INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0521

In Situ Gaseous Reduction System

Subsurface Contaminants Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

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INNOVATIVE TECHNOLOGY

Summary Report

In Situ Gaseous Reduction System

OST/TMS ID 123

Subsurface Contaminants Focus Area

Demonstrated at
U.S. Department of Defense
White Sands Missile Range
New Mexico, New Mexico

Innovative Technology Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Summary

Problem

Soils contaminated with redox-sensitive metals, such as chromium and uranium, are currently present in the shallow subsurface at numerous Department of Energy (DOE), Department of Defense (DoD), and industrial sites in the United States. When present in the oxidized form, e.g. hexavalent chromium, they are quite mobile and can be easily carried by waters percolating through the unsaturated zone. Baseline technology consists of excavation, treatment, and disposal. However, when these contaminants are present at greater depths, the baseline option becomes cost-prohibitive.

How It Works

Reduction and immobilization of hexavalent chromium or other redox-sensitive metals in soils can potentially be achieved through treatment with a low-concentration hydrogen sulfide (H_2S) gas mixture. The oxidized metals are reduced and immobilized as either an insoluble oxyhydroxide or sulfide.

For chromium-contaminated sites, the primary chemical reaction involves the reduction of hexavalent chromium [Cr(VI)] to trivalent chromium [Cr(III)], with subsequent precipitation as a nontoxic, insoluble solid.

$$8CrO_4^{2-} + 3H_2S + 10H^+ + 4H_2O \rightarrow 8Cr(OH)_3 + 3SO_4^{2-}$$

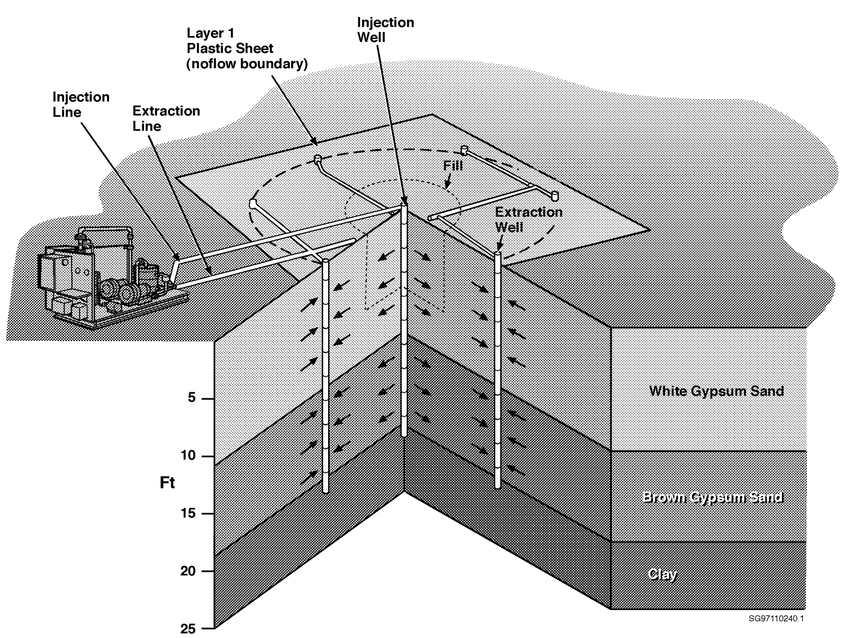

Figure 1. ISGR Vadose Zone Treatment Concept

In Situ Gaseous Reduction (ISGR) can be accomplished by injection into and extraction from a network of wells completed within the contaminant plume in the subsurface (Figure 1):

- the gas mixture is injected into a central well,
- gases are extracted by applying a vacuum in wells located at the plume boundary,
- the breakthrough of H_2S at the extraction wells is monitored over time to provide a basis for assessing treatment progress, and
- treatment performance is verified through comparison of Cr(VI) distribution in core samples before and after treatment.

Potential Markets

- DOE, DoD, and private-sector facilities that have Cr(VI) or other redox-sensitive metal-contaminated soils are the target market.
- It is particularly applicable at sites where contamination exists at depths that make excavation impracticable and costly.

Advantages Over Baseline

- Reduced exposure of workers to contaminated media
- Minimized disturbance of environment
- Potential cost savings

Demonstration Summary

ISGR was demonstrated during the spring and summer of 1998 at White Sands Missile Range, New Mexico, in a cooperative effort between the DOE and the U.S. Department of Defense (DoD). In situ remediation was undertaken by injecting 200 ppm_v H_2S into chromate-contaminated soils.

Key Results

- 70% of the Cr(VI) present at the site was reduced to Cr(III) during the demonstration, thus verifying the effectiveness of the approach. All post-test core samples met EPA cleanup criteria.
- The amount of H_2S consumed during the test was greater than the amount predicted in laboratory studies and is likely due to interfering reactions in the field or slower reaction kinetics.
- A life-cycle cost analysis suggests that ISGR should be a favorable alternative to the baseline of excavation for larger sites, especially when depth exceeds 15 or 20 ft.

During FY 1999-2000, a deployment is planned at the DOE Hanford Site to remediate Cr(VI) contaminated soils present in the 100 Area. Improvements in the design of the well-field network and other parts of the system are expected to increase the overall effectiveness of the technology.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://em-50.em.doe.gov under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference # for ISGR is 123.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The two major components of the ISGR system are the gas-treatment system and the well-field network (Figure 1). The gas-treatment system:

- prepares the gas mixture,
- provides enough pressure for the injection of the mixture into the zone to be treated,
- withdraws air from the well-field by application of a vacuum, and
- removes residual treatment gas from this stream before release to the site atmosphere.

The gas-treatment system is skid-mounted and is equipped with an injection pump, extraction pump, water knockout tank, and scrubber (Figures 2 and 3). H_2S is supplied from a commercial gas cylinder housed in a gas-storage cabinet and is introduced into the air stream immediately after it exits the injection pump. The gas treatment system is equipped with regenerative blowers, rated at several hundred ft^3/min under no-load conditions, for the injection and extraction pumps. The extraction blower, designed for use with H_2S gas streams, is surface treated or plated and has gas-tight seals. Air-bleed valves are located downstream of the injection blower and upstream of the extraction blower (Figure 2) to balance airflow and prevent overworking the blowers.

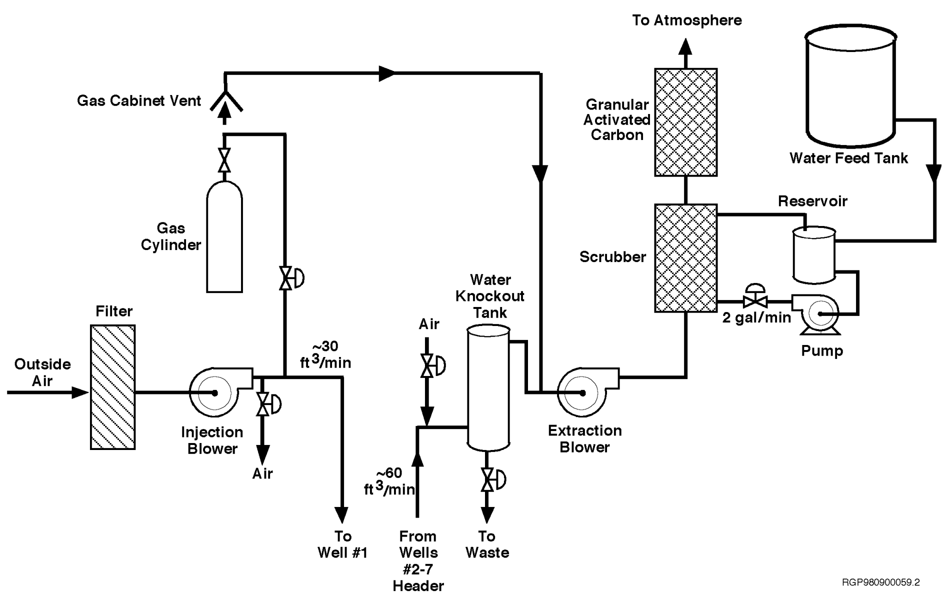

Figure 2. Schematic of ISGR Gas-Treatment System

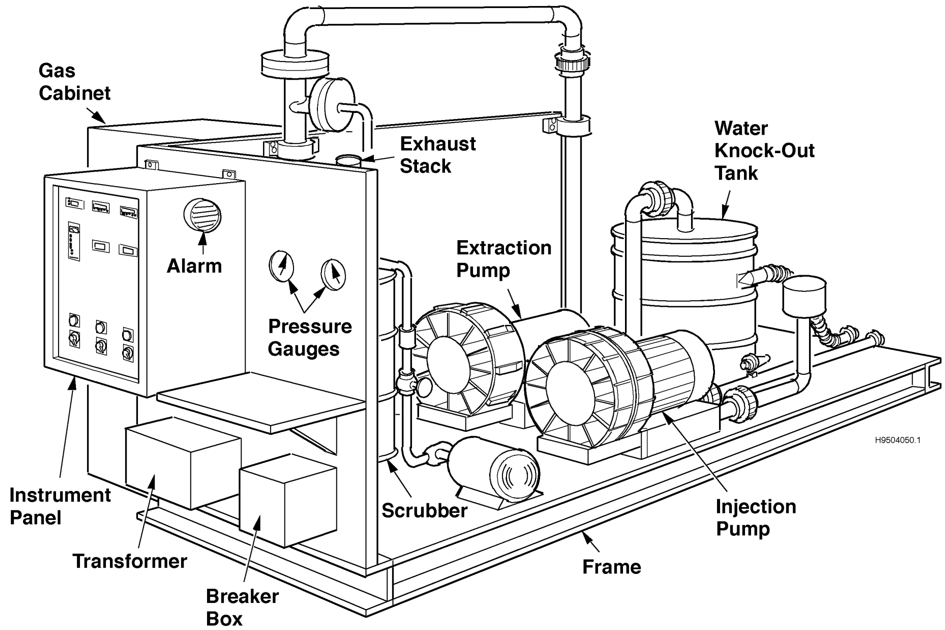

Figure 3. Perspective Diagram of ISGR Gas-Treatment System

- The basic ISGR well-field design and operation consists of:
  - a central injection well and six extraction wells situated in a hexagonal pattern around the injection well,
  - pressure injection of the H_2S mixture into the central well, and
  - extraction of the gas mixture radially outward through the formation via a vacuum applied to the extraction wells located at the edge of the contaminant plume.
- The injection and extraction wells are screened over the contaminated interval to restrict gas flow to that interval.
- An impermeable cover is also placed over the site to minimize escape of the treatment gas to the atmosphere and to maximize horizontal flow through the target interval. The cover is secured at the edges and sealed at the contacts with the well casings to minimize airflow through or around the cover.

The ISGR well-field network is presented in Figure 4, showing location of pressure gauges, flow meters, and gas-sampling ports associated with the injection and extraction wells. Also shown are the locations of soil-gas points that can be used to obtain additional pressure data and gas samples. Monitoring of the well field pressures and flow rates enables assessing gas-flow patterns, while chemical sensors are utilized to measure H_2S concentrations of well-field gas samples. Breakthrough of H_2S at the extraction wells provides a means of gauging treatment progress. Control of treatment gas flow through the site can be performed by adjusting extraction well valves, thus permitting uniform treatment of the site by directing the movement of the chemical reaction front.

The extracted air stream is pulled through a water knockout tank by the extraction blower and is then passed through a scrubber location on the gas-treatment skid (Figures 2 and 3). The water knockout, located on the vacuum side of the extraction pump, removes debris and moisture from the extraction air stream. The scrubber is positioned on the positive-pressure side of the extraction pump to remove the unreacted H_2S gas from the air stream prior to discharge. In addition, a site H_2S monitoring and alarm system is employed to indicate any significant releases of treatment gas.

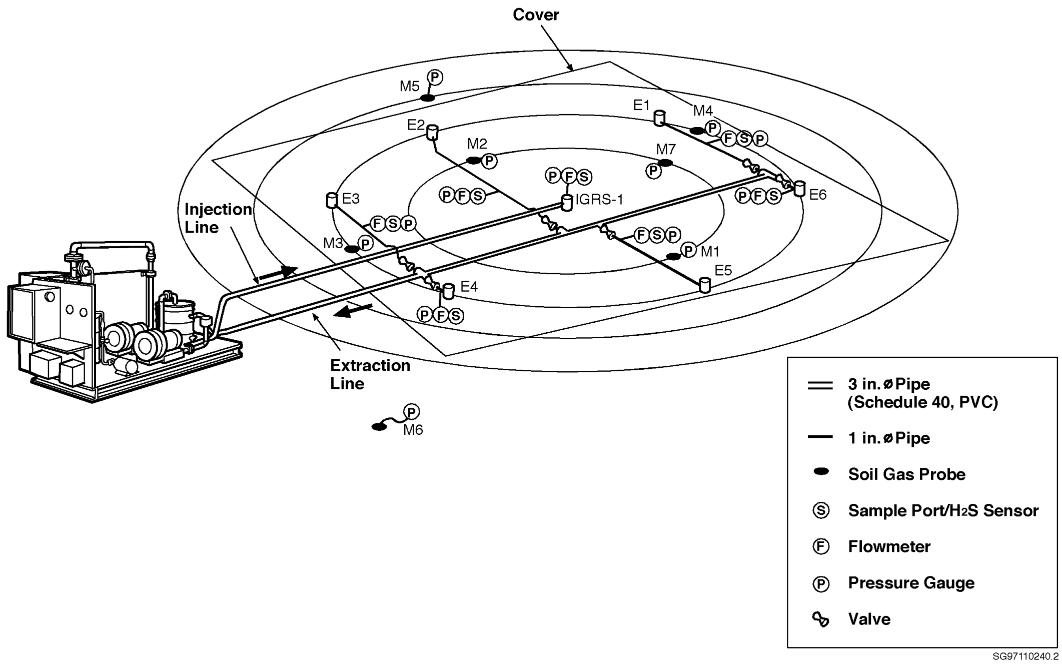

Figure 4. ISGR Well-Field Network

System Operation

The flow rate of vapors in the subsurface will vary depending on site soil characteristics.

H_2S is supplied from a commercial gas cylinder housed in an approved gas-storage cabinet (60 lbs). The H_2S is diluted to 100 or 200 ppm$_v$ by introducing into the injection air stream. H_2S gas flow is controlled by a regulator and flow meter and is automatically shut off by a solenoid valve in the event of a power failure. The gas cabinet is also equipped with a vent (Figure 2) as a safety feature that permits capturing any released H_2S within the gas cabinet and removal by directing it to the scrubber.

The H_2S scrubber contains 57 L (15 gal) of a caustic solution (1 molar NaOH) that is recirculated through the scrubber at a rate of ~7.6 L/min (2 gal/min). A water-feed tank supplies water to the scrubber lost by evaporation in the exhaust air stream (Figure 2). The required water-feed rate under operating conditions is ~3.8 L/h (1 gal/h). The scrubber solution pH is monitored and replaced when the pH drops below 10 to ensure efficient H_2S removal prior to discharge of the extraction air stream. The scrubber stack is also equipped with an H_2S sensor to monitor the discharged air stream. Spent scrubber solution is the only secondary waste stream specifically associated with the system.

The gas-treatment system operates on 480-V, 60-amp line power. A portable generator can be employed in the field if line power is not available or can be used as backup power in the event of a site power failure.

Manpower requirements associated with operation of the gas treatment system are relatively low. During the pilot-scale demonstration, the gas treatment system and well-field network were checked on a daily basis (about 1 hr/day by a technician or field engineer) to:

- record selected information on a standardized checklist (Thornton et al. 1999) including parameters associated with operation of the gas treatment system, gas flow rates, breakthrough H_2S data for the well-field network, and H_2S measurements for the site monitoring system;
- perform minor adjustments of gas feed concentration and well field extraction valves; and
- conduct periodic maintenance of the system, including refilling the water reservoir, replacing the spent scrubber solution, and calibrating and servicing the site H_2S sensors.

Presently the electronic data collection system associated with ISGR is limited to short term (8 hr) records of the site H_2S sensor measurements. Future plans include expanding this to include collection of other selected data (e.g., scrubber pH, gas flow rates and pressures, H_2S breakthrough concentrations, etc.). In addition, remote monitoring capabilities are planned (i.e., call up access to a data logger), which will reduce the amount of field time associated with operation of the system.

The primary operational concerns associated with the ISGR technology involve safety and environmental risks associated with the use of H_2S. To minimize these risks:

- H_2S concentration is reduced before injection;
- engineering controls are used to reduce exposure to workers or release to the site environment;
- a site monitoring and alarm system is employed to warn of releases; and
- a safety plan that discusses these controls in detail and identifies emergency response actions was prepared (Fullmer 1998).

SECTION 3

PERFORMANCE

Demonstration Plan

The ISGR pilot-scale demonstration was conducted at the DoD White Sands Missile Range Solid Waste Management Unit (SWMU) 143 (the Chromate Spill Waste Site). The demonstration site was contaminated in the early 1980's when a Cr(VI)-based corrosion inhibitor was released into the soil as a result of drum-mishandling operations. It is believed the Cr(VI) contamination in the soil at SWMU 143 is the source of contamination locally observed in ground water. More details about the site are provided in Appendix B.

The objectives of the ISGR demonstration were to:

- provide technical and cost performance information to assess the viability of ISGR,
- obtain operational information to verify that ISGR can be utilized in a safe and environmentally acceptable manner,
- determine the site airflow characteristics using a gas tracer test.

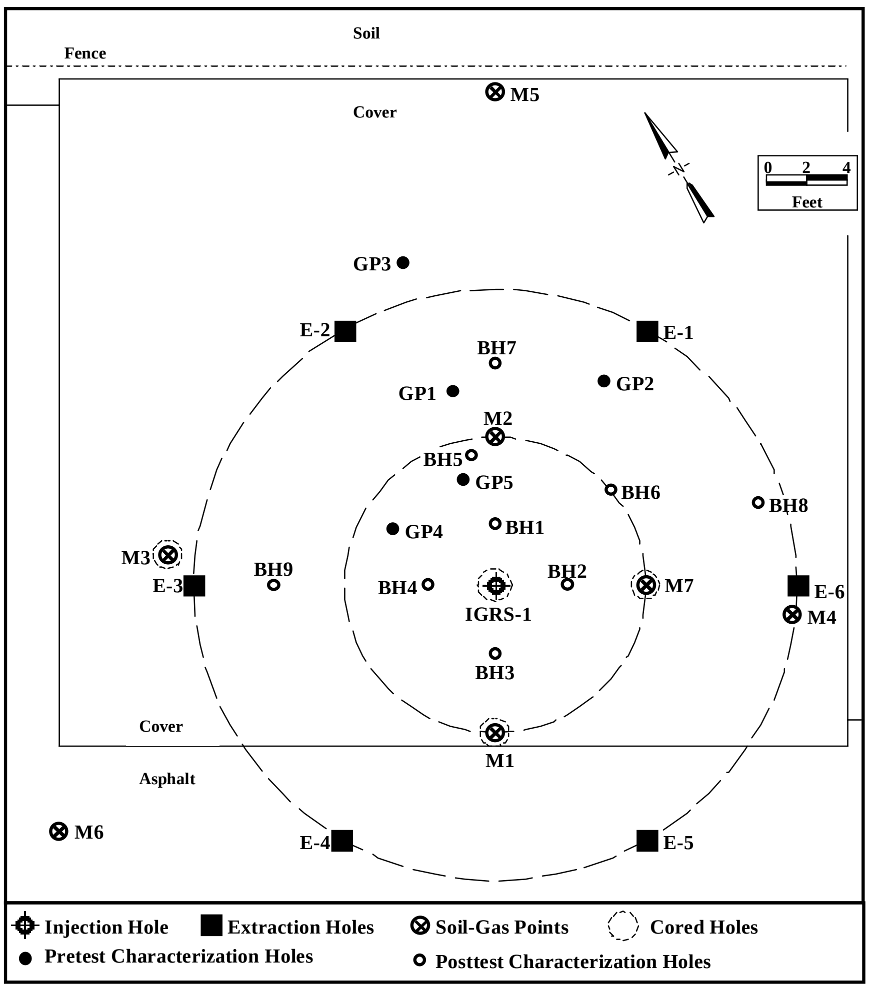

Figure 5. ISGR Configuration of Well-Field Network, Gas-Sampling Points, and Soil-Sampling Locations.

In 1996, DOE proposed injecting a low-concentration H_2S gas mixture into the soil to immobilize and detoxify chromium. The demonstration involved drilling pre- and post-test characterization boreholes, installing gas-sampling points, and installing the well-field network, as illustrated in Figure 5.

Pre-test characterization was conducted in April and August of 1996 to determine the distribution and concentration of Cr(VI) in the soil; samples were also collected for treatability testing. Determination of the geology and, in particular, the gas permeability of the sediments at the site provided important information for the design and operation of the demonstration. To assess air permeability, a vacuum pump test was conducted.

The well field with a diameter of 30 feet was installed in September 1996; wells were screened from 3 to 18 feet below the ground surface.

A laboratory treatability study was conducted to provide design parameters for the demonstration. The treatability study included the following:

- Gas treatment of a sediment sample, collected from the site, in packed columns using diluted H_2S mixtures (Thornton et al. 1999);
- Treatment progress assessed by monitoring the breakthrough of H_2S;
- Treatment effectiveness determined by water leaching of untreated and treated soil columns and comparison of the mass recovery of Cr(VI) in the leachate samples.

A gas-tracer test was conducted during September of 1997.

- The test involved injecting a nontoxic, nonreactive gas, sulfur hexafluoride (SF_6), diluted in air into the subsurface and monitoring of gas concentrations in the extraction wells and the site atmosphere to:
  - provide information related to gas-flow characteristics within the soil, and
  - determine if the treatment gas could be injected and recovered without significant releases to the site environment.

The ISGR demonstration was initiated in mid-April and ran for 76 days through June of 1998 at SWMU 143. During this test:

- 200 ppm_vH_2S in air was injected into the site,
- monitoring of treatment progress was performed by analyzing the extracted gas stream for residual H_2S (onset of breakthrough indicated completion of the treatment reaction), and
- an H_2S monitoring system was also operated to detect any releases of treatment gas to the site atmosphere.

After the conclusion of the demonstration (July 1998), soil samples were collected from nine boreholes (Figure 5) to obtain information regarding the concentration of Cr(VI) remaining in site soils. The Cr(VI) distribution and concentration levels were subsequently compared to determine the effectiveness of ISGR.

Results

The laboratory treatability tests showed that greater than 99% of the Cr(VI) present in the contaminated sediment was reduced.

Performance of the ISGR field demonstration was evaluated based primarily on a quantitative determination of the reduction in the mass of Cr(VI) at the site. The total mass of Cr(VI) in the soil at the test site was calculated before and after using pre- and post-test soil analytical data; the results were compared to determine the mass of Cr(VI) reduced during the demonstration.

The calculated mass of Cr(VI) per two-foot intervals before and after gas-treatment is presented in Figure 6 as a function of depth. This figure illustrates the following.

- Nearly all of the Cr(VI) in the interval from 4 to 10 feet was reduced. This zone corresponds to an interval containing clean white gypsum sand that initially contained the highest concentrations of Cr(VI).
- The mass of Cr(VI) did not appreciably change in the 10- to 16-foot interval, which corresponds to a brownish sand containing gypsum plus clay.

These results suggest that the effectiveness of ISGR is limited by subsurface heterogeneities, with channeling of the injected gases in the most permeable, whitesand. The deeper, less permeable brown-sand zone appears to have been bypassed by the injected gases. At this particular site, this zone contained relatively low concentrations of Cr(VI), however (Figure 6).

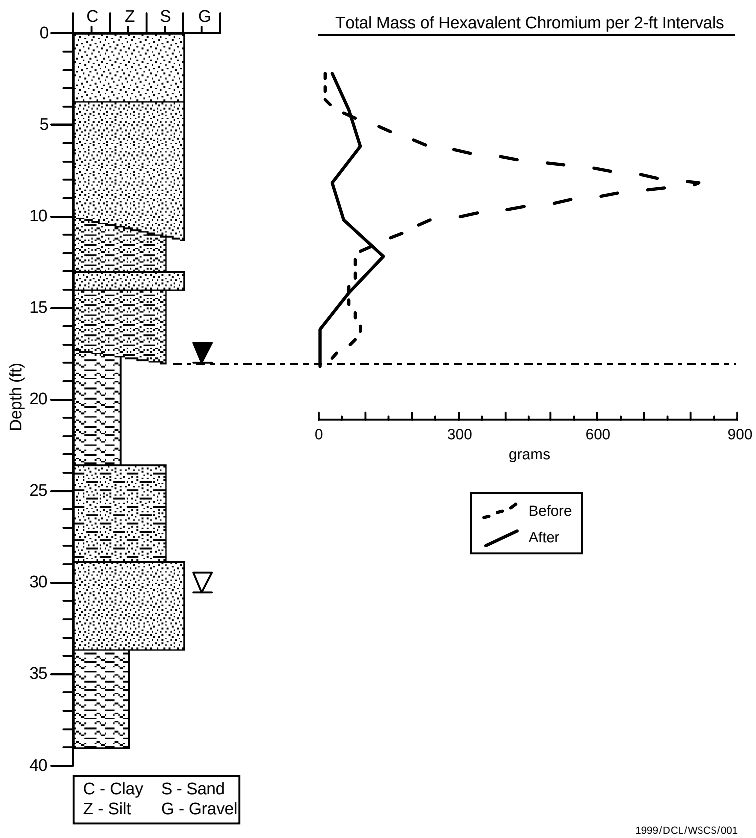

Figure 6. SWMU 143 Stratigraphy and Mass of Hexavalent Chromium Versus Depth Before and After ISGR

Comparison of the pre- and post-test Cr(VI) mass data indicates that at least 70% of the Cr(VI) present in the contaminated sediment at the site was reduced, thus verifying the effectiveness of the approach. In addition, all post-treatment sediment samples had less than 30 mg/kg Cr(VI), meeting the cleanup criteria of EPA Region 9.

Gas monitoring indicated good capture characteristics within the well-field with little release of the gas to the site atmosphere. The gas tracer tests described above demonstrated that the gas-treatment system performed as anticipated. However, the amount of H_2S consumed during the test exceeded the amount predicted by the laboratory treatability study (see Thornton et al. 1999). In addition, the levels of H_2S observed at the extraction wells were relatively low, even though a significant level of treatment was observed at the site. It is believed that interfering reactions or slower reaction rates are the likely causes of the high consumption of H_2S observed in the field. Further study is currently underway to test these hypotheses. Methods for optimization of the performance and reduction of unit costs will be investigated during future deployments.

No safety concerns were identified during the 76 days of the gas injection phase of the SGR demonstration. Thus, the pilot-scale demonstration confirmed that the technology can be applied in a safe and environmentally-acceptable manner.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The baseline technology for soil remediation is excavation. Several advantages of ISGR include:

- reduced exposure of workers to contaminated media,
- minimized disturbance of environment,
- minimized waste generation, and
- potential cost savings.

A comparison of ISGR to excavation and other alternative technologies is provided in Table 1.

Table 1. ISGR and Competing Technologies

Technology	Principle	Comments
In Situ Gaseous Reduction	Immobilize contaminant by injection of reactive gas	Likely to be economic for deeper contamination; limited to Cr(VI) and other contaminants that are immobile under reducing conditions; minimal alteration of soil characteristics
Excavation (Baseline)	Remove contaminated soil from site; treat and dispose of in approved location	Baseline technology; high cost, generates secondary waste
Electrokinetics	Contaminants removed from soil by application of electrical potential	Power consumption costs are high, limited to shallow depths; can cleanup goal be reached?
Deep Soil Mixing	Stir site soil by auger and mix in grout or chemical stabilization agents	Probably similar in cost to gaseous reduction, generally uses fluids, which may result in speading contamination, results in alteration of soil properties; depth limited
Jet Grouting	Inject grout/cement in site soil	Limited by soil heterogeneity, results in alteration of soil characteristics
Natural Attenuation	Monitor for effects of natural physical/chemical and biological processes in the subsurface	Depends greatly on nature and concentrations of contaminants and local conditions – may be slow
In Situ Vitrification	In place immobilization of contaminants by incorporation into glass	Power consumption costs are high, approach probably applicable to relatively small sites, results in destruction of soil

Technology Applicability

- The pilot-scale demonstration at White Sands Missile Range verified the applicability of ISGR for the treatment of Cr(VI)-contaminated soils. The stability of the reduced chromium is believed to be high on the basis of a review of the chemical literature and the results of limited short to intermediate-term laboratory tests.
- Other potential applications include the immobilization of other metals, such as lead and cadmium, by the formation of insoluble metal sulfide solids. These products are fairly stable, although oxidation may lead to release of the metal if infiltration of water occurs at the site.
- The radionuclides technetium and uranium can also potentially be reduced and immobilized by ISGR. Re-oxidation and subsequent release of uranium is a potential problem, however, and may also be a concern in the treatment of technetium-contaminated sediments. The rate of re-oxidation may be acceptable if the reduction capacity of the treated zone is significant and the infiltration rate of oxygenated water within the site is slow.

The pilot-scale demonstration consisted of one flow cell (i.e., one injection well and six extraction wells). The diameter of the network was 30 feet and the depth was 18 feet. Scale-up to a full-scale system may involve increasing the well-field diameter, target-zone thickness, or depth. The diameter of the well-field flow cell may be increased to some extent (perhaps to 50 feet), depending on site characteristics. The depth of the contaminated zone is not considered to be a limitation; wells that can readily be installed to any depth are utilized. The cost of the technology will obviously increase as depth increases, however. For larger waste sites, a network of flow cells can be constructed.

In general, ISGR should be applicable to any contaminated soil site that has medium to high permeability (sandy silt to gravel). Geologic heterogeneity is a limitation, as it is with many in situ technologies. At White Sands it was demonstrated that there was gas channeling through zones of higher permeability. Design of the ISGR system should address geologic heterogeneities as determined by pre-treatment site characterization activities. Individual zones can be selectively screened so that the treatment gas can be directed through less permeable strata.

Patents/Commercialization/Sponsor

The primary sponsor associated with development of the ISGR technology is the DOE Office of Environmental Management, Office of Science and Technology, Subsurface Contaminants Focus Area.

PNNL is currently the sole developer of the technology. Several potential commercial partners have been identified, but negotiations will not be initiated until an assessment of market size and potential users has been completed.

Several invention disclosures that are related to the ISGR concept have been prepared. A patent application has not yet been filed, due to the generality of the concept and simplicity of the current design. Advances in the design of the technology are expected to result in additional invention disclosures and a filing of patent application.

SECTION 5

COST

Methodology

A life-cycle cost model has been developed by Hogan (1998) to provide cost estimates for application of ISGR. A scalable cost-estimating tool has been constructed using spreadsheet software that allows a comparison to be made of project cost for ISGR remediation versus excavation. The ISGR portion of this model is based on cost data obtained from the demonstration conducted at White Sands and accepts input by the user of site-specific data. The excavation portion of the model is scaled on the basis of several parameters associated with mining operations.

Cost Analysis

The following cost estimate illustrates a comparison of ISGR versus excavation for a specific situation. The model output generated is presented in Table 2. Assumptions include:

- the soil contaminant plume has a length of 125 feet, a width of 90 feet, and a depth of 45 feet,
- 0.00004 pounds of H_2S is required to treat each pound of Cr(VI)-contaminated soil at the site (obtained from laboratory treatability tests),
- the borehole radius of influence is 20 feet, and
- well drilling and installation cost is $133 per foot at the site.

Table 2. Life-cycle Cost Model Output for ISGR vs. Excavation

Output	Excavation	Gaseous Reduction
Total Time to Treat, weeks	18.8	17
Total Time to Treat, years	0.4	0.3
Total Capital/Startup Costs	$2,045,743	$702,421
Annual O&M/Disposal Costs	$5,614,667	$311,437
Total Costs	$4,070,811	$800,545
Net Present Value (NPV) of Costs	$4,019,443	$798,163
Unit Costs, $/yd^3	$214	$43

The estimated cost savings for the example site can be calculated by determining the difference in the NPV estimated costs of the ISGR versus excavation approaches generated by the life-cycle cost model as shown below.

Excavation cost	$4,019,443
ISGR cost	798,163
Estimated cost savings	$3,221,280

Cost Conclusions

Based on the above model results, application of ISGR would result in a cost savings of approximately 80% compared to excavation for the specified site characteristics.

A comparison of the variation in unit costs of ISGR versus excavation as a function of waste-site size (expressed in length of the site in feet) is presented in Figure 7, which illustrates:

- the ISGR unit costs range from less than $50 up to $100 per cubic yard, depending on the size of the waste site,
- excavation costs generally range from about $100 to $300 per cubic yard, and
- a potential cost reduction of 50% or more may be realized by using ISGR when hexavalent chromium extends to significant depths.

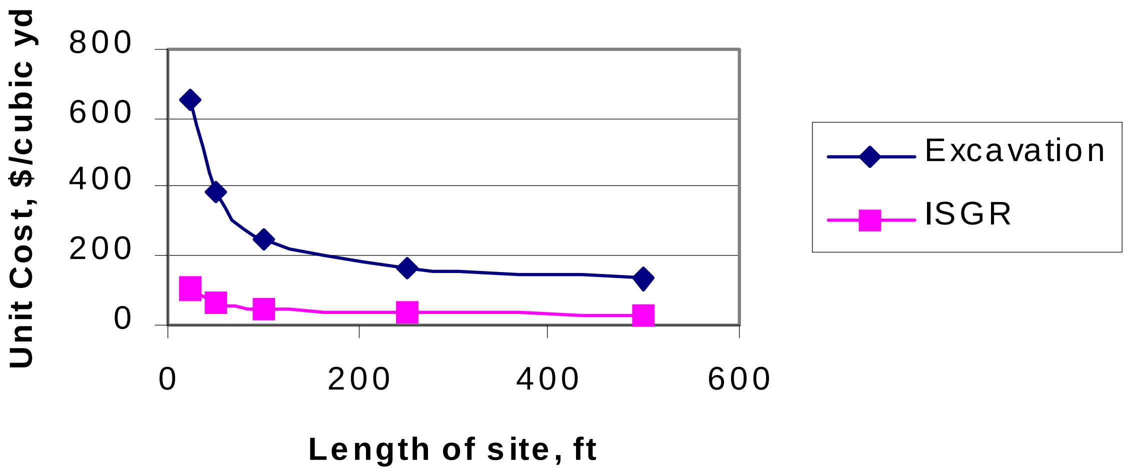

Figure 7. Unit Costs vs. Size of Waste Site

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

The field demonstration conducted at White Sands Missile Range met the regulatory compliance requirements that apply for a technology demonstration conducted at a RCRA waste site. The major federal and state environmental laws to be considered at a RCRA Research, Development, and Demonstration (RD&D) unit include:

- NEPA,
- the Clean Air Act,
- Clean Water Act, and
- the Emergency Planning and Community Right-to-Know Act.

NEPA documentation for the demonstration was completed by preparation of a Request for Environmental Consideration (REC). Discussions with White Sands and New Mexico Environmental Department (NMED) staff served to identify other regulatory issues including:

- a Ground Water Discharge Permit,
- evaluation of potential discharges to the site atmosphere, and
- management of hazardous waste.

Consideration of a Ground Water Discharge Permit was identified owing to a potential impact on a perched water zone at SWMU 143 and regional ground water of the deeper aquifer. NMED staff decided, however, that this was not necessary because the local ground water has a high total dissolved solids content and is thus not potable.

Other regulatory compliance requirements (e.g., Emergency Planning and Community Right-to-Know) were addressed in the demonstration test and safety plans, with NMED concurrence.

Hazardous waste generated during the demonstration at White Sands:

- was minimal,
- consisted of Cr(VI)-contaminated soil excavated during the drilling operations and mildly alkaline solutions generated by the gas scrubber, and
- was disposed of per site RCRA waste disposal procedures.

Regulatory requirements for demonstration or application of ISGR at sites falling under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) will include ARARs (applicable or relevant and appropriate requirements) similar to those identified above for the demonstration completed at White Sands Missile Range.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

The primary safety issue is related to the use of H_2S, because the gas is toxic and release of the gas to the environment is a concern.

- A detailed safety plan, including specific action levels and appropriate responses to releases of treatment gas, was developed prior to the test (Fullmer 1998).
- The test was accomplished without significant release to the site atmosphere through the use of engineered control systems.
- A gas scrubber was used to remove residual H_2S from the effluent gas stream before release of the air back to the site atmosphere. Thus, emission levels were maintained well below both safety-related regulations and also the applicable limits associated with the site air permit.
- Workers were trained with respect to the hazards of H_2S and the site was continuously monitored for H_2S during the test.
- No gaseous releases were observed, thus verifying that ISGR can be performed in a safe and environmentally acceptable manner.

Community Safety

A 60-day public review period for the demonstration test and safety plans was provided and a public meeting held. No significant issues were raised during the public meeting.

Environmental Impact

It should be noted that even if H_2S reaches ground water during soil treatment by ISGR, it is a weak acid and will not significantly affect ground water pH.

ISGR is designed to remediate contaminated soils without release of any gas residual (H_2S) to the atmosphere. This is accomplished through capture of residual treatment gas by the extraction wells and removal of H_2S from the exhaust by a scrubber. If concentrations of emissions exceed preset levels, as specified by a site air permit and environmental safety standards, gas injection will cease and corrective actions taken such that there will be no continued release into the environment (as specified in the safety plan).

No significant releases occurred during the demonstration.

Socioeconomic Impacts and Community Reaction

The ISGR demonstration indicated that state and community acceptance can be achieved if appropriate safety procedures and adequate environmental monitoring is performed.

SECTION 7

LESSONS LEARNED

Implementation Considerations

During FY 1999 and 2000 the technology will be deployed at the DOE Hanford Site. This demonstration will lead to full-scale deployment if the results verify that ISGR can meet rigorous cleanup criteria associated with the Hanford Site and is economically superior to other technologies for soil remediation, notably excavation. In particular, cost data collected during the deployment are needed to refine the cost model so that it becomes a useful tool for determining when ISGR is the best approach for specific sites.

The primary near-term market identified to-date consists of several DOE facilities that have Cr(VI)-contaminated soil waste sites. This may be expanded in the longer-term to include similar DoD and private-sector waste sites. Future opportunities may also develop for treatment of other metals or radionuclides if laboratory studies indicate that treatment with reactive gas mixtures is effective for these contaminants.

Technology Limitations and Needs for Future Development

Treatment results obtained from the White Sands Missile Range demonstration indicated that geologic heterogeneity is a limitation of ISGR. Specifically, test results revealed that channeling of the treatment gas occurred through strata having higher relative permeability. If treatment of less permeable zones is required at a specific site, a dual-zone completion design could be used to direct treatment gas through specific zones. To adequately address this limitation, collection of in situ permeability data is needed to support well-field design.

During the demonstration, a higher consumption of H_2S was observed than predicted from small-scale laboratory column tests. It is believed that interfering reactions or slower reaction rates are the source of this discrepancy. Laboratory testing activities are currently being conducted to provide reaction kinetic information needed to support scale-up of the technology. It is anticipated that an improved understanding of the processes associated with ISGR will lead to increased effectiveness of the technology and significant reduction of unit costs.

APPENDIX A

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APPENDIX B

DEMONSTRATION SITE DESCRIPTION AND HISTORY

Geology and Hydrogeology

The White Sands Missile Range lies within the Mexican Highland Section of the Basin and Range Province and is characterized by a series of tilted fault blocks that form longitudinal, asymmetric ridges or mountains and broad intervening basins. The major portion of the White Sands Missile Range lies within the Tularosa Basin. The average elevation of the basin floor is 1,219 m above mean sea level, and surface features consist of flat sandy area, sand dunes, basalt flows, and playas (dry lake beds).

The Tularosa Basin contains thick sequences of Tertiary and Quaternary alluvial and bolson-fill deposits. These sediments are 1,524 m thick in some areas, consisting mainly of silt, sand, gypsum, and clay weathered from the surrounding mountain ranges. The nature of the bolson-filled deposits varies both laterally and vertically throughout the basin. Coarse-grained, poorly sorted sediments deposited near mountain fronts grade into fine-grained, well-sorted sediments toward the center of the basin (Kelly and Hearne 1976). Sediments farther from the mountain fronts also contain a greater percentage of clay and gypsum. Vertically, the sediments are reported to become finer grained and more consolidated until reaching a laterally continuous clay unit at ~300 m below ground surface (Kelly and Hearne 1976).

Very little surface water exists at the White Sands Missile Range because of the low annual precipitation and high evaporation rate. Ground water in the vicinity of the High-Energy Laser System Test Facility (HELSTF) is characterized by total dissolved solids content of generally more than 10,000 mg/L, making it not potable. As such, the HELSTF obtains its water supply from three wells located ~13km northwest at the base of the San Andres Mountains. Ground water below HELSTF exists in the regional aquifer and also within several discontinuous, perched aquifers. The average depth to the top of water in the regional ground water aquifer is ~21 to 23 m, with a southeast flow direction (METATEC 1997). A series of hydraulically interconnected, discontinuous, perched water-bearing zones overlying the regional aquifer have been identified in the vicinity of HELSTF. Perched-water zones have been identified between ~5 to 6 and at 15 m bgs. These shallow, perched-water zones are believed to exist primarily from recharge of effluent discharge areas originated from the sewage lagoons and other facilities.

History of Contamination

Contamination was discovered at SWMU 143 in January 1990 when preparations were underway to pave the area. Greenish-yellow soil was found in the corner of the equipment yard; soil analysis was conducted and confirmed the presence of Cr(VI). A review of facility records indicated that several 55-gal drums of Entec 300 had spilled directly onto the ground in 1982 or 1983. On initial discovery of the spill, efforts to remove the contaminated soil were undertaken by the HELSTF Support Services Contractor. Approximately 17 55-gal drums of CrO_4^{2-} contaminated soil were excavated from the site in 1990. Clean closure could not be obtained, however, and the expensive excavation effort was stopped until a better cleanup method could be implemented. The site was overlain with several meters of clean fill and covered with a shingled wooden roof structure to inhibit leaching and run on.

This waste management unit was first regulated under the State of New Mexico's Hazardous Waste Bureau. The New Mexico Ground Water Bureau protects ground water with total dissolved solids concentrations below 10,000 mg/L. Even though total dissolved solids in the shallow, "perched" and deeper, "regional" aquifers under the HELSTF average above 10,000 mg/L, the New Mexico standards are still relevant for protecting potential future uses of the ground water. It is believed the Cr(VI) contamination in the upper soils of SWMU 143 is the source of contamination locally observed in HELSTF ground water.