Decontamination Technologies

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Decommissioning Program
Outline

- What is decontamination?
- Factors to evaluate for selection of a technique
- Decontamination techniques
- Resources to assist in selecting a technique
Decontamination

- Decontamination is defined as the removal of contamination from areas or surfaces of facilities or equipment by washing, heating, chemical or electrochemical action, mechanical cleaning or by other means.

- Generally some form of decontamination – large or small - is required in any decommissioning activity.

- Some techniques useful ex-situ while others are useful in-situ.
Surface Decontamination
Depiction of Contamination

Simplified contamination mechanism on inner metal surfaces
Depiction of Contamination (ctd)

Simplified contamination mechanism on outer metal or concrete surfaces

- Spray or steam from leakages
- Aerosols precipitating onto surface
Issues Posed by Decontamination

- **Characterization of Contaminants**
  - Facility type and history
  - Activation or contamination; depth of contamination
  - Sampling required
  - Induced / fixed / crusted / loose contaminants
  - Materials of construction; coatings and residues; leaching through pores

- **ESH Issues**
  - Radiological inventory and radiation fields
  - Chemical handling and use
  - Limited access to egress to/from areas
  - Airborne control systems and filtration required and waste treatment methods
  - Concentrated waste forms
Typical Applications

- Structural surfaces – concrete, wood, steel, metals, plastic
  - Systems piping and equipment
  - Structures - floors, walls, ceilings and stacks
  - Interior areas and exterior areas
- Bench tops, glove boxes and other experimental equipment
- Small piping and process system items and components
- Disassembled items
- Shielding materials
- Soils
Delivery Methods

- Trained staff from the facility
  - Larger jobs with multiple work sites

- Service providers from outside the facility
  - Small jobs with only limited application or work opportunities
The “Decontamination Factor”

<table>
<thead>
<tr>
<th>DF</th>
<th>% of activity removed</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>5</td>
<td>80%</td>
</tr>
<tr>
<td>10</td>
<td>90%</td>
</tr>
<tr>
<td>50</td>
<td>98%</td>
</tr>
<tr>
<td>100</td>
<td>99%</td>
</tr>
</tbody>
</table>

- % of Activity Removed = \((1 - 1/\text{DF}) \times 100\)

- A decontamination factor of 10 results in a 90% removal of radionuclides from the surface or

\[90\% = (1 - 1/10) \times 100\]
Factors to Consider

- **Safety** - no contamination spread or new hazards introduced as a result of using the technique

- **Efficiency** – technique should minimize operating costs, be a proven technology, require short application period and minimize personnel radiological exposures

- **Cost Effectiveness** – technique selected to be deployed should be less costly to decontaminate than to ship or handle the materials without decontamination

- **Waste Management** – minimize primary and secondary wastes and/or lower waste classification

- **Feasibility of Application** – avoid labor intensive techniques, or processes using unusually large quantities of materials

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**Do not confuse maintenance decon operations with decommissioning decon operations** - separate and unique processes - in decommissioning more destructive techniques can be used since damage to a component is insignificant
Reasons to Decontaminate

- Reduce radiation exposures (via reductions in contaminant levels) to personnel (ALARA)
- Reduce the level of personal protective equipment required to enter areas and eliminate water transmission pathways (minimize waste)
- Lower the volume of or classification of wastes (minimize waste)
- Aid in the release of materials from an area (minimize waste) or for shipment of items
- Cheap waste disposal may negate implementation (**)
- Secondary waste generation may be an issue
- Extensive handling of the materials after decon may negate any benefit
- Paint, fixatives and other coatings can complicate the process

A specific case study is typically needed to justify implementation of even a small- or for sure a large-scale decontamination operation !!!
Types of Decontamination Processes

- Chemical
- Electrochemical
- Mechanical and Manual
- Metal Melting
- Innovative
Chemical Decontamination*

- **Chemical Process**
  - Typically used in closed system for decontamination of primary circuit; can be used in open system in a batch mode as well
  - Concentrated or dilute reagents in contact with the contaminated items
  - Widely used, quick, relatively inexpensive and simple
  - Dissolve the accumulated crud layer and eventually the base metal - possibly using multiple cycles

*Requires someone sufficiently well schooled in the chemistry of the process to be employed in nearly all but the simplest of cases
Chemical Decontamination (ctd)

- Use of concentrated solutions takes less time and gives a higher DF
- Useful on complex geometries and uniform surfaces but ineffective on porous surfaces
- Recycling of reagents is crucial to avoid large secondary waste volumes
- Typical DF of 5-40 – with some strong acids up to 10,000 can be achieved
- Heating, contact time and agitation are important variables
- Complexants can be used to more effectively bind contaminants
- Foams, gels, pastes and fogging can be used to assist with application of chemical decontamination agents onto various materials
Chemical Decontamination (ctd)

- Chemical Processes
  - Water Flushing
  - Flushing of heated water at high pressure (hydro-lasing)
  - Mild chemicals – detergents and brushes

- Types of Chemicals
  - Oxidants
  - Reductants
  - Complexants
  - Acids/Bases
Chemical Decontamination (ctd)

- Chemical Processes
  - **Oxidants** - all lightly corrosive
    - AP
    - NP
    - Cerric Nitrate
    - CORD
  - **Reductants** - more aggressive
    - LOMI
    - More effective when used in combinations

- Chemical Processes
  - **Complexants** – moderately aggressive
    - Organic acids
    - Nitric/Oxalic acid
    - Corpex 921
  - **Acids/Bases** – very aggressive
    - Hydrofluoric/Nitric
    - Fluoroboric
    - Hydrochloric
    - Phosphoric
    - DfD
    - DECOHA
    - Sodium/potassium hydroxide
The DfD Chemical Decontamination Process

- A Decontamination process developed by EPRI for application during decommissioning of commercial NPP
  - Initiation – add Fluroboric Acid
  - Oxidation – add Potassium Permanganate
  - Destruction – add Oxalic Acid
  - Transition – add Potassium Permanagnate
Main Process System Skid for Chemical Decontamination

HP Centrifugal Pump

Chemical Mixing & Injection Unit

Flow Reversal Manifold

Filter Unit

Ion Exchange System (Resins)

Heater Unit
Decontamination process was carried out over 9 day period.
Decontamination Gels

- French nuclear industry has extensive experience in use of gels
- Spray gun and pump system used for application
- ‘Thixotropic gels’ are mixed with highly acidic or alkaline liquids

Photo courtesy of AREVA
Electrochemical Decontamination

- Electrochemical Process
  - In principle, these are chemical processes assisted by the use of an electrical field – the opposite process of electroplating
  - Object to be decontaminated is the anode and the cathode is either an electrode or the tank itself
  - Useful for treatment of carbon steel, stainless steel and aluminum
  - Processes are commercially available and relatively inexpensive and quick
  - A ‘tank immersion’ type application process is typically used with treated material in the form of smaller pieces
Electrochemical Decontamination (ctd)

- Typical acids used for this processing
  - Phosphoric acid
  - Nitric acid
  - Oxalic acid or Citric acid
  - Sulfuric acid

- Most useful on smaller diameter piping – however - oil, rust, grease and paint all pose problems

- Heating and agitation are needed along with a rinsing provision for the tank
- Not really adapted for use with small or complex geometry materials
- Low volume of secondary wastes
- Handling of components may lead to additional worker radiological exposures
- High DF upwards of 100 are feasible
Electro-polishing
Mechanical and Manual Decontamination

- Used extensively – simple, easy and cheap
- Surface cleaning/removal applications for smaller areas of loose or smearable surface contamination
- May be used in combination with other similar techniques
- For porous surfaces this techniques may be the only viable decontamination option
- Airborne contamination control measures generally required
Mechanical and Manual Techniques

- Sweeping / scrubbing / brushing / vacuuming
- Strippable coatings
- Ultrasonic cleaning / vibratory finishing
- Conventional and high pressure washing
- Steam vacuum cleaning
- Abrasives (sand blasting, grit blasting, etc)
- CO$_2$ blasting
- Scabblers / scalers
- Demolition hammer / hydraulic hammer / pneumatic hammer
- Shaving / Planing
- Shot blaster
- Drilling & spalling
- Grinding

Large range of tools are available to fulfill concrete decontamination tool needs.
Strippable Coatings

- Some typical strippable coatings:
  - ALARA 1146
  - TechSol 8001
  - PENTEK-604
  - Stripcoat TLC Free

- Encapsulates and binds loose contaminants; peel off the hardened layers

- Control airborne contaminants or as a fixative on structures to be demolished

- Engineered control for lowering PPE requirements to enter areas
  - 5-10 mil thickness- up to 40 mil
  - 100-200 sq ft per gallon
  - Curing time 4-12 hrs
  - Cost - $75-$100/gallon for material
Strippable Coatings (ctd)

Useful as both a decontamination agent (right side photo) and as a protective measures agent (left side photo) to assist operations.
### Strippable Coatings (ctd)

- **Traditional**
  - Latex Coatings
  - Remove some loose contamination
  - Very low waste generation

- **Modern**
  - Non-latex Coatings
  - Removes loose & fixed contamination better
  - Very low waste generation

<table>
<thead>
<tr>
<th>T</th>
<th>Avg Loose % Removal</th>
<th>Avg Fixed % Removal</th>
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</thead>
<tbody>
<tr>
<td>ALARA 1146</td>
<td>81%</td>
<td>58%</td>
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<tr>
<td>TLC Stripcoat</td>
<td>82%</td>
<td>61%</td>
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</table>

<table>
<thead>
<tr>
<th>M</th>
<th>Avg Loose % Removal</th>
<th>Avg Fixed % Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>PENTEK 604</td>
<td>93%</td>
<td>66%</td>
</tr>
<tr>
<td>Insta-Cote</td>
<td>94%</td>
<td>NA</td>
</tr>
</tbody>
</table>
**Abrasive Blasting**

- Used in wet and dry applications
  - Dry application – use air as material transporter - sand blasting, grit blasting using: sand, magnetite, steel shot, aluminum oxide, glass beads, plastic pellets, sponge
  - Wet application – use fluid as material transporter
  - Done in containment with ventilation and filtration system
- Work piece must be grounded and options to recycle the abrasive must be considered

- Oil and grease on work piece surfaces pose problems
- Can provide very good DF but often repeated applications are needed

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Sponge Blasting
Abrasive Blasting (ctd)

http://www.aqua-dyne.com

www.powerproductsonline.com
Blastrac Abrasive Blaster

FIG. 9. Portable abrasive blasting equipment. (Credit: Blastrac.)
Carbon Dioxide Blasting

- Pellets projected at high speed onto the work piece, evaporate and remove the contaminants
- Well established technique but can be very expensive to use
- Requires use of protective suit in a ventilated work room while being used
- Works through thermal shock, gas sublimations and abrasive action
- Produces no secondary waste
- Not effective on deep contamination
Carbon Dioxide Blasting

http://www.icesolv.com
Carbon Dioxide Blasting Pellets

from: http://www.coldjet.com
Surface Scabblers

- **Scabblers** use a set of pneumatically driven piston heads (typically 3-7 heads) using tungsten carbide cutters

- Available in electrically or pneumatically driven hand held or walk behind units

- Produces a rough surface finish by physically abrading both coated and uncoated concrete and steel surfaces

- Worker fatigue and air contamination controls are critical issues to be addressed
Scabbling is Hard Work
Concrete Shavers

- **Shavers** use a diamond tipped rotary cutting drum to give a smooth finish - both manual and automated systems are available.
- Cut through bolts and other metal in the concrete as well while producing up to 50% less waste than scabbling.
- About 5 times faster than scabbling.
Concrete Shavers (ctd)
Decontamination Experience

![Graph showing the removed (mm) and rate (sq m per hr) for different decontamination tools.}

- Needle Scaler
- Hand Scabbler 1 Hd
- Floor Scabbler 7 Hd
- Wall Scabbler 3 Hd
- Wall Scabbler 7 Hd
- Floor Shaver
- Wall Shaver

- Removed (mm): Needle Scaler 2, 2, 3, 3, 4, 1.5, 1.5
- Rate (sq m per hr): Needle Scaler 0.1, 0.6, 4.6, 4.6, 8.4, 13.6, 21

The graph compares the effectiveness of different decontamination tools in terms of removed material and rate of decontamination.
Hydraulic or Pneumatic Hammer

- Simple tools which are easy to use; hands-on use (conventional jackhammer) or electrically powered hydraulically controlled unit (BROKK)
- Worker fatigue and air handling systems are a critical issue; produces a rough and irregular surface to a work piece
- BROKK - Hammer, excavator, bucket, scabbler end-effectors; amenable to remote control operation & a very efficient tool
Metal Melting

- Large quantities of slightly contaminated metallic scrap generated during decommissioning
- Melting allows for the recovery of valuable resources and could conserve valuable disposal space or even optimize its use
- Metal melting has been used in: Germany (Siempelkamp), Sweden (Studsvik), France (Cenraco), Russia (Ekomet S) & USA
**Metal Melting** (ctd)

- Metal melting can be considered as a decontamination technique
- Contaminants melded into a metal matrix while concentrating bulk of the radionuclides in slag and filter dust
- Useful on complex geometries
- Final product is a metal ingot
Energy Solutions Melting Facility

- Facility operated near Oak Ridge, TN started metal melting operations in about 1992
- Uses an induction type furnace for melting CS, SS and Al with a typical charge size of 20 tons of material
- Re-use as shielding blocks for R&D facilities and as waste disposal containers
- Other material released to ‘clean scrap pile’ if it meets release criteria
Innovative Processes

- Some recent emerging decontamination technologies include:
  - Biological - microbial actions
  - Light ablation - passive process
  - Microwaves – needs further development
  - Lasers – nearing deployable state
  - Supercritical fluids - early
  - Exothermic powders - early
  - Electrical heating of re-bars - early
Floor Scabbling at PBRR

Photo courtesy of Bluegrass Bit Company
After Decontamination
Conclusions

- A variety of chemical and non-chemical decontamination technologies are available
- Selection of the best one suited for a specific application requires a site-specific and project-specific cost benefit analysis
- Even in some cases decontamination may only be of marginal benefit and must be carefully considered
- New innovative technologies are on the horizon
Recommended Reading

- IAEA TRS #395 (1999) and TRS #401 (2001)
- EC, Decommissioning of Nuclear Installations, EUR-16211 (1995)
- Survey of Decontamination Processes Appl to DOE Nuclear Facilities, ANL-97/19, 1997
- Technology Reference Guide for Rad Contam Surfaces, EPA, April 2006, EPA-402-R-06-003
- ASME Decommissioning Handbook – Decontamination Chapter
### Chemical decontamination factors and resulting waste volumes

<table>
<thead>
<tr>
<th>Chemical Reagent</th>
<th>Reaction Type</th>
<th>DF S2-Cs</th>
<th>DF S2-Zr</th>
<th>Evaporated Volume (m³)</th>
<th>Calcine Volume (m³)</th>
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</thead>
<tbody>
<tr>
<td>CORPEX 918*a</td>
<td>Chelant</td>
<td>1.7</td>
<td>1.3</td>
<td>0.03</td>
<td>0.08</td>
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<td>CORPEX Smearaway</td>
<td>Chelant</td>
<td>2</td>
<td>1.7</td>
<td>0.03</td>
<td>0.02</td>
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<td>Water</td>
<td>Water</td>
<td>3.5</td>
<td>1.2</td>
<td>0.03</td>
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<td>Nitric Acid</td>
<td>Corrosive</td>
<td>4.7</td>
<td>1.3</td>
<td>0.03</td>
<td>0</td>
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<tr>
<td>Nitric/Oxalic Acid</td>
<td>Oxidizer</td>
<td>5</td>
<td>1.2</td>
<td>0.67</td>
<td>0.18</td>
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<td>Turco ARR</td>
<td>Corrosive</td>
<td>5.5</td>
<td>1.2</td>
<td>0.5</td>
<td>0.3</td>
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<td>Nitric Permanganate</td>
<td>Oxidizer</td>
<td>6.4</td>
<td>1.2</td>
<td>0.0125</td>
<td>0.019</td>
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<td>Tartaric Acid</td>
<td>Reductant</td>
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<td>6.7</td>
<td>1.1</td>
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<td>Hydrogen Peroxide</td>
<td>Oxidizer</td>
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<td>1.2</td>
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<td>Turco 4502</td>
<td>Oxidizer</td>
<td>7</td>
<td>1.4</td>
<td>0.45</td>
<td>0.34</td>
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<td>Citric Acid</td>
<td>Reductant</td>
<td>8.8</td>
<td>1.3</td>
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<td>Aluminum Nitrate</td>
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<td>11.4</td>
<td>1.4</td>
<td>0.273</td>
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<td>Nitric 800ppm Hydrofluoric</td>
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<td>14.2</td>
<td>5.9</td>
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<td>TECHXTRACT 100, 200, 300</td>
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<td>17</td>
<td>6</td>
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<td>Fluoroboric Acid</td>
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<td>24</td>
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<td>CORPEX 921</td>
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<td>44.3</td>
<td>7.8</td>
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### Average % removal for non-chemical decontamination technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>SIMCON 1-Cs % Removal</th>
<th>SIMCON 1-Zr % Removal</th>
<th>SIMCON 2-Cs % Removal</th>
<th>SIMCON 2- Zr % Removal</th>
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<tr>
<td>Water Rinse</td>
<td>100</td>
<td>99</td>
<td>0**</td>
<td>0**</td>
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<td>Ultrasonic</td>
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<td>100</td>
<td>70</td>
<td>88</td>
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<td>CO₂ Pellet Blasting</td>
<td>91</td>
<td>92</td>
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<td>SDI CO₂ unit</td>
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<td>CO2 Snowflake</td>
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<td>26</td>
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<td>Centrifugal CO₂</td>
<td>*</td>
<td>*</td>
<td>83</td>
<td>98</td>
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<td>ZAWCAD</td>
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<td>99</td>
<td>76</td>
<td>95</td>
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<tr>
<td>Plastic Grit</td>
<td>100</td>
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<td>Glass Beads</td>
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<td>Alumina Grit</td>
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<td>Dissolvable Grit</td>
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<td>ALARA 1146</td>
<td>83</td>
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<td>76</td>
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<tr>
<td>PENTEK 604</td>
<td>96</td>
<td>90</td>
<td>57</td>
<td>75</td>
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</table>

* Tests not performed.  ** All SIMCON II coupons are cleaned with water rinses prior to initial analysis.

Extracted from paper by Argyle, Demmer, Archibald and Tripp, INEEL, presented at the ICEM2003 Conference.
<table>
<thead>
<tr>
<th>Technology Family</th>
<th>Performance&lt;sup&gt;a&lt;/sup&gt; Loose Contamination</th>
<th>Performance&lt;sup&gt;a&lt;/sup&gt; Fixed Contamination</th>
<th>Types of Substrate</th>
<th>Initial Cost&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Production Rate&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Decon Item in Place&lt;sup&gt;a&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt; pellet blasting</td>
<td>H</td>
<td>M-L</td>
<td>Metal, wood, plastic, concrete</td>
<td>H</td>
<td>L</td>
<td>Y</td>
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<tr>
<td>Water blasting</td>
<td>H</td>
<td>M</td>
<td>All</td>
<td>M</td>
<td>H</td>
<td>Y</td>
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<tr>
<td>Scabbling</td>
<td>H</td>
<td>H</td>
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<td>L</td>
<td>H</td>
<td>Y</td>
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<td>H</td>
<td>Concrete</td>
<td>L</td>
<td>H</td>
<td>Y</td>
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<tr>
<td>Abrasive grit</td>
<td>H</td>
<td>H</td>
<td>All</td>
<td>M</td>
<td>H</td>
<td>Y</td>
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<td>Grinding</td>
<td>H</td>
<td>H</td>
<td>All</td>
<td>L</td>
<td>L</td>
<td>Y</td>
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<tr>
<td>Milling</td>
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<td>H</td>
<td>All</td>
<td>M</td>
<td>L</td>
<td>N</td>
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<td>Vibratory finishing</td>
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<td>H</td>
<td>Primarily metal</td>
<td>L</td>
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<td>Hand scrubbing</td>
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<td>M</td>
<td>Y</td>
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<tr>
<td>Stripable coatings</td>
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<td>L</td>
<td>All</td>
<td>L</td>
<td>L</td>
<td>Y</td>
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<td>Vacuuming</td>
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<td>L</td>
<td>All</td>
<td>L</td>
<td>H</td>
<td>Y</td>
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<tr>
<td>Ultrasonic cleaning</td>
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<td>H</td>
<td>Primarily metal</td>
<td>L</td>
<td>L</td>
<td>N</td>
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<tr>
<td>Turbulator</td>
<td>H</td>
<td>M</td>
<td>Metal, plastics</td>
<td>L</td>
<td>L</td>
<td>N</td>
</tr>
<tr>
<td>Plasma cleaning</td>
<td>H</td>
<td>M</td>
<td>Primarily metal</td>
<td>H</td>
<td>L</td>
<td>N</td>
</tr>
<tr>
<td>Light ablation</td>
<td>H</td>
<td>M</td>
<td>Metal, concrete</td>
<td>H</td>
<td>L</td>
<td>N</td>
</tr>
<tr>
<td>Electrokinetic</td>
<td>H</td>
<td>M</td>
<td>Primarily concrete</td>
<td>M</td>
<td>L</td>
<td>Y</td>
</tr>
</tbody>
</table>

H=High; M=Medium; L=Low and Y=Yes and N=No

From CRC Press ‘Hazardous & Radioactive Waste Treatment Technology Handbook’
<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Limitations</th>
<th>Special Considerations</th>
<th>Quality of Performance Data***</th>
<th>Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chelation &amp; Organic Acids</td>
<td>Can be tailored to wide range of contaminants. Safer than other chemical techniques.</td>
<td>Requires considerable on-hand chemical knowledge for best application.</td>
<td>Contaminant solubilization requires great care in waste treatment. Danger of mobilization of the contaminant.</td>
<td>Poor</td>
<td>$10.76/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($1.00/ft²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($2.00/ft²)</td>
</tr>
<tr>
<td>Chemical Foams &amp; Gels</td>
<td>Increased contact time aids performance. Can reach remote and hidden areas.</td>
<td>May require repeated applications to achieve maximum effectiveness.</td>
<td>Care must be taken when flushing since foams can travel to areas beyond the reach of liquids.</td>
<td>Adequate</td>
<td>$21.53/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($2.00/ft²)</td>
</tr>
<tr>
<td>Oxidizing &amp; Reducing Agents</td>
<td>Disrupts matrix where contaminants hide so small amounts can be very effective.</td>
<td>Must be targeted at appropriate situation. Will not work if redox chemistry is not suitable.</td>
<td>Often used as one step of a multiple step process.</td>
<td>Adequate</td>
<td>$21.53/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($2.00/ft²) and above</td>
</tr>
<tr>
<td>TechXtract</td>
<td>Highly flexible. Can be tailored to specific contaminants.</td>
<td>Best for batch operation for small objects or for smaller areas.</td>
<td>Requires optimization for contaminant and substrate.</td>
<td>Good</td>
<td>$2.15/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($0.98/lb)</td>
</tr>
</tbody>
</table>
### Exhibit 1-2. Physical Decontamination Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Limitations</th>
<th>Special Considerations</th>
<th>Quality of Performance Data***</th>
<th>Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strippable Coatings</td>
<td>Produce a single solid waste. No airborne contamination. No secondary liquid waste.</td>
<td>The spray gun nozzles clog. From a cost perspective, may be best suited for smaller decontamination activities.</td>
<td>Only works for easily removed (smearable) contaminants.</td>
<td>Good</td>
<td>$52.20/m² ($4.85/ft²)</td>
</tr>
<tr>
<td>Centrifugal Shot Blasting</td>
<td>Especially good at removing paint and light coatings from concrete surfaces in open areas away from wall-floor interfaces.</td>
<td>Escaped shot may pose a hazard to workers. May require an air compressor, systems for dust collection and air filtration, a forklift, and a generator.</td>
<td>Can be limited by large size, hence unable to get into corners.</td>
<td>Good</td>
<td>$368.66/m² ($34.25/ft²)</td>
</tr>
<tr>
<td>Concrete Grinder</td>
<td>Fast and mobile. Less vibration.</td>
<td>Small size limits utility.</td>
<td>Often best used in combination with other technologies.</td>
<td>Good</td>
<td>$31.43/m² ($2.92/ft²)</td>
</tr>
<tr>
<td>Concrete Shaver</td>
<td>Good for large, flat, open concrete floors and slabs. Fast and efficient.</td>
<td>Does not maneuver well over obstacles. Good only for concrete floors and slabs.</td>
<td>Attractive alternative to hand-held scabblers.</td>
<td>Good</td>
<td>$14.21/m² ($1.32/ft²)</td>
</tr>
<tr>
<td>Concrete Spaller</td>
<td>Good for in-depth contamination. Fast.</td>
<td>Requires predrilling of holes. Leaves behind a rough, uneven surface.</td>
<td>Limited commercial availability.</td>
<td>Good</td>
<td>$199.35/m² ($18.52/ft²)</td>
</tr>
<tr>
<td>Technology</td>
<td>Strengths</td>
<td>Limitations</td>
<td>Special Considerations</td>
<td>Quality of Performance Data***</td>
<td>Cost*</td>
</tr>
<tr>
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<td>---------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Dry Ice Blasting</td>
<td>CO₂ gas generates very little extra waste. Very good for contamination on a surface.</td>
<td>Cannot remove contamination more deeply embedded in the surface matrix.</td>
<td>Requires support systems: air-compressors, dryers and filters.</td>
<td>Adequate</td>
<td>N/A**</td>
</tr>
<tr>
<td>Dry Vacuum Cleaning</td>
<td>Readily available. Works well with other physical decontamination technologies.</td>
<td>Only good for loose particles.</td>
<td>Typically used in conjunction with other decontamination technologies</td>
<td>Adequate</td>
<td>$21.53/m² ($2.00/ft²)</td>
</tr>
<tr>
<td>Electro-Hydraulic Scabbling</td>
<td>Generates less secondary waste than other technologies using water. Very efficient. Removes deep contamination.</td>
<td>Requires a skilled operator. Generates some secondary liquid waste.</td>
<td>Works best for horizontal surfaces.</td>
<td>Poor</td>
<td>$107.64/m² ($10.00/ft²) and up</td>
</tr>
<tr>
<td>En-vac Robotic Wall Scabbler</td>
<td>Works well on large, open spaces, including walls and ceilings. Worker exposure to contaminants is limited: remote operation and integrated vacuum system.</td>
<td>Requires additional attachments to address irregular surfaces, obstacles, and tight places such as near wall-ceiling and wall-floor interfaces.</td>
<td>Remote controlled aspect allows operation in areas unsafe for humans.</td>
<td>Good</td>
<td>$52.74 per hour; cost effective at approx. 139.35 m² (1500 ft²)</td>
</tr>
<tr>
<td>Grit Blasting</td>
<td>Well-established technology. Different types of grit and blasting equipment are available for a variety of applications.</td>
<td>Generates large amounts of dust and particulates during operation.</td>
<td>Wide range of grits and abrasives available for special situations.</td>
<td>Good</td>
<td>Cost based on En-vac system.</td>
</tr>
<tr>
<td>Technology</td>
<td>Strengths</td>
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<td>Special Considerations</td>
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<td>---------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>High Pressure Water</td>
<td>High pressure systems are readily available.</td>
<td>Generates a significant secondary waste stream.</td>
<td>Can physically destroy substrate. Best used on sturdy structures.</td>
<td>Adequate</td>
<td>$39.07/m$² ($3.63/ft²)</td>
</tr>
<tr>
<td>Soft Media Blast Cleaning (Sponge Blasting)</td>
<td>Removes virtually all of the contamination from the surface.</td>
<td>Generates significant amounts of airborne contamination. Lower productivity.</td>
<td>Applicable to surface decontamination only.</td>
<td>Good</td>
<td>$49.51/m$² ($4.60/ft²)</td>
</tr>
<tr>
<td>Steam Vacuum Cleaning</td>
<td>Easy to use. Washed surfaces dry quickly. Good for large flat surfaces.</td>
<td>Not good for irregular surfaces. Not good for grease. Poor ergonomic design.</td>
<td>Not recommended for surfaces that can be damaged by steam temperatures.</td>
<td>Good</td>
<td>$146.82/m$² ($13.64/ft²)</td>
</tr>
<tr>
<td>Piston Scabber</td>
<td>Remotely operated and standard units are available. Good for open, flat, concrete floors and slabs.</td>
<td>The units are loud. Remote units cannot operate close to wall-floor interfaces.</td>
<td>Remote controlled aspect allows operation in areas unsafe for humans.</td>
<td>Good</td>
<td>$64.58/m$² ($6.00/ft²)</td>
</tr>
</tbody>
</table>

* Costs may vary widely depending on site specific conditions such as the size of the decontamination project.

** N/A: reliable cost information was not available.

*** The quality of performance is based on professional judgement made on the basis of data collected.