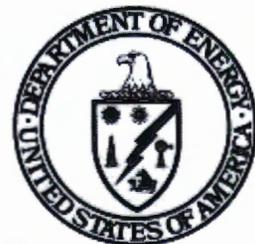




# Multistage Combustion for Removal of NO<sub>x</sub> from Incinerator Offgas - NO<sub>x</sub>idizer

TRU and Mixed Waste Focus Area



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

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# Multistage Combustion for Removal of NO<sub>x</sub> from Incinerator Offgas - NO<sub>x</sub>idizer

OST/TMS ID 3181

TRU & Mixed Waste Focus Area

*Demonstrated at*  
Brookhaven National Laboratory  
Upton, New York



## **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://www.em.doe.gov/ost> under "Publications."

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# SECTION 1 SUMMARY

## Technology Summary

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The Department of Energy (DOE) has entered into an agreement with the State of Idaho to remove by December 31, 2012 sodium-bearing wastes (SBW) currently held in liquid-storage tanks at the Idaho National Engineering and Environmental Laboratory (INEEL) at the Idaho Nuclear Technology and Engineering Center (INTEC). The quantity of liquid waste that must be processed includes current inventory and all that will be added to the tanks by the deadline on December 31, 2012. The current plans are to convert the SBW to a glass form by direct vitrification. This SBW is a liquid containing about 6M nitric acid. Under the high temperature expected in a melter, this stream produces large amounts of NO<sub>x</sub> (oxides of nitrogen). The offgas flow is expected to be approximately 1100 sm<sup>3</sup>/h, and have NO and NO<sub>2</sub> present with mole fractions of 0.0248 each (~50,000 ppm total NO<sub>x</sub>). The offgas also contains about 5,000 ppm of carbon monoxide (CO) and unburned hydrocarbons.

It is expected that the Environmental Protection Agency (EPA) will regulate air pollutant emissions from the vitrification melter based on maximum achievable control technology (MACT) as outlined in 40CFR63EEEE (see Federal Register September 30, 1999). There are two major implications and several second-order considerations of MACT with respect to NO<sub>x</sub> in the vitrification melter offgas:

- The first implication is that mercury concentrations in the offgas will be significantly above the limits set forth under MACT unless mercury is removed from the offgas. However, high NO<sub>x</sub> levels in a granulated activated carbon (GAC) bed are of concern, because of the potential for oxidation of the bed causing severe temperature excursions ("bed fires"). To safely remove mercury from the offgas, NO<sub>x</sub> must first be removed.
- The second implication of MACT is that sampling and analysis for volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) will be required. High levels of NO<sub>x</sub> interfere with standard EPA sampling and analysis protocols.
- Second-order considerations for NO<sub>x</sub> removal include: (a) assurance that INEEL's total permitted NO<sub>x</sub> release would not exceed 40 tons/y, (b) elimination of the "brown plume" that has been a visible eyesore when processing high-nitrate wastes in the past, and (c) reduction of secondary waste from the wet scrubber.

In November 1997 INTEC personnel performed a feasibility study comparing selective catalytic reduction (SCR) combined with selective catalytic oxidation (SCO) and multistage combustion (MSC). Two other technologies, wet scrubbing of NO<sub>x</sub> combined with flameless thermal oxidation, and gas-phase corona discharge were eliminated as being developmental. This study was aimed toward upgrading the New Waste Calcining Facility (NWCF) originally planned to process the SBW. Although the process is different from the direct vitrification option now under consideration, the offgas from the NWCF would have been very similar, so the results were judged to be applicable. SCR is a well established technology, but has not typically been applied to streams with NO<sub>x</sub> of up to 50,000 ppm and high levels of mercury. MCS was selected over SCR as the baseline, for several reasons:

- Destruction and removal efficiency (DRE) for MCS was predicted to be superior
- Refractory life for MCS was predicted to be longer than the catalyst life for SCR
- Mercury will poison the SCR catalyst
- Thermal degradation of the SCR catalyst caused by NO<sub>x</sub> reactions could further shorten catalyst life.

The feasibility study recommended a system from John Zink Company known as a NO<sub>x</sub>dizer™, which is a three-stage system (See Figure 1). The first stage uses a natural gas or propane-fired burner under reducing conditions at 2,100°F producing nitrogen, carbon monoxide, and unburned hydrocarbons. The second stage is a water quench to reduce the temperature to 1,550°F. Air is injected in the final stage, which operates at less than 2,000°F. At this temperature, the carbon monoxide, hydrogen and unburned hydrocarbons are oxidized, but the reformation of NO<sub>x</sub> is minimized.

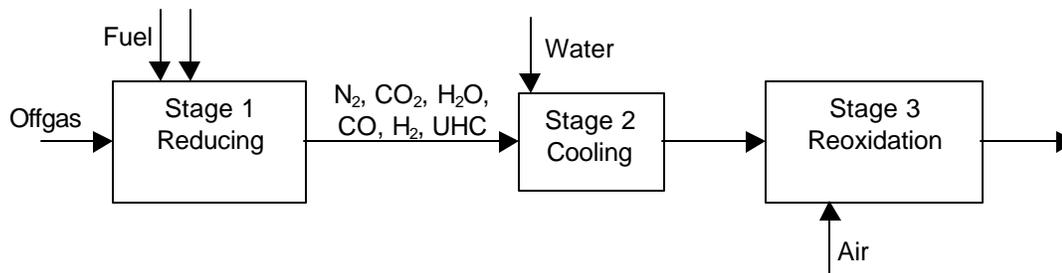


Figure 1. Simplified three-stage flow diagram of John Zink NO<sub>x</sub>dizer™.

One caveat in selecting the MCS technology as the baseline was the lack of sufficient data from the MSC system to fully judge its applicability to the processing of high-NO<sub>x</sub> offgas from a SBW treatment system. To address this concern, the TMFA undertook a project to evaluate the NO<sub>x</sub>dizer™ system.

## Demonstration Summary

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Ideally, one would want to conduct a demonstration on the actual unit to which the technology is to be applied. In the case of SBW treatment, no facility yet exists, and even if it did exist, conducting tests in a hot-cell environment is prohibitively expensive. Therefore, to provide the data needed by INTEC for final technology down selection, tests were conducted in 2000 and 2001 by MSE Technology Applications, Inc. in Butte, MT, on a pilot-scale plasma-arc melter with a natural gas-fired secondary-combustion chamber (SCC). The pilot plant SCC produces 8 lb/min of offgas, which is similar in composition to the predicted offgas from a melter. Of this 8 lb/min, a slip stream of 2 lb/min was used as the source term for the NO<sub>x</sub>dizer™. The pilot plant has been operated to support numerous demonstrations of offgas control technologies, so its operation is well documented and instrumented. High levels of NO<sub>x</sub> were produced by injecting concentrated nitric acid into the offgas-source stream and heating the stream to 1,200°F. Using this technique, the inlet NO<sub>x</sub> concentration ranged from 30,000 ppm to 50,000 ppm and the ratio of NO to NO<sub>2</sub> ranged from about 0.6 to 1.0. This is the offgas stream that was introduced to the NO<sub>x</sub>dizer™.

The first year of testing of the NO<sub>x</sub>dizer™ was used to establish the optimum operating conditions to maximize the DRE for NO<sub>x</sub>. Control parameters included:

- Flow of fuel and quench water in the reduction section to control reduction temperature
- Flow of combustion air in the reduction section to control the differential temperature between the quench and re-oxidation section

The goal of the testing was to achieve a DRE of 90% with an outlet NO<sub>x</sub> concentration less than about 1,000 ppm, low enough to prevent problems in a subsequent GAC bed. Another goal was to have a carbon monoxide concentration of less than 100 ppm in the exit gas.

In addition to establishing the DRE for NO<sub>x</sub> in the system, INTEC was interested in determining the fate of mercury and target organic species through the NO<sub>x</sub>dizer™.

## Key Results

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Results of the testing showed that the outlet NO<sub>x</sub> concentration was typically less than 500 ppm for a DRE of about 95%, which met the goal established. Outlet CO concentration was generally less than 10 ppm, which also met the goal. An important finding during this optimization phase was that the optimization is fairly flat. That is, acceptable DREs were obtained over a wide operating envelope, which indicates that control would be fairly straightforward.

The first goal during the second year of testing, was to determine the impact of modifying the reduction section burner to operate using propane for the combustion fuel rather than natural gas. This change was made because the INTEC does not have access to natural gas. Also during the second year, the fate of mercury and target organic species was evaluated. Understanding the speciation of mercury leaving the NO<sub>x</sub>dizer™ is important, because it will impact the downstream mercury removal technology. Benzene was selected as a representative organic specie. It was injected to ensure that the system could demonstrate sufficient destruction to achieve a 10 ppm total hydrocarbon concentration at the exit.

Results of this second round of testing showed that operating with propane, the NO<sub>x</sub>dizer™ could still achieve DRE for NO<sub>x</sub> of 94% to 96% yielding an exit NO<sub>x</sub> concentration of 400 ppm to 600 ppm and CO levels were low. Again, the operating envelope was fairly broad.

When a ratio of 60% mercuric chloride (HgCl<sub>2</sub>) and 40% elemental mercury (Hg<sup>0</sup>) was injected into the offgas stream prior to the NO<sub>x</sub>dizer™, the exit gas contained 99.8% Hg<sup>0</sup>. When injecting 369 ppm of benzene, the exit gas concentration of benzene was below detection limits, indicating a DRE of greater than 99.7%.

Based on these results, personnel at INTEC are currently evaluating options for NO<sub>x</sub> control. Potential future work includes addressing the fate specific components that could be in the offgas from a melter and evaluation of methods to reduce the amount of added air and quench water in the NO<sub>x</sub>dizer™. This latter could be an important effort considering the very high cost of hot cell space. INTEC has also indicated that integrated tests of the NO<sub>x</sub>dizer™ with an acid scrubber are also a possibility.

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## **Other**

All published Innovative Technology Summary Reports are available on the OST We site at <http://www.em.doe.gov/ost> under "Publication." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies , and problems. The OST Reference Number for the NOx reduction project is 3181.

## SECTION 2 TECHNOLOGY DESCRIPTION

### Overview of Process

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Liquid sodium bearing waste at the INEEL is scheduled to be fully processed and ready for shipment for final disposal by 2012. The SBW consists of approximately 6M nitric acid with a wide variety of inorganic and organic constituents. The current choice for processing the SBW is direct vitrification. This will produce an offgas containing significant amounts of NO<sub>x</sub> as well as CO, mercury, and organics. It is likely that this facility will contain provisions in the operating permit to limit emissions of CO, mercury, and total hydrocarbons as well as other constituents to levels consistent with the MACT Rule for hazardous waste combustors. A major concern is how to remove mercury from a high-NO<sub>x</sub> offgas. The carbon beds typically used for mercury removal may react with the NO<sub>x</sub> causing temperature excursions or even bed fires. Therefore, it is necessary to reduce the concentration NO<sub>x</sub> in the offgas prior to mercury removal. A goal has been established to have less than 1,000 ppm NO<sub>x</sub> at the entrance to mercury treatment. In addition, it will be necessary to achieve less than 100 ppm CO, and less than 10 ppm total hydrocarbon at the exit of the offgas system.

The concept of reburning to destroy NO<sub>x</sub> in offgas was introduced about 50 years ago. At high temperature, NO<sub>2</sub> is quickly reduced to NO, which in the presence of excess methane or other similar reductants is converted to N<sub>2</sub>. The principal products of this process are N<sub>2</sub>, CO<sub>2</sub>, and H<sub>2</sub>O. However, because the process is substoichiometric, CO, H<sub>2</sub>, and other products of incomplete combustion (PICs) are also produced. These must be destroyed in a second step, while minimizing the reformation of NO<sub>x</sub> through thermal NO<sub>x</sub> mechanisms. The reburning concept has been demonstrated in a wide variety of utility boiler systems. It has never been applied in a DOE process, such as INTEC. Two differences between a utility boiler and a melter processing the high-nitrate SBW wastes were felt to be concerns. The NO<sub>x</sub> concentration from a boiler is typically less than about 5,000 ppm whereas the offgas from a melter will be up to about 50,000 ppm. Also, the ratio of NO to NO<sub>2</sub> in a boiler is about 10:1. The offgas from the melter should be almost the opposite, or a ratio of NO<sub>2</sub> to NO of 8:1.

### Process Description

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John Zink Company has developed a reburning concept, known as a NO<sub>x</sub>idizer,<sup>TM</sup> which uses a three-stage system designed to destroy NO<sub>x</sub> and eliminate PICs. Although this is commercial technology, the TMFA funded a demonstration test of the system specifically aimed at answering the above concerns.

The NO<sub>x</sub>idizer<sup>TM</sup> is essentially a hollow, refractory-lined tube with a burner at the entrance. (See Figures 2 and 3). It can be positioned either vertically or horizontally, depending upon requirements for space. In the first, or reducing stage natural gas or propane is introduced with air in a burner. Operating fuel-rich produces reducing conditions producing nitrogen, carbon monoxide, and PICs. Water is also injected to maintain the temperature at about 2,100°F.

Immediately following the reduction stage is a water quench to bring the temperature down to about 1550°F. The diameter of the unit is also reduced at this point to maintain appropriate flow velocities.

The offgas then enters the reoxidation stage where sufficient additional air is injected to fully combust all the CO, H<sub>2</sub>, and PICs. The temperature at this point is still high enough that spontaneous combustion occurs, and no outside combustion source is required. The temperature in the third stage is maintained less than 2,000°F. At this temperature, the carbon monoxide, hydrogen and PICs are destroyed, but the reformation of thermal NO<sub>x</sub> is minimized.

Offgas was produced using a natural gas fired burner in the pilot-scale melter. No waste was processed during any of this testing, in order to maintain a predictable source of offgas. NO<sub>x</sub> was introduced by first

vaporizing 6M nitric acid into the offgas. The resulting stream was then passed through the flameless oxidizer at 1,200°F to convert nitric acid to NO and NO<sub>2</sub>. This stream then served as the inlet to the NO<sub>x</sub>idizer™. CEMs were used to continuously monitor the inlet and outlet concentrations of NO and NO<sub>2</sub>. A third NO<sub>x</sub> CEM was installed in the high-temperature area at the exit of the reducing section.

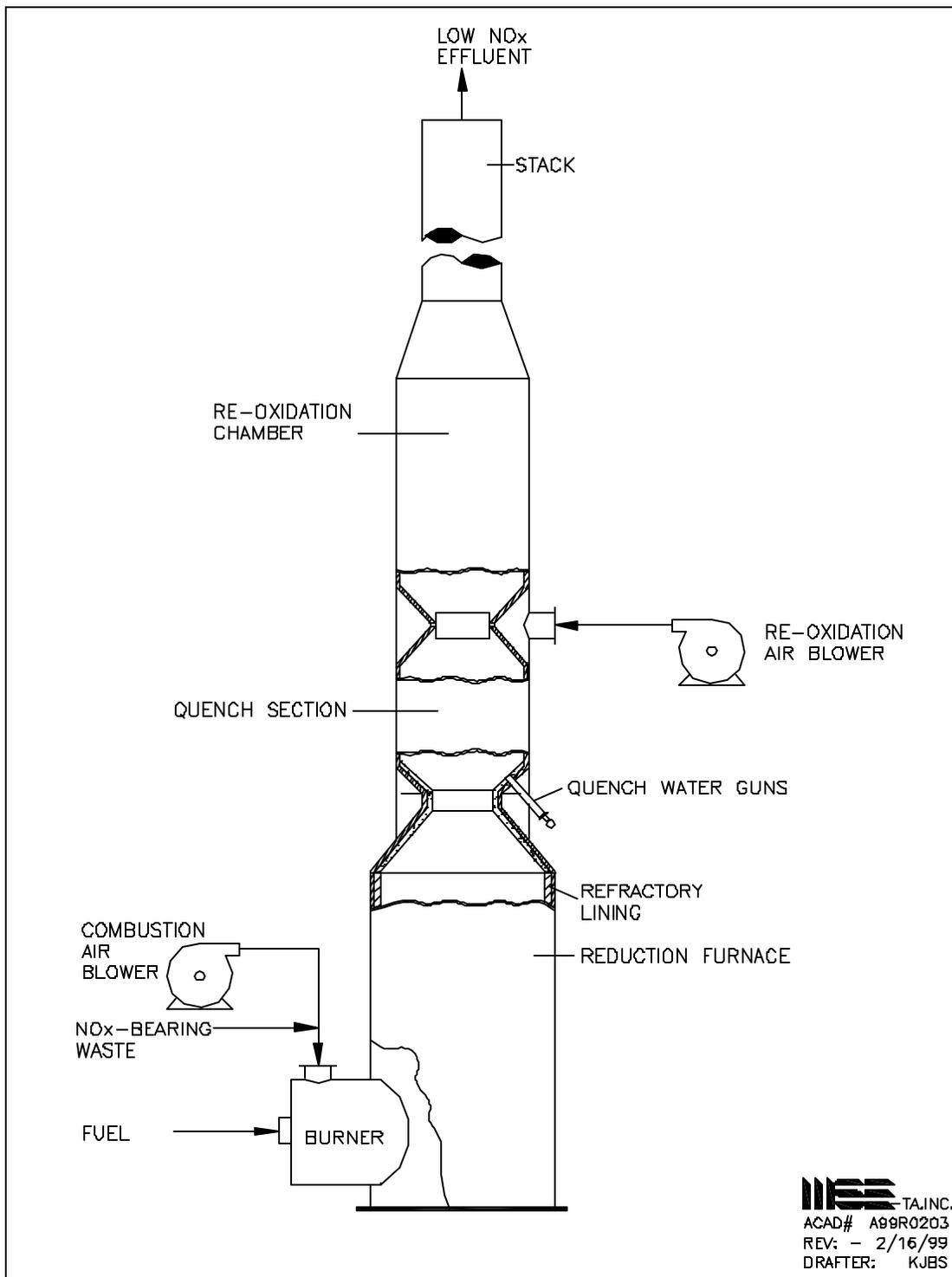


Figure 2. Schematic of NO<sub>x</sub>idizer™.



Figure 3. Photograph of NO<sub>x</sub>dizer™ installed at MSE Technology Applications in Butte, MT.



# SECTION 3 PERFORMANCE

## Demonstration Plan

The John Zink NO<sub>x</sub>idizer™ was tested over the course of two years by MSE Technology Applications at their facility in Butte, MT. The facility consists of a pilot-scale plasma arc melter with a natural gas fired secondary combustion chamber. For the purposes of these tests, only the secondary combustion chamber was used as a source of offgas. This simplified and lowered the cost of operation. This system has been used extensively for demonstration of offgas components and is well characterized. The offgas system from the melter contains two parts: the primary offgas system processing 8 lb/min and a one-quarter scale slip stream test bed (SSTB) from the primary offgas consisting of 2 lb/min. The NO<sub>x</sub>idizer™ is located in the SSTB. Associated equipment includes an electric heater, the nitric acid delivery system, a Thermatrix flameless oxidizer, and continuous emission monitors (CEMs). Figure 4 shows a schematic of the facility.

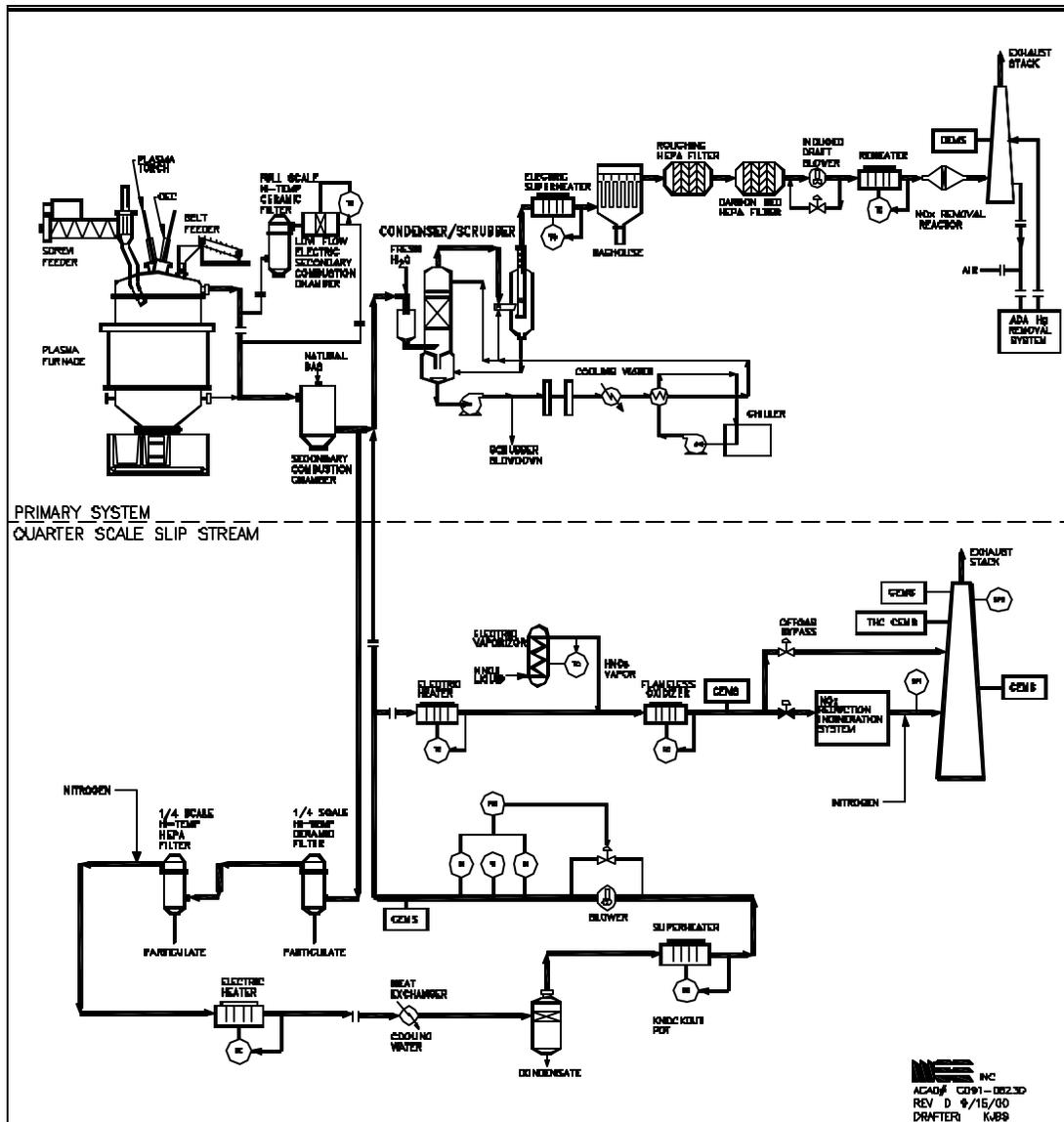


Figure 4. Schematic of MSE pilot plant offgas demonstration facility.

The overall goal of the testing was to establish the performance of the NO<sub>x</sub>dizer™. Specifically, could it destroy NO<sub>x</sub> sufficiently to yield an exit gas concentration of less than 1,000 ppm while also producing less than 100 ppm of CO and 10 ppm of total hydrocarbons. Secondary objectives during the second year were to understand the fate of mercury and target organic constituents in the NO<sub>x</sub>dizer™.

The plan during the first year was to establish optimum operating conditions to maximize the NO<sub>x</sub> DRE using natural gas in the reducing section burner. This would also give an indication of how sensitive the DRE was to changes in the operating envelope. Two of the principal control parameters were:

- Flow of fuel and quench water in the reduction section to control the reduction temperature
- Flow of combustion air in the reduction section to control the differential temperature between the quench and the reoxidation sections.

During the second year, the reduction section burner was changed to operate on propane. Otherwise the objectives were basically the same as during the first year with the addition of the mercury and organic tests.

## Results

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Table 1 presents results of the first year of testing. The first seven runs used ambient air as the offgas source to establish the baseline performance. The final 5 runs were made using the natural gas fired SCC.

Table 1. Destruction and Removal Efficiency (DRE) using natural gas as fuel to the NO<sub>x</sub>dizer™.

Run	Inlet NO <sub>x</sub> Concentration, ppmv	Outlet NO <sub>x</sub> Concentration, ppmv	% NO <sub>x</sub> DRE
1	25,326	226	93.1
2	26,460	221	92.4
3	25,480	187	94.9
4	25,956	266	94.1
5	30,960	315	94.2
6	34,333	684	96.3
7	29,886	328	94.0
8	30,151	376	94.2
9	30,842	372	92.4
10	32,053	434	94.4
11	33,410	516	91.4
12	32,932	1,029	81.5

The average destruction and removal efficiency (DRE) over all the runs was 92.7% with an outlet concentration of 440 ppm. In the last run, it was discovered that the programmable logic controller failed, causing the NO<sub>x</sub>dizer™ reducing section to run in an oxidizing mode for most of the test. Therefore, the outlet NO<sub>x</sub> concentration was higher, and the DRE was lower than other runs. Discounting this run, the DRE and outlet concentration become 93.7% and 386 ppm, respectively. This is well within the goal established.

Tests of CO destruction were conducted by injecting CO into the NO<sub>x</sub>idizer™ inlet and measuring the outlet concentration. Inlet concentrations ranged from about 8,000 ppm to 21,000 ppm and in all cases the exit concentrations were below the detection limit of 10 ppm. This again met the goal.

During the second year of testing, the NO<sub>x</sub>idizer™ burner was modified to burn propane. Inlet NO<sub>x</sub> were maintained at about 50,000 ppm for all tests. Table 2 shows the DREs for 13 separate runs.

Table 2 Destruction and Removal Efficiency (DRE) using propane as fuel to the NO<sub>x</sub>idizer™.

Run	Outlet NO <sub>x</sub> Concentration, ppmv	% NO <sub>x</sub> DRE
1	420	95
2	280	96
3	420	94
4	320	96
5	360	94
6	370	95
7	340	95
8	380	96
9	370	94
10	380	95
11	440	94
12	460	94
13	440	92

As seen in the table, the target exit concentration of 1,000 ppm was again met routinely. The concentration of CO at the outlet was again below the detection limit of 10 ppm.

For the mercury speciation tests, liquid mercury was vaporized at controlled temperature and then mixed with chlorine gas, which produced a mixture containing about 60% HgCl<sub>2</sub> and 40% Hg<sup>0</sup>. When added to the source offgas, a total inlet mercury concentration of about 550 µg/dscm (dry standard cubic meter) was produced. After passing through the NO<sub>x</sub>idizer™, the exit offgas contained 99.8% Hg<sup>0</sup>. Therefore, almost all mercury is converted to elemental form.

For the organic destruction test, benzene was injected to produce an inlet stream of 369 ppm. The concentration of total hydrocarbon (THC) was measured before and after benzene injection to determine the impact of the added benzene. Results showed that the outlet THC concentration remained below detection limits of 5 ppm, indicating a DRE for the benzene of at least 99.7%.

## Demonstrations

No further demonstrations on this equipment or larger systems are planned until the INTEC selects a final flowsheet for treating the remaining sodium bearing waste.



## SECTION 4 TECHNOLOGY APPLICABILITY AND ALTERNATIVES

### Competing Technologies

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Competing technologies for NO<sub>x</sub> removal/destruction include:

1. Selective catalytic reduction (SCR).
2. Selective noncatalytic reduction (SNCR),
3. Steam reforming, and
4. Corona discharge.

Of these four technologies, only SCR and SNCR have been used commercially. While both steam reforming and corona discharge are theoretically feasible, no fully engineered commercial systems have been produced. Therefore, the only viable alternatives under consideration are SCR and SNCR.

The performance of the NO<sub>x</sub>dizer™ is expected to be superior to either SCR or SNCR. The NO<sub>x</sub>dizer™ will produce an outlet NO<sub>x</sub> concentration of less than 500 ppm, while SCR or SNCR are likely to be in excess of 2,000 ppm. It may be possible to add additional SCR beds to achieve comparable performance, but the system will become increasingly complex and overall pressure drop will increase.

The NO<sub>x</sub>dizer™ system is very simple and its operation is straightforward. SCR or SNCR are more complex in that they will require injection of a reductant, usually ammonia, to reduce NO<sub>x</sub>. To ensure complete conversion of NO<sub>x</sub>, an excess of ammonia is injected, which becomes an emission, known as ammonia slip. This ammonia slip is coming under increased scrutiny by regulators, so it is necessary to closely match the amount of ammonia injected to the concentration of NO<sub>x</sub>. This requires a continuous, near real-time NO<sub>x</sub> monitor that can feed the ammonia injection.

A potentially significant disadvantage with the NO<sub>x</sub>dizer™ is the increase in offgas volume produced. Typically, the volume of offgas exiting the NO<sub>x</sub>dizer™ is four to five times greater than the inlet volume. In one configuration being considered, the NO<sub>x</sub>dizer™ would be located directly after the melter, which would have a major impact on the size of all downstream offgas components. The resulting hot cell space required to house those components would be much higher. If the NO<sub>x</sub>dizer™ is located downstream, after scrubbers and immediately before the carbon bed mercury treatment system, the impact would be lessened, but is still a consideration if located in a hot cell. If the offgas is sufficiently clean prior to the NO<sub>x</sub>dizer™, so that it does not need to be located in a hot cell, then space requirements are less of a concern. The NO<sub>x</sub>dizer™ itself would be somewhat larger, but the cost savings of a new building outside the hot cell over space inside hot cell far outweigh the difference in size of the NO<sub>x</sub>dizer™. Reengineering of the NO<sub>x</sub>dizer™ to use pure oxygen and/or less quench water would also reduce the volume increase, but these have not been tested to date.

SCR and SNCR should add little volume to the offgas. However, SCR or SNCR systems will require the addition of some type of oxidizing technology to destroy residual hydrocarbons. A catalytic or thermal oxidizer would be a logical choice. Either of these will require some additional air, but the impact should be less than that with the NO<sub>x</sub>dizer™.

Secondary waste is always a concern in treatment of radioactive waste. None of these processes directly produce a secondary waste. The only significant source of secondary waste is the units themselves. The ceramic refractory in the NO<sub>x</sub>dizer™ may be subject to corrosion or thermal shock. The projected life of the refractory is 3 to 5 years, but corrosion or shock could shorten its life. Rather than replace just the refractory, it is likely that an entire section of the NO<sub>x</sub>dizer™ would be replaced. This would be a significant

expense, generate considerable secondary waste, and while it is being changed, the melter could not be operated. The catalytic or noncatalytic matrices in SCR or SNCR are also subject to degradation caused by thermal shock or temperature excursions resulting from the reaction of the high concentrations of NO<sub>x</sub>. Another concern with SCR is poisoning of the catalyst by mercury. Projected life of the catalyst matrix is only 1 to 1.5 years. As with the NO<sub>x</sub>dizer™, when it fails, the entire SCR unit would need to be replaced, not just the catalyst matrix.

## **Technology Applicability**

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The NO<sub>x</sub>dizer™ system can be applied to any waste treatment process that produces an offgas stream containing high levels of NO<sub>x</sub> that must be reduced either for regulatory reasons or for subsequent offgas treatment. The primary application will be to those treatment systems that treat a waste stream that contains high levels of nitrates, and also contains mercury, because NO<sub>x</sub> can be a significant problem in mercury removal systems. Therefore, the application will probably be limited to waste streams such as the sodium-bearing waste and calcined high-level waste at INTEC, and possibly the high-level waste at the Hanford Reservation.

## SECTION 5 COST

### Cost Analysis

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The capital and operating costs of the NO<sub>x</sub>dizer™ system depend to a large extent upon where the system is located. The cost for the NO<sub>x</sub>dizer™ itself would be \$400K to \$500K. If the NO<sub>x</sub>dizer™ is located immediately after a melter inside a hot cell, then the cost, including propane tank, delivery system, hot cell space, and installation would be about \$6,200K. If the NO<sub>x</sub>dizer™ is located downstream in the offgas system, outside the hot cell then the cost, including propane tank, delivery system, a new building, and installation would be about \$1,300K. The advantage of locating the system outside the hot cell is evident.

Operating costs for this technology are generally limited to propane fuel and treated quench water. There would be no need for a dedicated operator and maintenance should be minimal. Table 3 shows the annualized operating costs for the NO<sub>x</sub>dizer™ system.

Table 3. Annual operating costs of the NO<sub>x</sub>dizer™ system.

Cost Item	Annual Cost
Propane	\$1,600K
Treated Water	\$40K
Annualized cost of NO <sub>x</sub> dizer™ (See note 1)	\$300K
<b>Total</b>	<b>\$1,940K</b>

Note 1. Annualized cost assumes a NO<sub>x</sub>dizer™ cost of \$1,500K and a five year life

Installed capital cost for a SCR system is lower than for the NO<sub>x</sub>dizer™ at about \$700K for a system that is not located in a hot cell. Operating costs include ammonia, catalyst replacement, and fuel for heating the incoming offgas stream. Table 4 presents the annualized operating costs for an SCR.

Table 4. Annual operating costs of a selective catalytic reduction system.

Cost Item	Annual Cost
Catalyst	\$10K
Ammonia and fuel	\$500K
Annualized cost of SCR (See note 1)	\$350K
<b>Total</b>	<b>\$860K</b>

Note 1. Annualized cost assumes an SCR cost of \$700K and a two year life

### Cost Conclusions

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The cost of the NO<sub>x</sub>dizer™ system is greater than a comparable SCR system. However, the impact of mercury and other potential poisons on an SCR system has not been established, and the cost could escalate.



## **SECTION 6 OCCUPATIONAL SAFETY AND HEALTH**

There are two potential occupational safety and health concerns with the NO<sub>x</sub>dizer™, but neither is unique or unusual. There are no hazardous materials associated with the system. The first potential hazard is propane fuel which is an explosive. Storage and handling procedures for propane are well known and are not onerous. The second hazard is the high surface temperature of the NO<sub>x</sub>dizer™ itself. While the system is insulated, the surface temperature can be about 200°F, so appropriate barriers and signs must be used. If used in a hot cell, this would be a relatively small concern.

Selective catalytic reduction, has similar hazardous, but has one additional hazard: ammonia. The need to add ammonia to the system requires storage and handling facilities in addition to ambient monitoring equipment to check for leaks. However, ammonia is used in many industrial and commercial processes, and procedures for its safe handling are well established.

### **Advantages of Safer Technologies**

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No inherently safer technology has been identified.

### **Development and Demonstration Safety and Health Considerations**

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These are discussed above.



## **SECTION 7 REGULATORY AND POLICY ISSUES**

### **Regulatory Considerations**

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The NO<sub>x</sub>idizer™ would be only one small piece of a waste treatment facility, but as an emission control device, it will have a positive environmental impact. It will be covered by a facility RCRA Part B permit. For its first anticipated application, direct vitrification of SBW, NO<sub>x</sub> removal will probably not be required for compliance with NO<sub>x</sub> emission limits. The permitted emission limit of NO<sub>x</sub> from the New Waste Calcining Facility (NWCF) has been established by the State of Idaho to be 40 tons/y, and it is not anticipated that the SBW treatment would exceed this value. It is unknown if that emission limit would be changed under a new operating permit for the SBW facility, but implementing the NO<sub>x</sub>idizer™ would reduce the NO<sub>x</sub> emissions by a factor of 10 to 20, thereby ensuring that NO<sub>x</sub> emissions would be in compliance.

A second environmental benefit from removal of NO<sub>x</sub> is that it will aid in compliance issues. The process permits downstream mercury removal and will greatly facilitate offgas sampling and monitoring. Mercury and offgas are compliance issues, so implementation of the NO<sub>x</sub>idizer™ will greatly enhance the permitability of the facility.

### **Safety, Risks, Benefits, and Community Reaction**

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Operation of the NO<sub>x</sub>idizer™ is expected to be straightforward with few unusual safety concerns. The unit does operate at high temperature, but is well insulated so the external temperature is not excessive. However, as a cautionary measure, hands-on access to the unit during operation should be controlled. Normal safety measures would be taken for the propane storage tank and delivery system. No hazardous materials are used or produced by the system.

Risks associated with operation of the NO<sub>x</sub>idizer™ should be small. If it were to fail, it would jeopardize operation of the rest of the facility, but the NO<sub>x</sub>idizer™ should be one of the more reliable units in the SBW treatment facility.

Community and public stakeholders should view the NO<sub>x</sub>idizer™ as a benefit, because it will eliminate the unsightly brown plume emitted during operation of the New Waste Calcining Facility (NWCF) that has been a public eyesore for many years. Also, with the ability to analyze and monitor the offgas from the facility, the public can be assured that emissions are within permitted limits.



## SECTION 8 LESSONS LEARNED

### Implementation Considerations

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Given the commercial availability of the NO<sub>x</sub>dizer™, implementation would be fairly straightforward. The system was readily converted to operate using propane as combustion fuel with no loss in performance. The only consideration still remaining is where to locate the unit in the offgas control system. Given the cost of placing the unit directly after the melter in a hot cell, it seems that location of the unit outside the hot cell after primary radionuclide control is a better option.

### Technology Limitations and Needs for Future Development

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The only significant shortcoming of the NO<sub>x</sub>dizer™ is the increase in offgas volume resulting from combustion air and quench water. One area of future development would be to engineer the system to reduce this added volume. Possibilities include using pure oxygen or oxygen-enriched air for combustion air and reducing the quench water in the oxidation section.

### Technology Selection Considerations

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Final selection of the NO<sub>x</sub>dizer™ rather than an equivalent SCR system will depend on issues discussed under Section 3. These include the concern for the offgas volume increase from the NO<sub>x</sub>dizer™, the potential for poisoning of the SCR catalyst, and the higher pressure drop through the SCR. If the added volume of offgas and the subsequent larger carbon bed are not a major concern, then a multistage combustor such as the NO<sub>x</sub>dizer™ will likely be a superior option. The NO<sub>x</sub>dizer™ also provides the additional benefit of destroying residual organics or products of incomplete combustion that might be present following any thermal treatment system.



## **APPENDIX A BIBLIOGRAPHY**

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## **APPENDIX B ACRONYMS AND ABBREVIATIONS**

CEM	continuous emission monitors
CO	carbon monoxide
DOE	Department of Energy
DRE	destruction and removal efficiency
EPA	Environmental Protection Agency
GAC	Granulated activated carbon
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MACT	maximum achievable control technology
MSC	multistage combustion
NO <sub>x</sub>	oxides of nitrogen
NWCF	New Waste Calcining Facility
PIC	product of incomplete combustion
SBW	sodium-bearing waste
SCR	selective catalytic reduction
SNCR	selective noncatalytic reduction
SSTB	slip stream emission monitors
SVOC	semivolatile organic compound
VOC	volatile organic compound