Florida Department of
Environmental Protection
Bob Martinez Center
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

November 19, 2008

Greg Beyke
Thermal Remediation Systems, Inc.
4137 Jensome Lane
Franklin, Tennessee 37064

Re: **Electrical Resistance Heating (ERH)**

Dear Mr. Beyke:

The Division of Waste Management (the Division) hereby accepts Electrical Resistance Heating (ERH) by Thermal Remediation Systems Incorporated as a technology for in situ remediation of petroleum, chlorinated hydrocarbons and other suitable contaminants in groundwater and soil. There are no objections to the use of ERH for the remediation of contaminated sites in Florida, provided a site-specific Remedial Action Plan is approved by the Department. Regulatory information is provided in Enclosure 1, and supplemental information in Enclosure 2.

Although the Division of Waste Management does not provide endorsement of specific or brand name remediation products or processes, it does recognize the need to determine their acceptability in the context of environmental regulations, protection of public health, and safety. In no way shall this regulatory acceptance be construed as certification of product performance. Additionally, the Division emphasizes a distinction between its regulatory "acceptance" letter and an approval. Products and processes are accepted but they are not approved. Vendors and environmental consulting companies must market the products and processes on their own merits regarding performance, cost, and safety in comparison to competing alternatives in the marketplace.

Remedial Action Plans that include use of an accepted product or process should include a copy of the acceptance letter in the plan's appendix, and reference it in the text of the document. It is <u>not</u> a requirement that a particular remediation product or process have an official acceptance letter in order for it to be proposed in a site-specific Remedial Action Plan. The plan, however, must contain sufficient information about the product or process to show that it meets all applicable rules and regulations.

The Division reserves the right to revoke its acceptance of a product or process if it has been falsely or incompletely represented. Additionally, Division acceptance of any product or process does not imply it has been deemed applicable for all cleanup situations, or that it is preferred over other treatment or cleanup techniques in any particular case. A site-specific evaluation of applicability and cost-effectiveness must be considered for any product or process, whether conventional or innovative, and adequate design details must be provided in a site-specific Remedial Action Plan submitted for Department review and approval. Questions about hazardous waste cleanup applications should be directed to Gary Millington, and questions about petroleum cleanup applications should be directed to Rick Ruscito.

Sincerely,

Gary Millington

Rick Ruscito

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c: T. Conrardy - FDEP/Tallahassee
Rob Cowdery – FDEP/Tallahassee

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ENCLOSURE 1

REGULATORY INFORMATION

1. Regulations: Users of the ERH system shall comply with all applicable regulations. This includes meeting applicable groundwater contaminant standards by the time of cleanup project completion. The following chapters of the Florida Administrative Code (F.A.C.) are cited: Chapter 62-550, F.A.C., for primary and secondary water quality standards; Chapter 62-520, F.A.C. for groundwater classes and standards; Chapter 62-522, F.A.C., for groundwater permitting and monitoring requirements; Chapter 62-528, F.A.C., for underground injection control; Chapters 62-770, 62-780, 62-782, and 62-785 F.A.C., for cleanup criteria; and Chapter 62-777, F.A.C., for cleanup target levels. The foregoing is not intended as an exhaustive list, and depending on the circumstances not every chapter of the Florida Administrative Code, either in part or in its entirety, may be applicable. Some of the key regulatory considerations with respect to the ERH system are discussed below.

2. Vapor effluent: For petroleum cleanup projects, rules 62-770.700(5)(a) and (e) require air emissions treatment for at least the first 30 days of system operation. Treatment may be discontinued after the first 30 days of operation if the total mass of petroleum hydrocarbons emitted does not exceed 13.7 pounds per day. For Bureau of Waste Cleanup sites, air emission requirements can be found in subsections 62-780.700(3) and (4), F.A.C.

3. Liquid effluent: Excess ERH condensate that meets the groundwater cleanup target levels set forth in Chapter 62-777, F.A.C., may be disposed on site via infiltration. Effluent may also be disposed by way of underground injection, storm water sewer or sanitary sewer. For more information about disposal of effluent via injection, and a requirement to provide notice to the Underground Injection Control Section, see the guidance document titled "BPSS-8 Effluent Disposal via Injection Well", currently located at web page www.dep.state.fl.us/waste/categories/pcp/pages/active.htm. For information about disposal via National Pollutant Discharge Elimination System (NPDES) permit to a storm sewer, see the guidance document titled "BPSS-3 Design Requirements and Procedures for NPDES Discharges", also currently located at web page www.dep.state.fl.us/waste/categories/pcp/pages/active.htm. For disposal via sanitary sewer, observe the requirements of the local sewer use ordinance.

4. Electrode hydration: Some of the ERH system condensate is recirculated to the subsurface to keep the vadose portion of each electrode hydrated. The amount is small, approximately 1 - 2 gallons per hour per electrode. Since some of this water could ultimately percolate into the underlying groundwater, it is worthwhile to consider the matter with respect to regulations ahead of time. Three situations are possible.

   In the first situation, condensate that meets the groundwater cleanup target levels set forth in Chapter 62-777, F.A.C., can be recirculated to the subsurface for electrode hydration.

   In the second situation, condensate that does not meet the groundwater cleanup target levels of Chapter 62-777, F.A.C., for a cleanup site's contaminants of concern can be recirculated to the subsurface pursuant to rule 62-522.300(2)(c), F.A.C., which provides a mechanism for the granting of permission for a temporary injection zone of discharge for the recirculated contaminants, if they will percolate deep enough to reach the underlying groundwater, otherwise no zone of discharge is needed.

The third situation is in regard to the magnesium sulfate (Epsom salt) that is used during the installation of electrodes. The concentration was not disclosed but an application rate of one (1) gallon per foot of electrode was provided. If the site-specific conditions are such that sulfate (a secondary groundwater contaminant) at a concentration of 250 milligrams per liter (mg/L) or greater is added either directly to the groundwater during installation, or could be flushed into the underlying groundwater by the 1 - 2 gallons per hour of recirculated condensate per electrode that serves as hydration, then rule 62-522.300(2)(c), F.A.C., provides a mechanism for a temporary injection zone of discharge for the sulfate. In that case, in order to comply with the rule, the groundwater must be monitored for sulfate. At a minimum, when such monitoring is conducted, the Division of Waste Management recommends the quarterly monitoring of sulfate at one (1) electrode at or near the center of the electrode cluster. The monitoring should continue until the groundwater meets the 250 mg/L secondary standard for sulfate or the site's natural-occurring concentration of sulfate in the groundwater, whichever is less stringent.

5. Pilot study: Per subsections 62-770.700(2), F.A.C., for an innovative technology, a pilot study shall be conducted prior to the design of a full-scale treatment system. The rule, however, in recognition that a pilot study may not always be warranted, provides for the submittal of a proposal that explains the rationale to forego it. Requirements for pilot studies under Chapter 62-780, F.A.C., are located at subsection 62-780.700(2), F.A.C.

6. Utilization of wells: Stainless steel is the material of construction for ERH electrode-wells because --- unlike PVC --- it is both conductive and resistant to heat. For those reasons, it is unlikely that there will be many opportunities to convert existing monitoring wells in Florida to electrode-wells, given that PVC is the material of construction for nearly all monitoring wells installed for contamination assessment purposes. However, if a remediation site happens to have an abundance of suitable, conductive, heat-resistant monitoring wells, then the Division has no objection to the use of some as ERH electrodes, provided they are not "designated" monitoring wells dedicated to the tracking of remediation progress.

ENCLOSURE 2

SUPPLEMENTAL INFORMATION

1. Description: As indicated by Thermal Remediation Systems Incorporated, the ERH system applies 3-phase or 6-phase, 60 Hertz alternating current to subsurface electrodes. The 3-phase system is the more common of the two. Six-phase is suitable for circular areas of approximately 65-feet or less in diameter, while 3-phase is better suited for the heating of larger, non-circular areas. The electrodes are usually stainless steel vapor recovery wells, but other conductive items such as steel piling can be used.

   The electrical resistance of soil in both the vadose and saturated zones between the electrodes generates heat that slowly brings contaminants and moisture to the boiling point. This produces a hot mixture of vaporized contaminants and steam that is captured by vacuum and routed to a condenser in which only the steam condenses. Contaminants remain in the vapor phase as they pass through the condenser. They are subsequently treated by granulated activated carbon or other appropriate methods.

   In Figure 1, the bulk of the liquid from the condenser is sent to a cooling tower, where most of it evaporates. A small portion is used as drip water to keep the vadose moist at the electrodes. The remainder of the condensate is discharged as effluent or as blowdown to prevent scaling in the condenser due to an accumulation of dissolved solids. Thermal Remediation Systems indicates that the amount of contaminants in the vapor stream exiting the condenser is typically 99% or more of that which enters. The balance exits with the condensate at a typical concentration of 50 parts per billion or less.

2. Typical system: This information is only for illustrative purposes and should not be considered absolute, nor should it be used in lieu of site-specific information. Electrode spacing: 14 - 22 feet; active remediation time: 4 - 8 months, typically, for a 99% reduction of a contaminant such as trichloroethylene; and approximately a one (1) year "cool-down" time for the subsurface to return to ambient temperature.

3. Soil type: ERH is not sensitive to soil type and permeability. It can be used in rock, provided there are fractures through which the electricity can follow the path taken by the contaminants. Unfractured rock, however, is not suitable.

4. Electrodes: Stainless steel is used as the material of construction for electrodes because it conducts electricity and is unaffected by the operating temperatures of the ERH system.

5. Path of the electricity: Thermal Remediation Systems Incorporated indicates that electricity on the secondary side of the ERH transformers flows only between the electrodes, not beyond them. Steel underground storage tanks and other adjacent facilities are not used as electrodes and are therefore not part of the secondary circuit.

6. A.C. eliminates electrolysis: Alternating current is deliberately chosen for the ERH system because -- unlike direct current -- it does not cause electrolysis that would otherwise split groundwater molecules into a flammable mixture of hydrogen and oxygen gas.

7. Viscosity and density: Heat produced by ERH reduces the viscosity and density of contaminants, which aids in their removal from the subsurface. Additionally, as heat is

added, the rate at which the densities of hydrocarbons decrease is faster than that of water. A beneficial effect of this difference in rate is that the DNAPL of a "heavier-than-water" contaminant (e.g. creosote) can be converted to an LNAPL, which is then vaporized and carried away by steam bubbles.

8. Surface seal: For cleanup sites having a shallow water table of approximately 2 feet or less, a cap of asphalt, high density polyethylene (HDPE) or other suitable material is recommended.

9. Electrolytic degradation product: Vaporization is not the only process at work in an ERH system. Thermal Remediation Systems indicates that destruction of halogenated alkanes, methylene chloride and some pesticides and fumigants by hydrolysis occurs at temperatures near 100 degrees C. A beneficial side-effect of the hydrolysis in the case of chlorinated hydrocarbons is that the liberated chloride ions are an electrolyte that aids in the conduction of electricity.

10. Power Control Units: Available at levels of 500; 700; 950; 2,000; and 4,500 kilowatts.

11. Avoidance of stray current: The electricity flows only from electrode-to-electrode within the treatment area, not beyond them.

12. Microbial activity: Thermal Remediation Systems indicates that while temperatures of 100 deg. C can be reached in the subsurface, not all indigenous microorganisms will be killed. Some of those in areas where temperatures exceed 60 deg. C will become inactive until the temperature declines. And in areas where the subsurface moisture is not raised to the boiling point but only elevated to 30 to 40 deg. C., the anaerobic activity of dehalogenating microbes has been observed to increase. For these reasons, the remediation process does not necessarily stop when current to the electrodes ceases, but rather shifts to polishing via bioremediation.

13. Treatment depth: The ERH process is not depth-limited. To date the deepest treatment has been 130 feet, and a system is currently in design for treatment to a depth of 150 feet.

14. DNAPL: Can be used for DNAPL (95-99% reduction).

15. Temperature vs. distance: The Division of Waste Management cites the following article by Vermeulen and McGee, available on the Internet, which contains a comparison plot of the ground temperature vs. distance profiles for inductive and resistive subsurface heat sources: *In Situ Electromagnetic Heating for Hydrocarbon Recovery and Environmental Remediation; Journal of Canadian Petroleum Technology, Volume 39, No. 8, p. 25-29, August 2004*. For <u>resistive</u> heating, the Division has read a few points to define the profile and lists them as follows, after converting from metric to English units:
248 deg. F at 0.44 ft.; 212 deg. F at 1.54 ft.; 150 deg. F at 6.09 ft.; and 113 deg. F at 16.4 ft. For <u>inductive</u> heating, the profile is as follows: 248 deg. F at 0.2 ft.; 167 deg. F at 0.44 ft.; 113 deg. F at 1.54 ft.; 86 deg. F at 6.09 ft.; and 75 deg. F at 16.4 ft. It should be noted that this inductive profile is for the dissipation of heat, by thermal conduction, from a point source. These profiles are cited only as supplemental information. They shall not be

construed as design standards to be imposed during the preparation of a Remedial Action Plan proposing the use of ERH.

It is likely that the resistive temperature profile will be of more interest during the layout and spacing of electrodes for an ERH system, and that the inductive (thermal conduction) profile is likely to be of more interest during an evaluation of the rate at which heat dissipates by conduction beyond the periphery of the electrode cluster. From a safety standpoint, the reviewer of a Remedial Action Plan proposing ERH may be interested in the thermal conduction profile if there is concern about a subsurface object, utility or underground storage tank system and associated piping that lies close by, but outside the treatment area heated by electrodes.

16. Safety: The safety considerations below shall not be construed as an exhaustive list.

    a. Monitoring of subsurface temperature: This is standard procedure for Thermal Remediation Systems' ERH.

    b. Subsurface utilities: Thermal Remediation Systems indicates that the materials of construction for buried utilities and petroleum storage tank systems should be reviewed for their resistance to heat and their chemical compatibility with the concentrations of contaminants that will be in contact with them. Non-heat-resistant utilities should be relocated or replaced with stainless steel, and non-heat-resistant PVC monitoring wells in the treatment area should be replaced with stainless steel.

    c. Occupational Safety & Health Administration (OSHA): 29 CFR, Subpart S, 1910.303(g)(2)(i) requires that the live parts of electric equipment operating at 50 volts or more be guarded against accidental contact. 29 CFR, Subpart R, 1910.269, Appendix C discusses methods for "Protection from Step and Touch Potentials", since voltage gradients can exist in the subsurface.

    The Division of Waste Management has reviewed the precautions that Thermal Remediation Systems will take with respect to subsurface voltage gradients that can extend to the surface or impact subsurface metal objects such as pipes, and has determined that they are consistent with OSHA requirements. The precautions are as follows: (a) the establishment of an electrode field personnel exclusion zone when voltage is initially applied; (b) repeated measurement of step-touch voltages outside the exclusion zone as voltage is increased during startup, with special attention being paid to metal objects within 100 feet of the electrode field; and (c) placement of a fence or barrier at the location where the step-touch voltage is 15 volts or less (which is conservatively less than the 50-volt maximum cited by OSHA).

    If, during startup, it is determined that potentially hazardous voltages could develop outside of the exclusion zone, then the corrective options cited by Thermal Remediation Systems include but are not necessarily limited to re-orientation of the surface grid; adding grounding rods; connection of the offending component to the facility ground system; breaking the conductive path that is directing voltage out of the exclusion zone; or changing the size of the exclusion zone.

d. Petroleum underground storage tanks (USTs): Remedial Action Plans proposing the use of ERH near underground petroleum storage tanks and their associated piping shall identify and address all appropriate safety concerns. Thermal Remediation Services recommends, at a minimum, that underground petroleum storage tanks be emptied prior to active remediation if they are within the zone to be heated. If a site-specific situation warrants additional precaution, then the Division of Waste Management suggests that consideration be given to filling of the emptied tanks with inert gas. The Division also suggests, if a situation is such that a tank is not within the zone to be heated, or not so close to that zone as to warrant the emptying of its contents, that consideration could be given to blanketing of the partially filled tank with inert gas.

e. Electrodes near USTs: Thermal Remediation Services offers, as a rule of thumb, that the distance between the electrodes and a tank be no less than 8 to 10 feet.

f. Temperature and materials of construction for USTs: In regard to the potential effects of temperature on petroleum storage system materials there is more concern for fiberglass tanks and piping than for steel. Since fiberglass storage tank specifications require that the tank be capable storing petroleum at ambient underground temperatures of 150 degrees Fahrenheit or less at the interior surface of the tank, the Division of Waste Management advises that any heat-generating type remediation system be constructed and operated in such a way that the 150-degree Fahrenheit operating limit is not exceeded at the tank wall. Given that the subsurface response to a reduction in heat input will not be instantaneous, it is also advised that a safety factor be applied to both temperature and distance, in order to reduce the heat input before -- not after -- the 150-degree heat arrives at the tank wall.

g. Temperature monitoring at USTs: The temperature of the subsurface around an underground storage tank system should be monitored when using heat for remediation purposes. Additionally, consideration should be given as to whether or not the temperature of the liquid inside the tank and the vapor space above it should be monitored.

h. Mobilization of vapors: Thermal Remediation Systems recommends the monitoring of subsurface utilities that could serve as conduits for vapor migration during active remediation. The Division of Waste Management adds that the monitoring should be at the outlets and termination points of potential migration pathways such as sewers, drains and other utilities. For flammable petroleum contaminants, potential ignition sources along the potential migration pathways, their outlets and termination points should be identified and addressed, and measured vapor concentrations at those locations during system operation should be compared to their lower explosive levels. For nonflammable contaminants such as chlorinated solvents, potential receptors along the migration pathways should be identified, and measured vapor concentrations should be compared to the maximum allowable limits recommended by toxicologists.

i. Other: Observance of the National Electrical Code; personal protection of remediation workers; and safety considerations regarding non-remediation personnel present at the site; and passersby.

17. Operating parameters: The vapor recovery component of the ERH system is similar to that of a conventional multi-phase extraction, with the exception of a steam condenser instead of a moisture separator, and the higher temperature of the vapors recovered from the subsurface. Thus, with the exception of temperature, the parameters to be tracked during the operation of the vapor recovery component would be the same as those of a conventional multi-phase extraction system: flow rates; vacuum; contaminant concentrations, air emissions, etc.

    As for the electric component, the operating parameters of interest would be applied voltage, current, power, subsurface temperature, soil moisture (5% or greater is desirable to promote conduction of electricity), condensate flow rate, electrode hydration flow rate, depth to water, total organic carbon, NAPL thickness, groundwater sulfate concentration (if conditions are such that magnesium sulfate could be flushed from the vadose to the underlying groundwater by electrode hydration water), stray voltage at points of concern, and the concentrations of vapors at potential migration pathway outlets and termination points. If an underground storage tank is present and close to the heated zone, then consideration may be given to monitoring of temperature of the tank's contents if it is not emptied, and verification that an inert gas blanket over the tank's contents (if blanketed) remains in place during the period of active remediation. The foregoing is not intended as an absolute or exhaustive list of parameters to be tracked, and a determination should be made on a site-specific basis and proposed in a Remedial Action Plan.

18. Sampling: A method that involves a minimum 12-hour shutoff of the ERH system prior to well purging and sampling has been developed by Thermal Remediation Services, in order to obtain samples of heated groundwater during <u>active</u> remediation. An ice-water bathed coil is used to cool the sample. A method for the sampling and cooling of hot soil cores has also been developed. The objective of each method is to take an accurate sample and to preserve its integrity without burning the sample taker. These methods appear adequate for the purpose of process control and gauging the progress of the cleanup during active remediation. As for the required subsequent one (1) year of post active remediation monitoring, during which the more critical data will be collected to justify the issuance of a Site Rehabilitation Completion Order, the soil and groundwater will be cooler and conventional methods of sampling these media shall be used.

19. Limitations and advisories from Thermal Remediation Systems Incorporated:

    a. Not for metals, PCBs, or dioxin.

    b. Not recommended for remediation beneath buildings if depth to the underlying groundwater is approximately 2 feet or less, in order avoid undesirable expansion of the building's slab and the potential nuisance of heating the floor. Additionally, for legal concerns not specified, Thermal Remediation Systems prefers not to use the ERH process for remediation beneath residences.

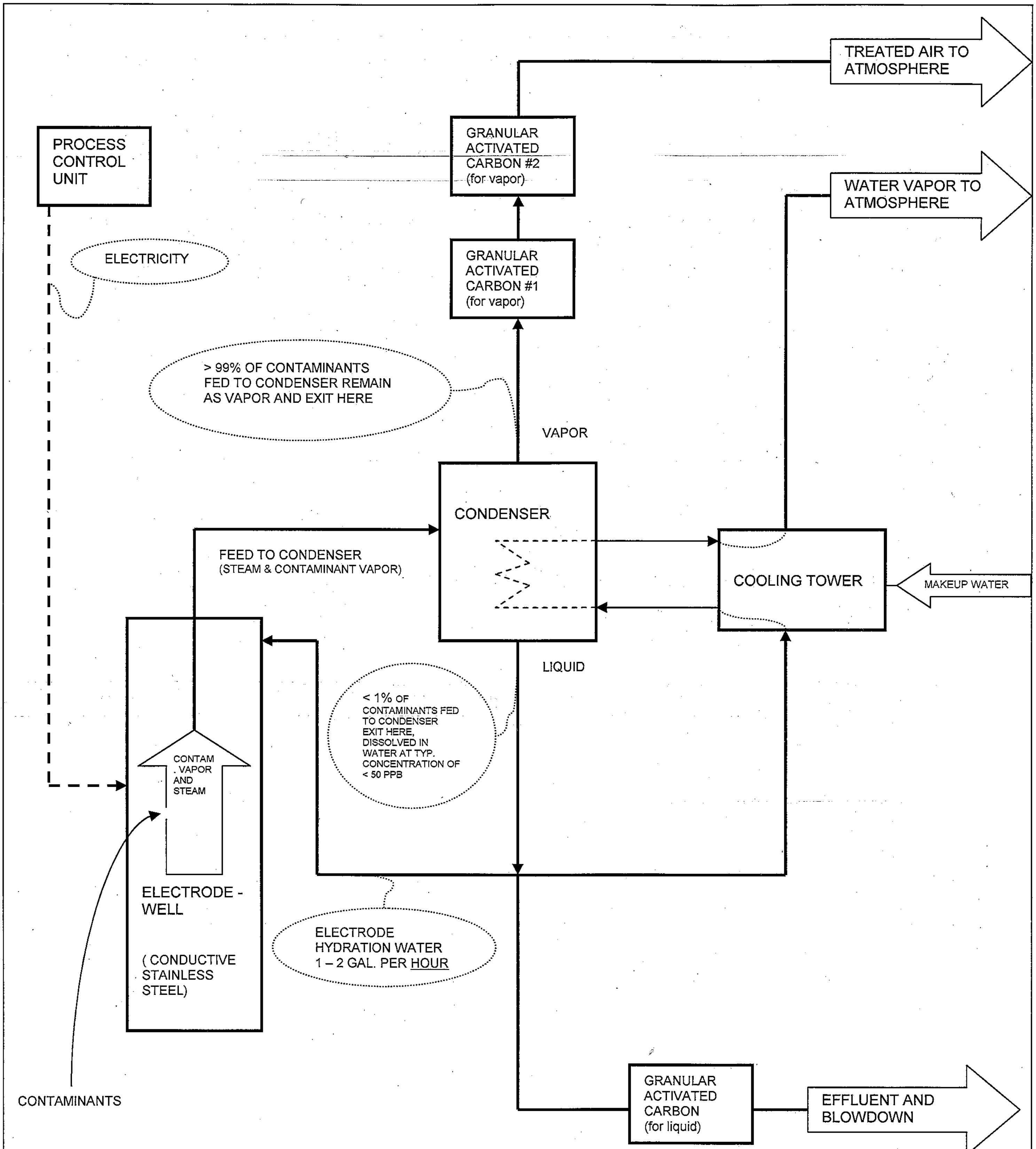

Figure 1. Block diagram of the Electrical Resistance Heating (ERH) process.