LA-UR -91-907

LA-UR--91-907

DE91 009958

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SUBMITTED TO The 1991 INCINERATION CONFERENCE
KNOXVILLE, TENNESSEE
MAY 13 - 17, 1991

A NOVEL DEVICE FOR PROCESSING RADIOACTIVE COMBUSTIBLES

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ABSTRACT

Los Alamos National Laboratory is assisting EG&G Rocky Flats, Colorado, with the development of a special incinerator for wastes contaminated with plutonium, a radioactive element. This paper describes one conceptual design that was developed by T. K. Thompson, Inc., under contract to Los Alamos National Laboratory. The design is a tentative proposal that tries to address the many constraints that are peculiar to this project. It has not been endorsed or accepted by EG&G Rocky Flats, and it is subject to revision. Nevertheless, it is noteworthy because of the novel concepts it embodies.

SAFETY CONCERNS

Before examining the design itself, it is instructive to understand the constraints imposed by safety and operational concerns. There are three main requirements related to safety:

1. There may be no emissions of radioactive material, either to the atmosphere or into the building that houses the incinerator. This means that: (a) there can be no fly-ash in the exhaust gas, (b) the combustion chamberr must operate at sub-ambient pressure, and (c) the combustion chambers must be contained within gloveboxes.

2. The outer surfaces of the combustion chamber must be kept below 140 oF so that the lead-lined rubber gloves will not melt if the operator reaches inside the glovebox while the incinerator is hot.

3. The combustion chambers and other locations where plutonium-containing ash could accumulate must be designed in such a way that it would be impossible for a criticality accident to occur. "Criticality" refers to the concern that if sufficient plutonium were to accumulate somewhere in the device and if the incinerator were to become filled with water for some reason, there might be an intense release of neutrons. (It should be noted that it would be very unlikely that both of the things mentioned above could happen at the same time. Also, it should be noted that "criticality" does not imply that there could be any chance whatsoever of an explosion, because the amounts of plutonium involved would be much too small for that to happen.)

OPERATIONAL CONCERNS

Besides those relating to safety, the design must satisfy three important constraints related to its operation:

1. The device must operate continuously and at a constant temperature. This would yield two benefits. First, it would reduce the thermal shock and the resultant damage to which the refractory would be subjected; and, second, it would maximize the capacity of the unit. Although steady-state operation is the norm for large commercial incinerators, such has not been the case for incinerators that treat radioactive wastes.

2. The incinerator must be able to burn polyvinyl chloride (PVC), and the off-gas treatment system must remove the hydrogen chloride (HCl) that would form. The removal efficiency would have to meet the standards set by the EPA and the State of Colorado.

3. The combustion chambers and the off-gas treatment system must be easy to disassemble for maintenance and inspection.

GENERAL DESIGN APPROACH

In order to minimize the amount of fly-ash that would be produced, it was decided that the incinerator must be of the "Controlled Air" type. In such a design (see Figure 1) combustible feed material would be prepared in a separate enclosure then conveyed continuously into the primary chamber where that material would be converted to char in an oxygen-deficient atmosphere. Air would be introduced into the primary combustion chamber in a very controlled manner to ensure the flow of gases was not turbulent.

Volatile gases from the char would pass into the secondary chamber where they would be completely burned in an oxygen-rich atmosphere under turbulent conditions. The char would collect in a trough comprising the lower half of the primary chamber. There the char would be oxidized to ash.

Continuous operation would be achieved by continuously removing the ash with a screw conveyor. Such a conveyor would be rather unusual for an incinerator.

To reduce the amount of plutonium that might diffuse into the refractory and insulation, it was decided to employ metal liners wherever feasible. Even if the liners became contaminated, they would be easier to remove and clean than brickwork.
Because the incinerator must process polyvinyl chloride, as mentioned previously, and because the resultant HCl would be so highly corrosive, special materials would have to be

used. For example, the metal liners would have to be made of high-nickel alloy and the glovebox would have to be lined with polyvinylidene fluoride.

DESIGN FEATURES FOR SAFETY

In operation, shredded combustible material would enter through the Feed Port (shown near the left end of the diagram in Figure 2.) It would be forced in by a screw feeder (not shown) and would fall onto a small ceramic shelf where it would be pyrolyzed and partially ignited. The shelf would contain any molten plastic until the plastic could burn or vaporize. From the shelf, the charred feed would drop onto a specially-designed screw conveyor (the device with teeth, shown shaded in Figure 2.) As the char moved from one end of the trough to the other, it would be oxidized to ash.

A fuel oil burner would be located above the ceramic shelf to provide a positive ignition source and to preheat the primary chamber during start-up. A mixture of oxygen and an inert gas such as nitrogen or carbon dioxide would be supplied to the burner in such a way that the gas flow in the upper half of the chamber would be laminar and of low velocity, in order to minimize the amount of ash blown into the secondary chamber.

The primary combustion chamber and its associated ash trough would form a unit that would be almost cylindrical, as shown in Figure 3. The walls would be constructed of a castable refractory backed by low-density insulation and contained within a stainless pressure shell. The shell would be necessary because the incinerator would be contained within a glovebox, and the pressure both inside the incinerator and inside the glovebox would be kept below ambient as a precaution against any ash or dust escaping from the unit.

Because combustion would be severely limited in the primary chamber, its internal temperature would be held below 800 oC (1472 oF). With a temperature this low and with the thick insulation supplemented by an air gap, the temperature of the external shell would be maintained at 60 oC (140 oF) or below. This would ensure that anyone who touched it during operation would not get burned, nor would their protective rubber gloves be melted.

The char and ash would occupy the annular region between the screw conveyor's shaft and the floor of the trough. (See Figure 3.) Because this region is so narrow, it would provide complete safety against a criticality accident, even if the trough were to become full of plutonium-bearing ash and the whole chamber were to become filled with water for some reason. (Other features of the ash trough and conveyor are described more fully below.)

The secondary combustion chamber would similarly be safe against a criticality accident because, although its total volume would be fairly large, it would essentially be a very narrow, U-shaped duct. (See Figure 1.) This kind of "slab" geometry would allow neutrons to escape from the plutonium, should it accumulate, thereby precluding the chance of any chain reaction occurring.

DESIGN FEATURES FOR OPERATION

As described above, continuous operation would be achieved by feeding combustible waste with a screw feeder and by continuously removing the ash with the screw conveyor. Continuous and steady-state operation would be an innovation because the radioactive waste incinerators presently operated at Department of Energy nuclear facilities are operated in batch mode.

The special ash conveyor depicted in Figure 2 is probably the most innovative aspect of the system, because it would perform two functions. As a screw conveyor, it would move the ash along the length of the trough until the ash exited through a star valve or double knife valve. In addition, the conveyor would be equipped with a helix of pins, so that it could mix the pile of char and thereby improve carbon burn-out. The pins would be very sturdy so they could break up any clinkers that formed. Each pin would be hollow with an internal poppet valve that would let oxygen flow through the pin only when the pin was pointing downward and was, therefore, immersed in the bed of char. The flow rate and the composition of the gas supplied to the pins could be varied along the length of the trough to control the rate of carbon oxidation. Electric strip heaters beneath the trough would provide continuous control of the temperature.

The vapor space in the primary chamber would be maintained at 800 oC (1472 oF) by controlling the rate at which combustible material was introduced. If the feed rate became too low, the fuel oil burner would provide supplemental heat. Excess heat would be removed from both the top and bottom sections of the primary chamber by a stream of cooling air forced through an annular space beneath the outermost stainless steel shell.

As mentioned previously, the trough would be lined with a high-nickel alloy to prevent radioactive contamination of the castable refractory. The operating temperature is expected to be low enough that such a liner would be feasible. A liner for the upper half of the primary chamber would probably not be necessary because the refractory would not be in contact with plutonium-bearing ash.

Upon entering the secondary chamber, the gaseous pyrolysis products from the primary chamber would pass upward through a mixing choke (not shown). At that point excess air or oxygen would be injected, ignition would be initiated, and turbulence would be induced. Because the capacity of this incinerator would be small, it would probably be more economical to use oxygen than air. Using oxygen would minimize the volume of flue-gas that would have to be handled by the off-gas treatment system.

Electrical heaters would be used for temperature control instead of oil-fired burners, although oil-fired burners would be more conventional. Again, this would be done to reduce the volume of gas handled by the downstream treatment system. Ordinarily, the electrical heaters would be needed only during start-up because the plastics (PVC) in the feed would have such a high heating value that supplemental heating would not be necessary.

The secondary chamber would have sufficient volume to provide a residence time of 2 sec at 1200 oC (2192 oF). This should be sufficient to completely convert all carbon-containing gases to carbon dioxide and water and to convert all chlorine-containing species to hydrogen chloride.

The walls of the secondary chamber would have an inner shell of castable refractory backed by a layer of low density insulation contained within a stainless pressure shell. As with the primary chamber, the secondary would be built in segments that could be easily separated for inspection.

FLUE-GAS TREATMENT

The conceptual design for the off-gas treatment system has not been developed as fully as the design for the combustion chambers. Nevertheless, we know that the system would have to perform three functions: (a) quench the gas that leaves the secondary chamber so that dioxins could not form by recombination reactions, (b) remove the hydrogen chloride produced from the vinyl chloride entering with the feed, and (c) remove the fly-ash.

Operating experience from other controlled-air incinerators suggests that only 2 or 3% of the solids entering with the feed would be carried into the secondary chamber as fly-ash and, of those, over 95% would be retained in the secondary chamber. About 99% of the ash passing the secondary chamber would be removed by one or more free-jet scrubbers. Finally, the off-gas would pass through two or more banks of high-efficiency particulate air (HEPA or "absolute") filters that typically remove 99.99% of the entering solids. Even with these kinds of precautions, the exhaust gas would probably be monitored for radioactivity.

It is anticipated that the free-jet scrubbers would also remove hydrogen chloride with high efficiency if the scrubbing solution were alkaline. The preferred solution has not been chosen, however. To provide positive control, the exhaust gas would probably be monitored continuously for traces of hydrogen chloride as well as for other components as required by regulatory agencies.

ASH DISPOSAL

The plutonium content of the ash would be monitored closely. If the amount of plutonium were small, the ash would probably be shipped to its final disposal site after being immobilized. (Immobilization might be achieved by mixing it with cement and casting it as a solid.) If the amount of plutonium were large, however, the ash would be retained and treated to remove the plutonium.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions made by other members of the design team: Mr. Eugene Ignelzi, Lakewood, CO; Mr. Ralph A. Koenig, President, The Merlin Co., Boulder, CO; Mr. James A. Frye, President, EDC Engineering, Santa Fe, NM; and Mr. H. Edward Martinez, Staff Member, Los Alamos National Laboratory, NM.

IS-12990-3112

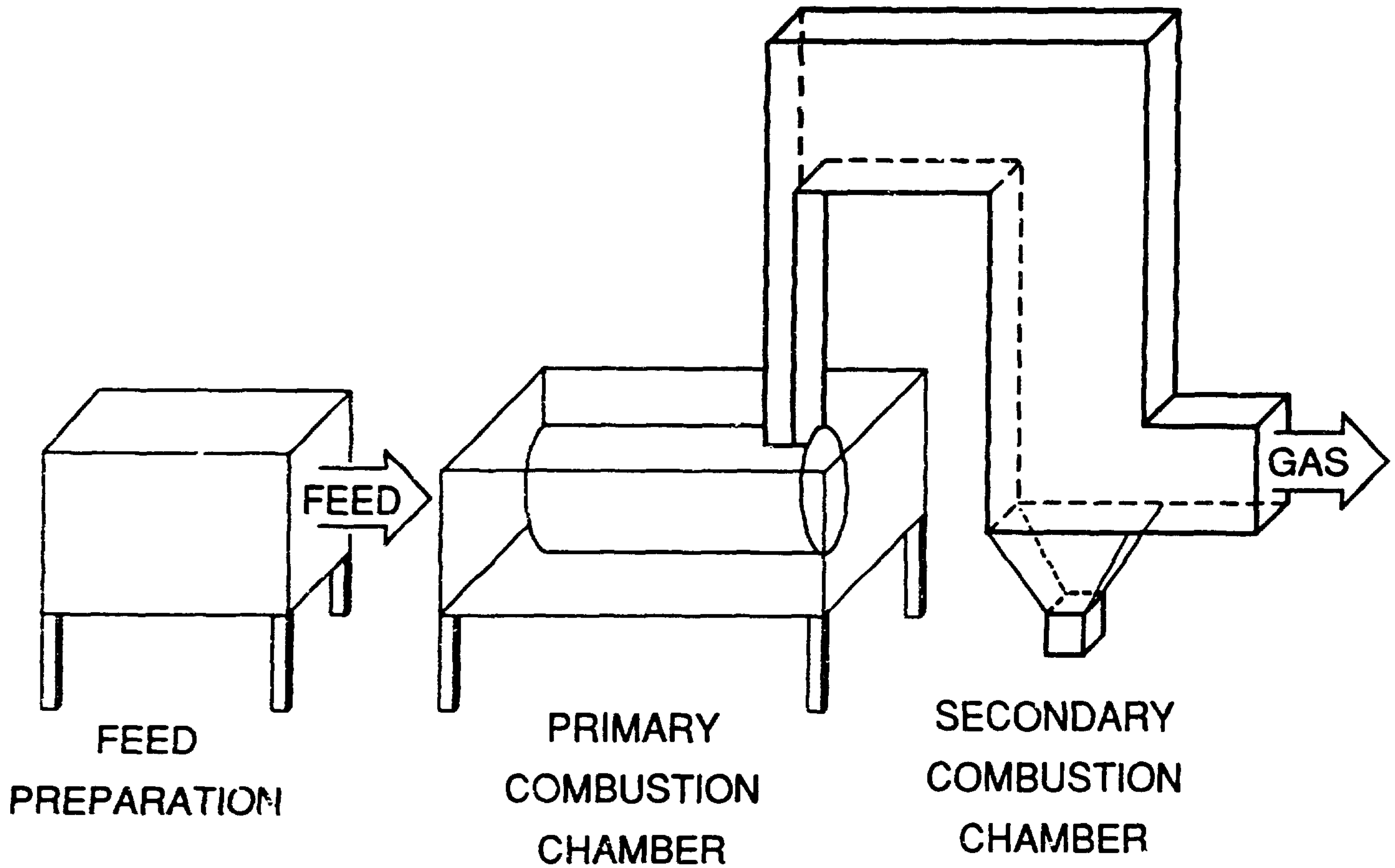

Fig. 1. Main components of Rad-Waste Incinerator

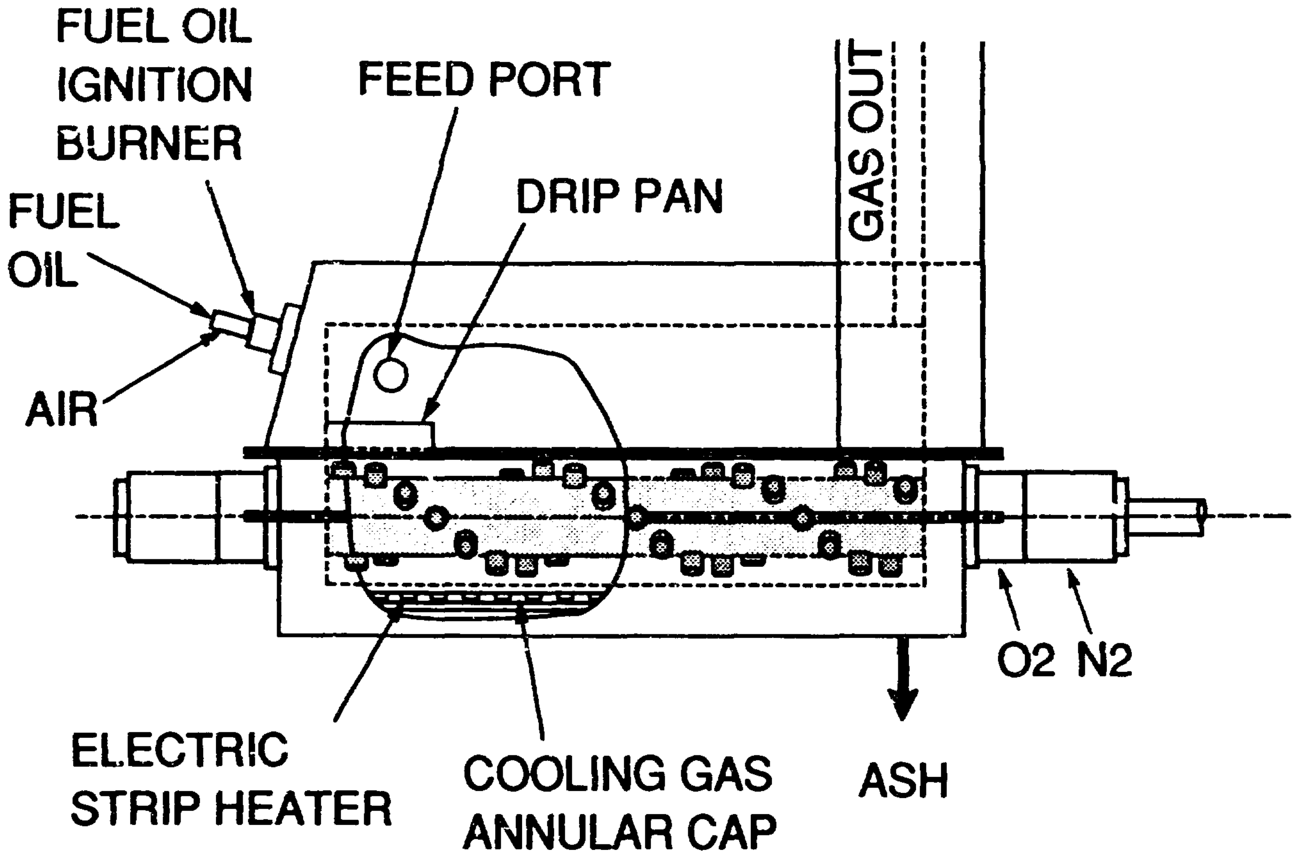

Fig. 2. Side view of primary chamber

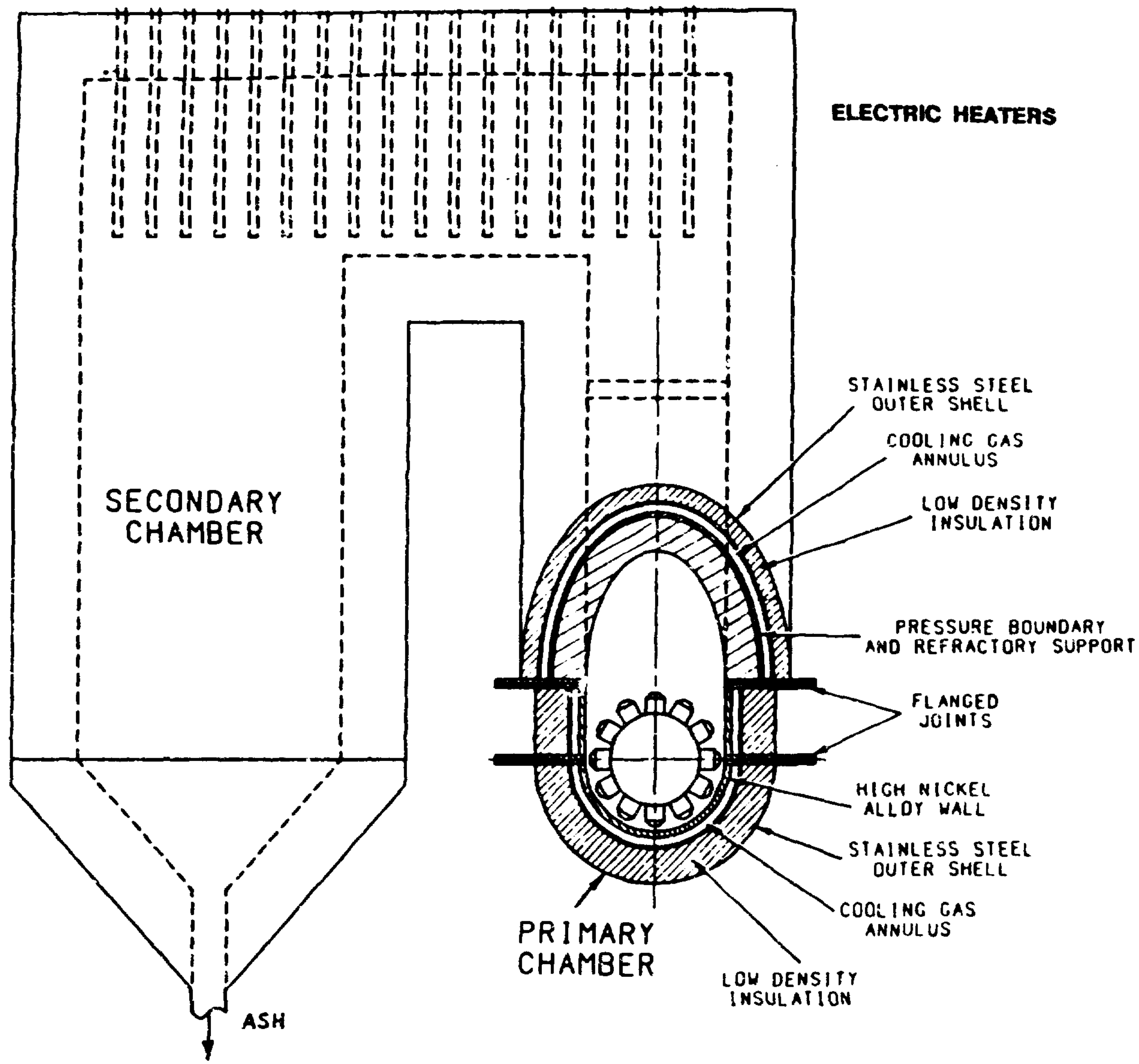

Fig. 3. End view of primary chamber