300	<1,000	<20	<200	*a*	>6
44	<300	9,000	<20	<200	<300	<1,000	<20	<200	*a*	>9
45	<300	400,000	<20	<200	<300	<1,000	<20	<200	*a*	>400
46[b]	400	70,000	<20	245	<300	<1,000	<20	<200	>1.3	>70
47	<300	20,000	<20	214	<300	<1,000	<20	<200	*a*	>20
48	<300	23,000	<20	<200	<300	<1,000	<20	<200	*a*	>23
49	<300	21,000	<20	275	<300	<1,000	<20	<200	*a*	>21
50	<300	1,600	<20	<200	<300	<1,000	<20	<200	*a*	>1.6
52	800	5,500,000	<20	745	<300	<1,000	<20	<200	>2.7	>1,000
64	<300	12,000	<20	<200	<300	<1,000	<20	<200	>1	>12
73	1,800	200,000	<20	663	<300	10,000	<20	<200	>6	20.0
76	<300	100,000	<20	<200	<300	<1,000	<20	<200	*a*	>100
81	350	150,000	<20	337	<300	<1,000	<20	<200	>1.2	>150
95	<300	120,000	<20	<200	<300	<1,000	<20	<200	*a*	>120
110	<300	140,000	<20	235	<300	9,000	<20	<200	*a*	15.6
114	536	130,000	<20	<200	<300	<1,000	<20	<200	>1.8	>130
122	400	120,000	<20	<200	<300	<1,000	<20	<200	>1.3	>120
127	770	2,000,000	<20	602	<300	<1,000	<20	<200	>2.6	>1,000
132	<300	4,000,000	<20	775	<300	<1,000	<20	<200	*a*	>1,000
136	<300	120,000	<20	612	<300	<1,000	<20	<200	*a*	>120
150	1,100	3,000,000	<20	1,336	<300	<1,000	<20	<200	>3.7	>1,000
154	700	100,000	21	551	<300	<1,000	<20	<200	>2.3	>34
167	<300	34,000	<20	<200	<300	8,000	<20	<200	*a*	4.3
169	1,700	4,000,000	<20	490	<300	7,000	<20	<200	>5.7	>1,000

[a]These ratios are indeterminate.
[b]These bricks were given two passes through the decontamination step.

Appendix B

TABULATED DATA FROM CO_2 BLAST DECONTAMINATING OF LEAD BRICKS

Table B.1. Tabulated data from CO_2 blast decontaminating of lead bricks

Brick no.	After handwipe decontamination				After CO_2 blast demonstration				Decon factor (probe)	
	Max probe (dpm)		Max smear (dpm 100 cm²)		Max probe (dpm)		Max smear (dpm 100 cm²)			
	α	β,γ	α	β,γ	α	β,γ	α	β,γ	α	β,γ
42	<300	13,000	<20	<200	<300	<1,000	<20	<200	*a*	>13
78[a]	<300	2,000	<20	<200	<300	2,200	<20	<200	*a*	0.9
87	<300	18,000	<20	<200	<300	<1,000	<20	<200	*a*	>18
92	<300	70,000	<20	<200	<300	<1,000	<20	<200	*a*	>70
110	<300	140,000	<20	<200	<300	<1,000	<20	<200	*a*	>140
121[a]	502	60,000	<20	<200	<300	1,500	<20	<200	>1.7	40.0
126	<300	44,000	<20	<200	<300	<1,000	<20	<200	*a*	>44
129	<300	26,000	<20	<200	<300	<1,000	<20	<200	*a*	>26
140	<300	5,000	<20	<200	<300	<1,000	<20	<200	*a*	>5
158[a]	<300	17,000	<20	<200	<300	1,700	<20	<200	*a*	10.0
171	800	120,000	<20	<200	<300	<1,000	<20	<200	>2.7	>120
178	<300	30,000	<20	<200	<300	<1,000	<20	<200	*a*	>30
179	<300	17,000	<20	<200	<300	<1,000	<20	<200	*a*	>17
180	<300	4,000	<20	<200	<300	<1,000	<20	<200	*a*	>4
196	<300	70,000	<20	<200	<300	<1,000	<20	<200	*a*	>70
205[a]	<300	15,000	<20	<200	<300	13,000	<20	<200	*a*	1.2
209	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
212	<300	8,000	<20	<200	<300	<1,000	<20	<200	*a*	>8
216	<300	10,000	<20	<200	<300	<1,000	<20	<200	*a*	>10
217	<300	40,000	<20	<200	<300	<1,000	<20	<200	*a*	<40
229	600	70,000	<20	<200	<300	<1,000	<20	<200	>2.0	>70
233	<300	30,000	<20	<200	<300	<1,000	<20	<200	*a*	>30
234	<300	60,000	<20	398	<300	<1,000	<20	<200	*a*	>60
235	<300	19,000	<20	<200	<300	<1,000	<20	<200	*a*	>19
236	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
238	<300	50,000	<20	302	<300	<1,000	<20	<200	*a*	>50
239	<300	13,000	<20	<200	<300	<1,000	<20	<200	*a*	>13
240	<300	18,000	<20	<200	<300	<1,000	<20	<200	*a*	>18
246	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
247	<300	3,500	<20	<200	<300	<1,000	<20	<200	*a*	>3.5
248	<300	12,000	<20	<200	<300	<1,000	<20	<200	*a*	>12
249	<300	8,000	<20	<200	<300	<1,000	<20	<200	*a*	>8
250	<300	1,300	<20	<200	<300	<1,000	<20	<200	*a*	>1.3
251	<300	8,000	<20	<200	<300	<1,000	<20	<200	*a*	>8
252	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5

Table B.1 (continued)

Brick no.	After handwipe decontamination: Max probe (dpm) α	After handwipe decontamination: Max probe (dpm) β,γ	After handwipe decontamination: Max smear (dpm 100 cm²) α	After handwipe decontamination: Max smear (dpm 100 cm²) β,γ	After CO_2 blast demonstration: Max probe (dpm) α	After CO_2 blast demonstration: Max probe (dpm) β,γ	After CO_2 blast demonstration: Max smear (dpm 100 cm²) α	After CO_2 blast demonstration: Max smear (dpm 100 cm²) β,γ	Decon factor (probe) α	Decon factor (probe) β,γ
253	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
254	<300	10,000	<20	<200	<300	<1,000	<20	<200	*a*	>10
264	<300	160,000	<20	<200	<300	<1,000	<20	<200	*a*	>160
265[a]	<300	350,000	<20	551	<300	2,000	<20	<200	*a*	175
266	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
268	<300	140,000	<20	<200	<300	<1,000	<20	<200	*a*	>140
269	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
270	<300	3,000	<20	<200	<300	<1,000	<20	<200	*a*	>3
271	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
277	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
301	<300	3,000	<20	<200	<300	<1,000	<20	<200	*a*	>3
302	500	60,000	<20	<200	<300	<1,000	<20	<200	>1.7	>60
303	<300	1,500	<20	<200	<300	<1,000	<20	<200	*a*	>1.5
304	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
305	<300	3,000	<20	<200	<300	<1,000	<20	<200	*a*	>3
306	<300	1,000	<20	<200	<300	<1,000	<20	<200	*a*	>1
308	<300	3,000	<20	<200	<300	<1,000	<20	<200	*a*	>3
309	<300	3,000	<20	<200	<300	<1,000	<20	<200	*a*	>3
310	<300	45,000	<20	<200	<300	<1,000	<20	<200	*a*	<45
311	<300	3,000	<20	<200	<300	<1,000	<20	<200	*a*	>3
312	<300	10,000	<20	<200	<300	<1,000	<20	<200		>10
313	350	6,000	<20	<200	<300	<1,000	<20	<200	>1.2	>6
314	<300	2,000	<20	<200	<300	<1,000	<20	<200	*a*	>2
315	<300	12,000	<20	<200	<300	<1,000	<20	<200	*a*	>12
316	500	80,000	<20	<200	<300	<1,000	<20	<200	>1.7	>80
317	<300	9,000	<20	<200	<300	<1,000	<20	<200	*a*	>9

[a]These ratios are indeterminate.

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