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STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF REMEDIATION - DOE OVERSIGHT OFFICE
761 EMORY VALLEY ROAD
OAK RIDGE, TN 37830

May 16, 2016

Mr. John Michael Japp
DOE FFA Project Manager
P.O. Box 2001
Oak Ridge, TN 37831-8540

Dear Mr. Japp

**TDEC Comment Letter**
**Remedial Investigation/Feasibility Study for Comprehensive Environmental Response, Compensation, and Liability Act Oak Ridge Reservation Waste Disposal, Oak Ridge, TN**
**DOE/OR/01-2535&D4**
**March 2016**

The Tennessee Department of Environment and Conservation (TDEC), Division of Remediation has reviewed the above referenced document pursuant to the Federal Facility Agreement (FFA) for the Oak Ridge Reservation (ORR). Based on that review, significant issues remain to be resolved. Some of the issues of greatest concern are summarized below. A complete list of comments with more specific detail is attached. Given these concerns, TDEC cannot approve the D4 RI/FS at this time and places the document in informal dispute.

At this juncture, TDEC sees no benefit in Department of Energy (DOE) submitting a proposed plan for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) waste disposal prior to agreement of FFA parties on the associated issues. Given that remedial operations at ORR will continue into the foreseeable future, TDEC recommends DOE increase its waste minimization and segregation efforts in order to conserve capacity at the existing CERCLA disposal facility, the Environmental Management Waste Management Facility (EMWMF).

## Summary of Concerns

1. Lack of consensus regarding which laws are applicable and/or relevant and appropriate (ARARs)
   Previously DOE has contended that TDEC 0400-20-11, *Licensing Requirements for Land Disposal of Radioactive Waste* were not ARARs. DOE's position has shifted to allow these rules as ARARs, with the exception of 0400-20-11-.17(1)(h), which states that the hydrologic

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unit used for disposal shall not discharge ground water to the surface within the disposal site. TDEC believes this rule is appropriate and should be an ARAR.

2. Site characteristics
The candidate sites being considered in this version of RI/FS require the use of an underdrain to suppress groundwater. Underdrains are engineered pathways for future release of hazardous substances, pollutants, and contaminants from the landfill. TDEC's position is that unless and until an acceptable evaluation is performed that demonstrates that an underdrain, releasing water and potentially leachate from under the EMDF, will be protective of human health and environment over the long-term, a design with an underdrain that would produce flowing water once the liner had been fully constructed is unacceptable.

As TDEC commented on 8/6/15, releases and future releases from all sources into Bear Creek Valley, including EMDF, EMWMF, and the Bear Creek Burial Grounds should be evaluated together for cumulative impact.

3. Weaknesses in the model used as the basis for assessment of risk and preliminary Waste Acceptance Criteria (PreWAC)
Although the risk assessment has been somewhat improved, the methodology has changed little through the various CERCLA documents that have been provided. The models remain too limited to predict accurate travel times for water or contaminants. It still includes just one scenario, three pathways, and addresses water resource protection ARARs for a finite time only – 1,000 years.

The draft whitepaper DOE presented concerning the Low-level Waste Disposal Facility Federal Review Group (LFRG) and RI/FS coordination allows the RI/FS to serve as the technical basis for the preliminary disposal authorization statement (DAS) in place of performance assessment and/or composite analysis. There remains a lack of consensus on model input parameters in the RI/FS, some of which affect timing and magnitude of release. It is TDEC's position that DOE perform performance assessment and composite analysis pursuant to DOE orders without influence from the RI/FS. Therefore, TDEC's position remains that an approved preliminary DAS is needed prior to RI/FS approval.

Given the importance of waste acceptance limits to protect human health and the environment, there remains a need to address outstanding programmatic issues with WAC attainment. For example, the WAC should be easy to audit; and responsible parties for WAC attainment and operation of the landfill should be independent from the demolition contractor.

4. PreWAC limits call cost justification into question
It appears that the proposed EMDF PreWAC limits for uranium (52 mg/kg) and technetium 99 (45 pCi/g) may be protective of human health and the environment. However the majority of waste currently disposed in EMWMF would not be accepted at EMDF, given

those limits. This calls into question the volume of waste that can be accepted for disposal at EMDF; and subsequently the cost justification for a project of this magnitude.

5. Mercury
   TDEC continues to have concerns regarding mercury disposal in the proposed landfill. Since mercury does not degrade over time and bio-accumulates in aquatic species, it presents a long term hazard. TDEC expects a full evaluation of mercury treatment and disposal options with the FFA parties before mercury waste is introduced to EMDF.

6. CERCLA Risk Range and ARARs for CERCLA waste in the EMDF.
   The RI/FS recognizes ARARs for the 1000 year compliance period and the CERCLA carcinogenic risk range for constituents that are modeled in the RI/FS to peak within 2000 years. It is TDEC's position that the CERCLA carcinogenic risk range, CERCLA protection for non-carcinogenic health threats, CERCLA protection of the environment, and ARARs apply for as long as CERCLA waste remains onsite in the EMDF.

Questions or comments regarding the contents of this letter should be directed to Howard Crabtree at the above address or by phone at (865) 220-6571.

Sincerely

Randy C Young

Randy Young
FFA Manager

Enclosure

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**Tennessee Department of Environment and Conservation Comments on: *Remedial Investigation/Feasibility Study for Comprehensive Environmental Response, Compensation, and Liability Act Oak Ridge Reservation Waste Disposal Oak Ridge, Tennessee Operations Plan, Oak Ridge, Tennessee* (DOE/OR/01-2535&D4)**

**Background**

In *Remedial Investigation/Feasibility Study* [RI/FS] *for Comprehensive Environmental Response, Compensation, and Liability Act* [CERCLA] *Oak Ridge Reservation* [ORR] *Waste Disposal, Oak Ridge, Tennessee* (DOE/OR/01-2535&D1), the Department of Energy (DOE) proposed a second on-site waste disposal facility for the disposal of CERCLA waste on the ORR. As proposed, the Environmental Management Disposal Facility (EMDF) would primarily be a Low Level Radioactive Waste (LLRW) Disposal Facility, but also authorized under CERCLA to dispose of hazardous and chemical wastes regulated under the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA). The Tennessee Department of Environment and Conservation (TDEC) and the U.S. Environmental Protection Agency (EPA) submitted comments on the D1 RI/FS in early 2013 that were not resolved in the D2 revision and that document was elevated to informal dispute. By agreement of parties to the Federal Facility Agreement (FFA), a D3 RI/FS (to be treated as D2) was to be submitted by DOE addressing associated issues.

TDEC received the D3 RI/FS on April 2, 2015. However, major issues identified in comments on the previous versions of the document and discussed in subsequent technical sessions remained unresolved. Contrary to the previous versions of the RI/FS, DOE took the position in the D3 RI/FS that state regulations governing the disposal of LLRW (TDEC 0400-20-11) were not relevant and appropriate to the disposal of DOE radioactive wastes; therefore, the state rules should not be considered Applicable or Relevant and Appropriate Requirements (ARARs) for the proposed facility. It was also DOE's position that DOE Orders regulating LLRW should not be cited as requirements or to be considered guidance (TBC) in Records of Decision and other CERCLA agreements. As a consequence, TDEC rules regulating LLRW were removed as ARARS from the D3 RI/FS, as were DOE Orders listed as TBC. DOE also proposed that TDEC and EPA waive provisions of 40 CFR 268 to allow treatment of mercury contaminated demolition debris within the EMDF disposal cells.

TDEC comments on the D3 RI/FS were submitted to DOE on August 6, 2015. The D4 revision of the document was received by TDEC March 17, 2016 and TDEC comments on the document submitted to DOE on 05/16/2016.

**General Comments**

1. The D4 version of the RI/FS was significantly modified from the D3 version in response to regulatory concerns. The changes provide partial resolution to several issues that have prevented TDEC approval of previous drafts. The inclusion of additional ARARs, particularly those specific to radioactive waste management, has strengthened the legal foundation for

authorization of the disposal facility. Additional alternatives were added, including disposal facilities at on-site locations thought to potentially be more compatible with State of Tennessee criteria for siting radioactive waste disposal facilities. An alternative that incorporated more aggressive volume reduction strategies and more off-site disposal was evaluated.

Changes to risk assessment methodology were relatively few but had significant consequences for certain important contaminants of concern. The establishment of waste acceptance limits at any on-site disposal facility that would be protective of water resources has been a consistent and significant regulatory concern. While the risk assessment methodology may still not properly address contaminants of concern for which travel time to the receiving stream or aquifer is critical to the risk evaluations, the risk assessment for contaminants that will be limited predominantly by release mechanisms at the source and dilution in the receiving waters has been significantly strengthened. The waste acceptance limits that would be imposed by the PreWAC given on page 77 and on pages 81-83 of Appendix H for relatively mobile contaminants that are assumed to undergo little radioactive decay or reaction throughout the compliance period are arguably within a range that would protect water resources.

2. The last paragraph of page ES-4 of the D4 version of the RI/FS states "Based on these results, it can be concluded that most future CERCLA waste to be generated after EMWMF reaches maximum capacity would be able to be disposed at the proposed EMDF." This conclusion is repeated in slightly different but equivalent form throughout the document, including on page 1-8, in section 2.1.3 on page 2-5, in section 2.3, and in Appendix H. However, there is little evidence to back up this assertion in the document.

   To the extent that time and resources have been available, TDEC has been able to verify that PreWAC limits for uranium and technetium presented in this RI/FS may fall within a reasonable range of waste acceptance limits that should protect health and environment from risks generated by a 2.2 million cubic yard radioactive waste disposal facility sited in Bear Creek Valley. Based on our current knowledge of contamination levels in future CERCLA waste, the limits suggested by the PreWAC would also preclude much of the projected CERCLA waste from the on-site disposal facility. At EMWMF, waste acceptance has been largely controlled by the levels of uranium and technetium isotopes in the waste. The majority of the waste disposed at EMWMF could not have been accepted under limits similar to those proposed in this PreWAC, 52 mg/kg for uranium and 45 pCi/g for technetium 99.

   If the claim that the PreWAC demonstrates that majority of CERCLA generated waste can be disposed safely on-site should prove valid, then it follows that much of the CERCLA waste could also meet disposal limits established for the permitted Y-12 landfill or other permitted solid waste disposal facilities. This can be inferred from a comparison between the waste acceptance limits at the Y-12 permitted landfill and the PreWAC for the proposed facility.

The limits imposed on any waste contaminated with depleted uranium (U 234 and U235 below the naturally occurring isotopic abundance) would be more stringent at the proposed facility than at the Y-12 landfill. The technetium 99 limit at the Y-12 landfill is only 5 pico-Curies per gram higher at the proposed facility than at the Y-12 landfill. Much of the projected waste from Y-12, including debris from buildings in the West End Mercury Area, is likely to be contaminated with depleted uranium. Birchfield and Albrecht (2012) report uranium concentrations at the 90 percent upper confidence level for Alpha 5 building structure at approximately 500 mg/kg, an order of magnitude greater than the PreWAC for uranium.

As stated on page G-12 (Appendix G, 4.1.1) of the RI/FS, PCB wastes with a PCB concentration greater than 50 ppm are not anticipated to contribute significantly to the quantity of CERCLA waste generated on the Oak Ridge Reservation. Page 2-4 states that RCRA F listed waste will not be disposed in the proposed CERCLA landfill, and characteristic waste must comply with the treatment standards of 40 CFR 268. Most RCRA and TSCA mixed waste, as well as low level radioactive waste which could be disposed in a future CERCLA disposal facility with PreWAC limits similar to those given in Appendix H, could be disposed in the ORR landfills.

This significant inconsistency between the numbers generated by risk assessment and the conclusions in the text effectively invalidates any cost comparison between the various alternatives set forth in the document. The limits on uranium and technetium, which generally match TDEC's attempts thus far to assess risks imposed by on-site disposal, show that rather severe limitations on waste acceptance will be necessary to ensure protection of human health and the environment at a radioactive waste disposal facility of this size and at these locations. Despite significant changes that address a number of regulator concerns, the D4 version of this document still fails to provide a sufficiently thorough risk assessment and enough additional information on candidate waste streams to form the basis for an informed decision concerning the value added by the proposed disposal facility to the overall remediation goals for the Oak Ridge Reservation.

**3.** CERCLA Section 121(d)(1) requires that *"Remedial actions selected under this section or otherwise required or agreed to by the President under this Act shall attain a degree of cleanup of hazardous substances, pollutants, and contaminants released into the environment and control of further release at a minimum which assures protection of human health and the environment. Such remedial actions shall be relevant and appropriate under the circumstances presented by the release or threatened release of such substance, pollutant, or contaminant."*

TDEC D3 RI/FS comment TDEC.S.099 in the *CERCLA D3 RI/FS Comment and Response Summary* identified concerns with risk posed from an underdrain. TDEC's comment stated that the proposed EBCV site underdrains, like the underdrain at the EMWMF, would presumably be able to supply several gallons per minute of water continuously even during drought conditions, and might be a usable water supply even when individual wells were dry. The D4

RI/FS did not identify the underdrain as a potential exposure pathway in either Appendix H Section 2.2 *Conceptual Model and Exposure Pathways* or Section 2.3 *Hypothetical Receptor*. Further, potential risk posed by an underdrain was neither quantified in the D4 RI/FS nor used in PreWAC development.

Underdrains are engineered pathways for future release of hazardous substances, pollutants, and contaminants from the landfill. Over time, the underdrains would contain constituents released from the landfill directly overlying the underdrain, as well as from other areas of the landfill where constituents are released to groundwater and the contaminated groundwater subsequently discharges to an underdrain.

**Page 7-51** of the RI/FS also states that while underdrain networks are necessary and effective in isolating wastes from the underlying saturated zone, they do provide avenues for localized and relatively rapid transport of contaminants in groundwater that could be released below the footprint and discharge at underdrain outfall locations. Figure H-16 shows the underdrain may have concentrations in the range of 0.1 to 0.9 of the leaching source in areas where underdrains may discharge to surface near the edge of the landfill. Once again, an underdrain that would presumably be able to supply several gallons per minute of water continuously even during drought conditions might be a usable water supply. Further, with the low flow in Bear Creek in the vicinity of the EBCV site, it is conceivable that a future farmer could impound flow from an underdrain to develop a farm pond for livestock watering or irrigation. Fish are common in farm ponds and risk from consuming fish from an underdrain fed farm pond was not evaluated.

Underdrains provide a direct conduit to surface water with potentially minimal sorption or other attenuation of constituents. Bear Creek is classified for recreational use, and impact on surface water resources including consumption of fish from Bear Creek was not evaluated.

These exposure pathways associated with a flowing underdrain should be added to the maximally exposed individual (MEI) evaluation to verify whether a site with a flowing underdrain meets the CERCLA Section 121(d)(1) threshold requirement for control of further release at a minimum which assures protection of human health and the environment. Further, these exposure pathways should be added to waste acceptance criteria (WAC) development to assure future waste disposed does not pose an unacceptable risk due to a flowing underdrain.

TDEC's position is that unless and until an acceptable evaluation is performed that demonstrates that an underdrain, releasing water and potentially leachate from under the EMDF, will be protective of human health and environment over the long-term, a design with an underdrain that would produce flowing water once the liner had been fully constructed is unacceptable.

4. TDEC believes that compliance with siting criteria and developing a WAC protective of human health and environment are necessary for long term protection of human health and the environment.

 <u>Page 7-19, Section 7.2.2.3</u> **Long-term Effectiveness and Permanence (On-site), Engineering and Institutional Controls, second paragraph** states the leachate collection system and removal system above the primary liner and the leak detection and removal system below the primary liner would be effective for the period of active institutional controls. The period of active institutional controls is not known, but is assumed for design purposes to extend for at least 100 years. Subsequently, the final cover system, secondary liner, and geologic buffer would provide long-term control of leachate release since these engineered features would last minimally for 500 years.

 <u>Page 7-31</u> **Cost** discusses a "Perpetual Care Trust Fund" and states said fund is intended to cover certain costs for 1,000 years following closure of the landfill.

 <u>Page 7-51, Section 7.3.3</u> states "Off-site disposal of waste at Energy Solutions, WCS, and NNSS in the long-term may be more reliable at preventing exposure than on-site disposal at the ORR, as they are located in arid environments that reduce the likelihood of contaminant migration or exposure via groundwater or surface water pathways. Fewer receptors exist in the vicinity of Energy Solutions, WCS, and NNSS than on the ORR." <u>Page 7-51</u> **also states that while underdrain networks are necessary and effective in isolating wastes from the underlying saturated zone, they do provide avenues for localized and relatively rapid transport of contaminants in groundwater that could be released below the footprint and discharge at underdrain outfall locations.**

 <u>Page 7-52</u> states that "The extent of the underdrain networks vary among the proposed sites. Assuming some degree of greater mobility is associated with the areal extent of the underdrain, the Hybrid Site 6 has the least underdrain network area (27,000 $ft^2$) and the EBCV Site has the most area (297,000 $ft^2$) with the Dual Site 7a/6b Option (132,000 $ft^2$) and the WBCV Site (259,000 $ft^2$) of intermediate area." Page 7-52 goes on to state that "while the cover system remains in place, migration of contaminants into groundwater and surface water is the only credible pathway of exposure," implying uncertainty as to whether and how long the cover system will remain in place.

5. TDEC does not agree that the risk assessment presented in Appendix H provides reasonable assurance that the proposed facility will be protective of human health and the environment, a threshold criterion for actions authorized under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The risk assessment in this RI/FS is based on the same general approach and the same set of software packages used for modeling risk at the EMWMF nearly two decades ago. TDEC has made numerous comments, both written and verbal, expressing both lack of confidence in the approach to

risk assessment and concerns with the applicability of the models over the past five years. However, the methodology has changed little through the various documents that have been written to initiate the process to authorize a new disposal facility for radioactive, hazardous and toxic waste.

As DOE has not suitably addressed these comments, some of which were first given informally to DOE in 2012 after the submission of the Focused Feasibility Study for Comprehensive Environmental Response, Compensation, and Liability Act Oak Ridge Reservation Waste Disposal, Oak Ridge, Tennessee (DOE/OR/01-2535&D0), it will be incumbent upon TDEC to ensure that independent verification of the risk assessment is performed and to confirm that CERCLA waste can be compliantly and cost effectively disposed on the Oak Ridge Reservation. Whether this is carried out by a group chosen by the FFA parties, an independent contractor answering directly to TDEC, or TDEC staff, this will require independent re-calculation of the PreWAC using a substantially different approach to that used in this and in the previous versions of this RI/FS.

Proper verification of the risk assessment will require that sufficient scenarios and pathways be evaluated to substantiate that the threshold criteria of CERCLA can be met while allowing acceptance of sufficient candidate waste to render the proposed facility viable. Some of the additional scenarios and exposure pathways that should be considered, at least at the screening level, include:

- Ecological and recreational risks in Bear Creek due to bioaccumulative hazardous substances, including radionuclides
- Radon flux through the facility cap to demonstrate compliance with 40 CFR 61.192, listed as an applicable requirement in Appendix G
- Air dispersion modeling to demonstrate compliance with 40 CFR 61.92, listed as an applicable requirement in Appendix G
- Direct exposure pathways

For exposure pathways where multiple sources may impact a receptor, such as radionuclide emissions to ambient air or recreational use of Bear Creek below BCK 9.2, cumulative risk from EMWMF and any proposed disposal facility should be evaluated.

A resident farmer scenario similar to that reported in this RI/FS, along with the remedial action objectives that require compliance with maximum contaminant limits (MCLs) in groundwater and ambient water quality criteria (AWQC) in surface water, could be used to ensure protection of water resources. However, other methods would need to be used to predict many key components of contaminant fate and transport. The software used in this RI/FS, with reasonable assumptions for key parameters, might yield a credible hydrologic balance, including estimates of release rates from the proposed facility and dilution factors in groundwater and in Bear Creek. Unfortunately, the models are too limited to predict accurate travel times for water or contaminants.

The HELP model cannot account for the effect of a sloping landfill base, which will lead to ponding and a distribution of travel times through even a uniform liner. The flow field through the liner would not be uniform even if the water pooled above it were of uniform depth, since flow through the geomembrane is controlled by orifice flow through discrete holes or tears, usually with an equivalent radius not greater than a few millimeters (Rowe, 2012). Several studies, including that of Giroud and Bonaparte (1989), showed that the greatest hydraulic resistance to leakage through composite liners is generally at the interface between the geomembrane and underlying clay liner. Until the geomembrane deteriorates considerably, which, as noted in the RI/FS, may take decades or even centuries, leakage rates depend primarily on such unpredictable variables as the care taken to prevent holes and wrinkles during installation of the barrier (Rowe, 2012).

As TDEC has expressed on numerous occasions, deterministic prediction of contaminant travel times in fractured media on the ORR, such as the bedrock in Bear Creek Valley, and, to a lesser extent, the saprolite and weathered residuum, does not seem viable. Tracing results in the bedrock and residuum of the Conasauga group yield travel times that are highly variable and clearly dependent on the specific location and design of the test (c.f. Spalding, 1987). A realistic prediction of travel times for contaminants is probably not feasible, and estimating travel times using consistently conservative assumptions may limit waste acceptance unnecessarily, perhaps to the point of indicating that the facility is not cost effective. It would seem that a stochastic approach to contaminant fate and transport prediction might provide a better basis for risk assessment.

6. As stated in General Comment 2, Uranium risk-based PreWAC values may be limiting factors as to what may be placed in a future EMDF. Please see the table below.

| Isotope | Non-carcinogenic Table H-12 (Page H-81) HI=3 (mg/kg) | Carcinogenic Calculated $10^{-4}$ ELCR (pCi/g) |
|---|---|---|
| U-233 | 60.5 | 57 |
| U-234 | 57.6 | 55.1 |
| U-235 | 52.2 | 50.7 |
| U-236 | 52.3 | 53.1 |
| U-238 | 52.2 | 55.2 |

PreWAC carcinogenic limits for Uranium-238 calculated using the risk-based approach included in the D4 RI/FS and a $10^{-4}$ ELCR will be on the order of 50 to 60 pCi/g. Table H-12 includes a non-carcinogenic PreWAC for uranium-238 of 52.2 mg/kg. The amount of future waste that meets uranium risk-based PreWAC limits should be evaluated to refine estimates of additional onsite landfill capacity needed. Risk based limits used for this evaluation must be consistent with CERCLA required carcinogenic risk range (i.e. $10^{-4}$ to $10^{-6}$) and non-carcinogenic (e.g. HI of 1 to 3) risk.

7. The waste volume estimates in Chapter 2 and Appendix A include both wastes that may be suitable for disposal at the Y-12 industrial and construction and demolition landfills (ORR landfills), as discussed on pages 1 and 2 of Chapter 6, and an added 25 percent of the projected waste volume to account for uncertainty. Inclusion of landfill waste into the overall waste inventory inflates the quantity of waste requiring disposal in a CERCLA facility by an undetermined amount, as well as the differential cost between the on-site and off-site alternatives. The U.S. Department of Energy Office of Inspector General performed an audit in 2013 that identified 140,000 cubic yards of material disposed in EMWMF that could have been disposed at the ORR landfills.

   Based on the candidate waste streams listed in Appendix A, TDEC might expect between 25 and 40 percent of the waste to be acceptable at the ORR landfills, depending on the level of waste segregation used. No characterization data is available to better define this range, which we acknowledge to be not much better than a guess. An effort to better estimate the probable quantity of waste suitable for disposal in the ORR landfills should have been made, identified separately in Appendix A, and subtracted from the total volume needed for disposal of waste in a CERCLA landfill.

   In the past, DOE has indicated that radioactive waste disposal under the authority of the Atomic Energy Act as implemented by DOE Orders was impractical due to the anticipated quantities of mixed low level radioactive and TSCA or RCRA waste. As stated elsewhere in these comments, the D4 version of the RI/FS states that DOE has no plans to dispose of significant quantities of either TSCA waste (> 50 ppm PCBs) or hazardous waste that exhibits a prohibited characteristic at the point of land disposal. In this case, additional on-site disposal alternatives might include disposal under DOE authority rather than through CERCLA. Also, since risk assessment of on-site disposal in the D4 indicates that some key contaminants of concern may have waste acceptance limits similar to those on the ORR landfill, an expansion of current permitted solid waste disposal capacity might prove to be just as feasible as disposal authorized under CERCLA.

8. The Remedial Action Objectives (RAOs) on page 4-1 and *goals* used to determine PreWAC concentrations on page 4-2 are inconsistent. RAOs on page 4-1 appear applicable as long as CERCLA waste is managed, disposed or entombed at the landfill and do not include a time limit. However, page 4-2 *goals* include a 1,000 year compliance period. Additional discussion of water resource protection on page H-75 references the goal language, not the RAOs, and implies that water resource protection is only accomplished within the 1,000 year compliance period. Similarly, the response to TDEC comment TDEC.S.100 references protection of water resources and ecological receptors within the 1,000 year compliance period, implying that protection of water quality and the environment after 1,000 years is not necessary. TDEC reads the RAOs on page 4-1 to include protection of water resources as long as CERCLA waste is in the landfill, a time period which presumably extends beyond 1,000 years. Remedial Action Objectives need to be consistent and consistently applied.

9. Disregarding the Remedial Action Objectives, the risk methodology specified in the RI/FS, and the CERCLA $10^{-4}$ to $10^{-6}$ risk range in proposing carcinogenic PreWAC limits for radionuclides is unacceptable.

The Remedial Action Objectives (RAOs) specify:

**Page 4-1:** *"1. Prevent exposure of human receptors to CERCLA waste (or contaminants released from the waste into the environment) that exceeds a human health risk of $10^{-4}$ to $10^{-6}$ Excess Lifetime Cancer Risk (ELCR) or hazard index of 1."*

**Page 4-2:** *"These PreWAC waste concentration limits are determined based on demonstrating the following goals are met during the 1,000 year compliance period:$10^{-5}$ ELCR and HI of 1 ... for the compliance period (to 1,000 years) using a resident farmer scenario, and $10^{-4}$ ELCR and HI of 3 at times exceeding 1,000 year compliance period."*

However, on **Page H-75:** *"A ratio is set up to scale this assumed concentration and corresponding risk to the appropriate carcinogenic risk goal (set as $10^{-5}$ for contaminants that peak <1,000 years post closure, and as $10^{-4}$ for those COPCs predicted to peak between 1,000 and 2,000 years, see Table H-1), which allows calculation of the PreWAC limit for each radionuclide COPC. For radioisotopes predicted to peak after 2,000-years post closure, preliminary administrative limits based on modeling exposures at 100 m have been assigned..."*

The methodology to assign PreWAC limits in the D4 RI/FS is a significant change from the D3 version. The D3 version calculated the PreWAC for carcinogenic radionuclides based on formulas in the RI/FS for all constituents that peak after 1,000 years utilizing a $10^{-4}$ ELCR, similar to the approach the D4 utilizes for the time period 1,000 to 2,000 after closure. The D4 RI/FS disregards Remedial Action Objectives and the CERCLA $10^{-4}$ to $10^{-6}$ risk range for constituents that, according to the D4 RI/FS, peak after 2,000 years. There are no analyses that demonstrate risk is within the CERCLA risk range where preliminary administrative limits are assigned for constituents that peak after 2,000 years.

For example, using the equations and approach specified in the D4 RI/FS, a carcinogenic PreWAC on the order of 55 pCi/g may be calculated for U-238 utilizing a $10^{-4}$ ELCR. The D4 RI/FS includes 3,170 (3.17E+03) pCi/g as the carcinogenic PreWAC limit for U-238 in Table H-10 (not an Adjusted PreWAC). Table H-10 includes no reference to preliminary administrative limits. A value of 3,170 pCi/g equates to about a 5.75E-03 (5.75 per thousand) ELCR. PreWAC limits for only four carcinogenic radionuclides (i.e. C 14, Cl-36, H-3, and Tc-99), highlighted in bold in the table below, were determined by the risk-based methodology specified in the D4 RI/FS. PreWAC limits for the remaining 28 carcinogenic radionuclides (i.e. Am-241, Am-243, Cf-249, Cf-251, Cm-245, Cm-246, Cm-247, Cm-248, I-129, K-40, Nb-94, Ni-59, Np-237, Pa-231, Pu-239, Pu-240, Pu-242, Pu-244, Re-187, Se-79, Si-32, Sn-126, U-233, U-234, U-235, U-236, U-238, and Zr-93) are presumably set using preliminary administrative limits. The process and rationale for modifying each carcinogenic radionuclide PreWAC with the administrative limit is not transparent and is not discussed in Appendix H. Risks for these 28 radionuclide PreWAC limits (modified by the administrative limits) range from approximately 2.6E-02 (2.6 per hundred) to 9.8E-04 (9.8 per ten thousand) ELCR, based on the limited resident farmer scenario.

The table below estimates risk-based PreWAC concentrations for radionuclide carcinogenic risk and compares the risk numbers to the D4 RI/FS PreWAC Table H-10 and Table H-13 limits. The calculated ELCR for the D4 Proposed EMDF PreWAC limits are also included.

**Table 1**

| Radionuclide | Appendix H, Attachment B, Table 1: $PR_{eff}$ | Target Risk Level using D4 proposed methodology | Calculated PreWAC (pCi/g) Based on Target Risk Level | Proposed Carcinogenic EMDF PreWAC Table H-13 (page H-91) | Calculated ELCR of D4 Proposed EMDF Carcinogenic PreWAC Limit |
|---|---|---|---|---|---|
| Am-241 | 9.031E-13 | 1.00E-04 | 6.92E+13 | 1.46E+15 | 2.11E-03 |
| Am-243 | 2.777E-01 | 1.00E-04 | 2.25E+02 | 4.74E+03 | 2.11E-03 |
| **C-14** | **9.068E-01** | **1.00E-04** | **6.89E+01** | **6.89E+01** | **1.00E-04** |
| Cf-249 | 2.774E-15 | 1.00E-04 | 2.25E+16 | 3.30E+17 | 1.46E-03 |
| Cf-251 | 1.281E-06 | 1.00E-04 | 4.88E+07 | 7.21E+08 | 1.48E-03 |
| **Cl-36** | **1.793E+00** | **1.00E-05** | **3.49E+00** | **3.49E+00** | **1.00E-05** |
| Cm-245 | 3.641E-01 | 1.00E-04 | 1.72E+02 | 3.48E+03 | 2.03E-03 |
| Cm-246 | 9.401E-02 | 1.00E-04 | 6.65E+02 | 1.32E+04 | 1.99E-03 |
| Cm-247 | 2.194E+00 | 1.00E-04 | 2.85E+01 | 6.05E+02 | 2.12E-03 |
| Cm-248 | 9.479E+00 | 1.00E-04 | 6.59E+00 | 1.58E+02 | 2.40E-03 |
| **H-3** | **1.643E-19** | **1.00E-05** | **3.80E+19** | **3.80E+19** | **1.00E-05** |
| I-129 | 3.173E+01 | 1.00E-04 | 1.97E+00 | 1.10E+02 | 5.58E-03 |
| K-40 | 7.358E-01 | 1.00E-04 | 8.49E+01 | 1.37E+04 | 1.61E-02 |
| Nb-94 | 1.013E-02 | 1.00E-04 | 6.17E+03 | 1.14E+06 | 1.85E-02 |
| Ni-59 | 1.490E-08 | 1.00E-04 | 4.19E+09 | 7.34E+11 | 1.75E-02 |
| Np-237 | 1.361E+00 | 1.00E-04 | 4.59E+01 | 1.05E+03 | 2.29E-03 |
| Pa-231 | 4.670E-03 | 1.00E-04 | 1.34E+04 | 1.31E+05 | 9.79E-04 |
| Pu-239 | 1.476E+00 | 1.00E-04 | 4.23E+01 | 9.27E+02 | 2.19E-03 |
| Pu-240 | 2.809E-01 | 1.00E-04 | 2.22E+02 | 4.87E+03 | 2.19E-03 |
| Pu-242 | 2.682E+00 | 1.00E-04 | 2.33E+01 | 5.04E+02 | 2.16E-03 |
| Pu-244 | 3.179E+00 | 1.00E-04 | 1.97E+01 | 4.78E+02 | 2.43E-03 |
| Re-187 | 1.910E-03 | 1.00E-04 | 3.27E+04 | 8.61E+06 | 2.63E-02 |

| Table 1. Continued | | | | | |
|---|---|---|---|---|---|
| Radionuclide | Appendix H, Attachment B, Table 1: $PR_{eff}$ | Target Risk Level using D4 proposed methodology | Calculated PreWAC (pCi/g) Based on Target Risk Level | Proposed Carcinogenic EMDF PreWAC Table H-13 (page H-91) | Calculated ELCR of D4 Proposed EMDF Carcinogenic PreWAC Limit |
| Se-79 | 3.384E-03 | 1.00E-04 | 1.85E+04 | 1.79E+06 | 9.69E-03 |
| Si-32 | 6.108E-11 | 1.00E-04 | 1.02E+12 | 2.64E+14 | 2.58E-02 |
| Sn-126 | 1.483E-01 | 1.00E-04 | 4.21E+02 | 9.37E+04 | 2.22E-02 |
| **Tc-99** | **1.370E+00** | **1.00E-04** | **4.56E+01** | **4.56E+01** | **1.00E-04** |
| U-233 | 1.096E+00 | 1.00E-04 | 5.70E+01 | 3.25E+03 | 5.70E-03 |
| U-234 | 1.134E+00 | 1.00E-04 | 5.51E+01 | 3.23E+03 | 5.86E-03 |
| U-235 | 1.232E+00 | 1.00E-04 | 5.07E+01 | 3.04E+03 | 5.99E-03 |
| U-236 | 1.177E+00 | 1.00E-04 | 5.31E+01 | 3.05E+03 | 5.74E-03 |
| U-238 | 1.133E+00 | 1.00E-04 | 5.52E+01 | 3.17E+03 | 5.75E-03 |
| Zr-93 | 1.879E-02 | 1.00E-04 | 3.33E+03 | 1.32E+05 | 3.97E-03 |

**10.** During Site Management Team (SMT) discussions between the D3 RI/FS and D4 RI/FS, DOE stated that all sites being considered for the possible waste management facility required underdrains. TDEC suggested that DOE evaluate the extent of underdrain(s) needed for each site and whether any site may require only "minimal underdrains." TDEC offered that "minimal underdrain" refers to siting and constructing a landfill facility over small spring(s) or seep(s) that will dry up, due to capping or cutting off the recharge area, so that the resulting facility will not require a continually functioning underdrain once the facility is constructed. It is believed that a minimal underdrain poses a significantly reduced threat compared to an extensive or flowing underdrain.

Both the East Bear Creek Valley (EBCV) site and the West Bear Creek Valley (WBCV) site have groundwater fed creeks flowing through the proposed landfill sites that will require extensive underdrains to convey the water from under proposed future landfills. The D4 RI/FS states (page 6-40) that the EBCV site requires an extensive underdrain system (Figure 6-12). Page 6-41 states that the individual pieces of the WBCV site underdrain system are similar to the EBCV option because the natural drainage ways extend across most of the WBCV site, but fewer areas of underdrain appear to be required than at the EBCV site. The RI/FS also states (page 6-41) that the conceptual underdrain proposed for Site 7a in the Dual Site Option is similar to that for the WBCV site (Figure 6 15).

Based on TDEC review of the RI/FS, Site 6b has the smallest underdrain system and is likely to require only minimal underdrains. The D4 RI/FS (page 6-41) states "Site 6b was selected as the onsite location for the Hybrid Alternative based on a conceptual design that requires the least expansive underdrain system. It is likely that these seeps would not produce any water once the liner had been fully constructed for this site. The locations would no longer have available recharge." (Figure 6-14).

11. TDEC personnel walked the periphery of sites 7a and 7b to evaluate the need for underdrains and potential for minimal underdrains. Based on TDEC observations, it appears possible that either site 7a, 7b, or both sites 7a and 7b may be configured without extensive underdrains. This would require changing the Site 7a conceptual design to avoid the underdrain. Suitability of sites 7a and 7b would need to be verified by site-specific hydrogeologic assessment. We agree with the D4 RI/FS text on page E-181 that states *"new site specific hydrogeological and geotechnical data will be required to establish key relationships between the base cell elevations and the underlying water table and bedrock configuration, as well as other data required for detailed design, modeling, etc."*

12. Calculations for the PreWAC values require clarification and verification. For example, the equation for calculating the peak creek dose (PD'eff) for non-carcinogenic constituents is given on page H-66. Multiple DFcreek and DFwell values are given on pages H-58 and H-64 and it is unclear which dilution factors are used for which calculations. Further, while trying to duplicate the non-carcinogenic PD'eff for uranium in Appendix H, Attachment B, Table 2 and the uranium Adjusted PreWAC in Tables H-12 and H-13, it appeared that a scaled dilution factor for DFcreek may have been used in the D4 RI/FS. This effort was further confused by the acrylonitrile example given on page H-80. The PD'eff for acrylonitrile referenced on page H-80 does not agree with the PD'eff for acrylonitrile in Attachment B, Table 2; utilizing the formula on page H-66 subsequently yielded a third PD'eff value for acrylonitrile. This may be dilution factor uncertainty again. Further, the acrylonitrile example on page H-80 specified dividing by the reference dose and instead of using the reference dose from Attachment A, Table 3-2, the value for the slope factor was used in the example.

13. <u>Page H-75 of the RI/FS specifies</u> "...water resource protection is accomplished within the 1,000 year compliance period as specified in the RAOs.......These PreWAC waste concentration limits are determined based on demonstrating the following goals are met during the *1,000 year compliance period*: Appropriate AWQC for chemicals (risk-based discharge levels for radionuclides in Bear Creek and tributary surface water are per the *Integrated Water Management Focused Feasibility Study* [UCOR, 2016].)" (*emphasis added*).

    TDEC comments to the *Integrated Water Management Focused Feasibility Study* (UCOR, 2016) are incorporated into these RI/FS comments by reference.

14. The conceptual site model assumes a surface water pathway where a future farmer utilizes surface water at BCK 11.54 for irrigating vegetation and watering livestock. In the D4 RI/FS modeling analysis, one input parameter required for PATHRAE is the river flow rate (the annual flow in Bear Creek). An annual flow of 736,000 cubic meters was input into the PATHRAE model in the D4 RI/FS to calculate the concentration of pollutants in surface water,

while an annual flow of 491,000 cubic meters was used in the D3 RI/FS. Use of a total annual flow rate appears to underestimate the risk.

Evaluating streamflow data for BCK 11.54, TDEC calculated average median flows for June 1 through November 30 and December 1 through May 31 as 155 L/minute and 1160 L/minute respectively. Converting median flow in L/minute to total flow in cubic meters yielded an average of 40,845 cubic meters for the period of June 1 through November 30 and 304,012 cubic meters from December 1 through May 31; this results in an average annual cumulative median flow on the order of 344,858 cubic meters.

Similarly, plotting BCK 11.54 on USGS StreamStats[1] shows BCK 11.54 has a drainage area of about 0.6 square miles. Evaluation of DOE flow data for BCK 11.54 shows that, over the five year period analyzed, 37% to 53% (average of 45%) of the total annual flow occurred over a 25 day period each year. The sensitivity analysis table on page H-71 shows there is a linear relationship between stream flow rate and peak concentration – if the flow is reduced in half, the calculated peak stream concentration doubles.

In conclusion, peak stream concentrations reported in the D4 RI/FS are low by about a factor of about 2. Doubling the peak steam concentration will double the peak effective risk for the carcinogenic pathway (see equations on page H-65 and H-66) and will double the peak effective dose for the non-carcinogenic pathway (see equations on page H-66.)

**15.** Utilizing $C'_{Creek}$ calculated from PATHRAE and the annual river flow rate input into PATHRAE, the peak flux/load per year and peak average flux/load per day to Bear Creek can be calculated. This flux may be used to evaluate EBCV site impact on capture and subsequent consumption of fish downstream of BCK 11.54. For example, utilizing assumptions in PATHRAE for U-238, including a basis of 1 kg/m$^3$ in the waste, PATHRAE yields a peak concentration in Bear Creek of 5.97E-2 mg/L. Utilizing an annual flow of 7.36E+5 m$^3$/yr, an annual peak load/flux of 4.39E+7 (43,900,000) mg/yr or 1.2E+5 (120,000) mg/day or 83.6 mg/min can be calculated. For U-238 with a specific activity of 3.36E-7, 83.6 mg/min equates to about 28,089 pCi/min. Adding this flux/load to calculated flux provided in TDEC comments on the *Integrated Water Management Focused Feasibility Study* (UCOR, 2016) shows concentrations exceed recreational use calculated risk standards based on capture and consumption of fish in Bear Creek at BCK9.2 without additional future release from EMWMF. (It is assumed that by the time EMDF is releasing constituents to Bear Creek, EMWMF will also be releasing constituents to Bear Creek.) This analysis should be redone using the PreWAC concentrations to evaluate loading/flux resulting from the landfill and whether the landfill WAC would potentially impact downstream water resources.

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[1] USGS StreamStats is found at http://streamstatsags.cr.usgs.gov/v3_beta/viewer.htm?stabbr=TN.

16. PreWAC development for constituents that peak after 200 years after maintenance of a dense fescue groundcover is discontinued or 4,000 years in the future, whichever is earlier, should be recalculated using infiltration rates consistent with a cover where the four foot vegetation layer and sand from the underlying one foot sand/gravel layer have been totally removed by erosion, evapotranspiration is negligible, and the amended clay layer and underlying compacted clay layer are compromised.

    TDEC utilized the Revised Universal Soil Loss Equation 2 (RUSLE2) to evaluate soil loss on the East Bear Creek Valley (EBCV) Site. Soil loss may be used to estimate future erosion in tons per acre of the engineered cover. Erosion of the cover affects infiltration through the cover and performance of remaining cover components. The model was run utilizing 5% slope for the first 100 feet, and 25% slope for the next 635 feet for a total of 735 feet with grade channels at 265 feet, 475 feet and 735 feet.

    Management of activities and vegetation on the cover and erosion of the cover are important considerations in long term effectiveness of the cover. Page H-24 discusses the importance of the upper part of the cover to support root systems for evapotranspiration, drain away water to remove chances of deeper root penetration, create a barrier for deep root development, prevent long term erosion and protect the underlying clay barrier from degrading effects of desiccation and the freeze thaw cycle.

    RUSLE2 modeling indicated that maintaining a dense fescue grass cover is needed to prevent substantial erosion of the portion of the cover with the 25% slope. It was estimated that within 200 years after maintenance of a dense fescue groundcover is discontinued or 4,000 years in the future, whichever is earlier, the four feet thick vegetative cover and sand from the underlying one foot sand/gravel layer could be removed through erosion.

    This increased infiltration will significantly change leachate volume, leachate concentrations, peak concentrations in surface water, groundwater well dilution rates and other factors. Summary of PATHRAE Model sensitivity analyses in Table H-9 on page H-71 shows that if the infiltration rate increases by a factor of 3, the peak concentration in surface water will increase by a factor of three or higher and the time to reach the peak concentration decreases by a 40 to 65%. Similarly, if the infiltration rate increases by a factor of 8.2, the peak concentration in surface water increases by a factor of 8 to 10 or higher and the time to peak concentration decreases by 65 to 85%.

17. Bear Creek is classified for recreational use. Human health risk from the capture and consumption of fish living in water polluted by site constituents and decay products (such as Po-210) is needed. Polonium-210 (Po-210) is in the decay chain for U-238, is highly toxic, and bioaccumulates in fish.

18. <u>Page 7-17</u> states that "One siting requirement, TDEC 0400-20-11-.17(1)(h), has been determined to be relevant but not appropriate. See Appendix G Section 4.3 for a

discussion." TDEC disagrees and determined siting requirement TDEC 0400-20-11-.17(1)(h) is both relevant and appropriate.

TDEC 0400-20-11-.17(1)(h) states "The hydrogeologic unit used for disposal shall not discharge groundwater to the surface within the disposal site."

The discussion in Appendix G Section 4.3 on page G-17 and G-18 distinguishes between

> (1) "shallow land disposal" where packaged waste is placed in excavated trenches and the filled trenches are backfilled with soil, capped, and mounded to facilitate runoff and
>
> (2) an engineered disposal facility that incorporates an engineered earthen cover, liner system, and geologic buffer. Further the engineered disposal facility is built above existing grade and utilizes underdrains to mitigate the effects of shallow groundwater.

**Page G-18** states that "Based on this analysis, the siting requirements appear to regulate a structure/facility that is vastly different from the proposed EMDF....while it may be relevant in that it applies to LLW disposal, is not appropriate due to the differences in the types of facilities..."

Tennessee is an NRC state, and TDEC 0400-20-11-.17(1)(h) is identical to 10 CFR 61.50(a)(8) which states "The hydrogeologic unit used for disposal shall not discharge groundwater to the surface within the disposal site."

10 CFR 61.50(a) includes criteria for determining whether a disposal site is suitable for near surface disposal. As defined in 10 CFR 61.2:

> *Near-surface disposal facility* means a land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth's surface.
>
> *Land disposal facility* means the land, building, and structures, and equipment which are intended to be used for the disposal of radioactive wastes.

10 CFR 61.7 Concepts recognizes in (a)(2) that, for near surface disposal, the disposal unit is usually a trench. However, near surface disposal facility is not limited to disposal in trenches as 10 CFR 61.7 (a)(1) states "Part 61 is intended to apply to land disposal of radioactive waste and not to other methods such as sea or extraterrestrial disposal. Part 61 contains procedural requirements and performance objectives applicable to any method of land disposal. It contains specific technical requirements for near-surface disposal of radioactive waste, a subset of land disposal, which involves disposal in the uppermost portion of the earth, approximately 30 meters. **Near-surface disposal includes disposal in engineered**

**facilities which may be built totally or partially above-grade provided that such facilities have protective earthen covers.** Near-surface disposal does not include disposal facilities which are partially or fully above-grade with no protective earthen cover, which are referred to as 'above-ground disposal.'" (emphasis added)

TDEC further considered that EMDF is proposed for disposal of long half-life radionuclides, such as, Tc-99 (i.e. half-life 2.13E+5 years) and various uranium isotopes (U-234 with a half-life of 2.45E+05 years, U-235 with a half-life of 7.04E+08 years, U-236 with a half-life of 2.34E+07 years, and U-238 with a half-life of 4.47E+09 years) that will remain in the disposal facility long after engineering components fail.

To further clarify 10 CFR 61.50(a)(8) and the identical state requirement, TDEC evaluated NUREG-0902 which deals with Site Suitability, Selection and Characterization and gives background on the purpose for the siting requirement. It states this requirement should provide sufficient space within the buffer zone to implement remedial measures, if needed, to control releases of radionuclides before discharge to the ground surface or migration from the disposal site. It further states the staff prefers long flow paths from the disposal site to the point of groundwater discharge in order to increase the amount of decay of radionuclides, increase the hydrodynamic dispersion within the aquifer, and increase the likelihood of retardation of radionuclides in the aquifer.

TDEC rules are consistent with the NRC purpose for this requirement, as disposal means the *isolation of radioactive waste from the biosphere inhabited by man and containing his food chains* by emplacement in a land disposal facility (*emphasis added*).

Underdrains (either under or adjacent to the disposal area and that will not dry up due to covering the recharge area) discharge groundwater and any pollution to ground surface. Underdrains may further provide concentrated pathways for conveyance of pollution from under the disposal site to onsite ditches or conveyances to surface water. The effect of extensive or flowing underdrains conflicts with the purpose for this relevant and appropriate requirement. EBCV site (Site 5), WBCV site (Site 14), and Site 7a contain underdrains that conflict with the purpose of this requirement. The effect of this requirement on Sites 6b and 7b with anticipated flow along strike to natural tributaries is not determined.

19. <u>**Page 7-17**</u> states that the facility design would also incorporate TSCA requirements for a chemical landfill to accommodate waste containing PCBs at concentrations > 50 ppm. The discussion on page 7-17 further states that this will require waivers of two TSCA technical requirements. The first waiver is required for: "There shall be no hydraulic connection between the site and standing or flowing surface water...The bottom of the landfill liner system or natural in-place soil barrier shall be at least fifty feet from the historical high water table." It further states that Appendix G Chapter 4 provides evidence and rationale in the following three categories to support this waiver:

(a) PCB management and disposal practices on the ORR;
(b) Equivalent or superior effectiveness of site soils and engineered features on the EMDF; and
(c) Results of risk assessment and related fate and transport modeling for PCBs.

One basis for this waiver in Appendix G assumes PCBs will be disposed only in bulk waste at concentrations of < 50 ppm. It is unclear that justification for a waiver based on disposing bulk PCB waste with concentrations <50 ppm applies to granting a waiver for disposing PCB>50 ppm.

a. PCB management and disposal practices on the ORR discussion: PCB management and practices are described on pages G-12 and G-13. Third paragraph on G-13 states that as a result of these in-place procedures on the ORR, disposal of PCB waste in the existing EMWMF has been limited to bulk PCB waste disposal (<50 ppm), and has been confirmed in Waste Lot acceptance documents to date. It further states that it is expected that these procedures will continue in effect throughout operation of a future on-site disposal facility as well, thereby limiting all on-site disposal of PCB waste to <50 ppm.

b. Equivalent or superior effectiveness of site soils and engineered features on the EMDF: Discussion on pages G-13 and G-14 demonstrate that the liner system proposed for EMDF should be superior to TSCA liner requirements. On page G-14 it also states that "In conjunction with the limitations imposed on the quantities and volume of PCBs allowed for EMDF disposal, these features limit the possibility of PCB releases that would present an "unreasonable risk of injury to health or environment" (emphasis added). The EMDF also relies on an underdrain network to lower the pre-existing water table. Underdrains are engineered pathways for future release of hazardous substances, pollutants, and contaminants from the landfill. Over time, the underdrains would contain constituents that release from the landfill directly above the underdrain and from other areas of the landfill where constituents are release to groundwater and said contaminated groundwater discharges to an underdrain. Underdrains may provide a diluted leachate discharge to surface that may flow in a ditch or tributary to surface water with potentially minimal sorption or other attenuation of constituents. The ditch or tributary may also provide for sediment erosion to Bear Creek. Bear Creek is classified for recreational use. Creation of extensive or flowing underdrains conflicts with the TSCA requirement that "There shall be no hydraulic connection between the site and standing or flowing surface water."

c. Results of risk assessment and related fate and transport modeling for PCBs: Pages G-14 and G-15 describe results of risk assessment and modeling. This analysis did not evaluate the effect of an underdrain on PCB risk and transport of PCB contamination to surface water and Bear Creek. Fish downstream in Bear Creek already have PCBs in their tissue. The discussion once more assumes that PCBs are disposed in the future EMDF only in the solid phase and in relatively low bulk concentrations. It also assumes "significantly reduced infiltration rates within the landfill footprint."

20. Page 7-18, first paragraph, the second TSCA requirement requiring a waiver is needed for EBCV (Site 5) only and requires "The landfill site shall be located in an area of low to moderate relief to minimize erosion and to help prevent landslides or slumping. The discussion on page G-16, Section 4.2.2. states that the majority of the EMDF footprint (about three-fourths of the footprint area) lies on existing slopes of 30% steepness or less, while only about one-fourth of the footprint is developed on steeper slopes of Pine Ridge. Page G-15, Section 4.2.1 states that PCB limiting procedures are expected to continue thereby *limiting all on-site disposal of PCBs waste to <50 ppm*. This information was given as evidence the proposed facility will not pose an unreasonable risk of injury to health or the environment from PCBs when the requirement is not met. The basis for this waiver in Appendix G assumes PCBs will be disposed only in bulk waste at concentrations of < 50 ppm. It is unclear that justification for a waiver based on disposing bulk PCB waste with concentrations <50 ppm applies to granting a waiver for disposing PCBs>50 ppm.

21. Consensus has not been reached on input parameters to the modeling. These parameters control the calculated amount of leachate, the calculated leaching rate, and time to peak concentration in surface water.

22. The Remedial Action Objectives (RAO) on page 4-1 references several RAOs which define protectiveness of the remedy including:

   a. Prevent exposure of humans receptors to CERCLA waste (or contaminants released from the waste into the environment) that exceeds a human health risk of $10^{-4}$ to $10^{-6}$ Excess Lifetime Cancer Risk (ELCR) or Hazard Index of (HI) 1.

   b. Prevent adverse impacts to water resources or unacceptable exposure to ecological receptors from CERCLA waste contaminants through meeting chemical-, location-, and action specific ARARs, including RCRA waste disposal and management requirements, Clean Water Act (CWA) Ambient Water Quality Criteria (AWQC) for surface water in Bear Creek, and Safe Drinking Water Act (SDWA) MCLs in waters that are a current or potential source of drinking water.

Other goals are identified on page 4-2 that page 4-1 states do not define protectiveness. Page 4-2 states that "PreWAC waste concentration limits are determined based on demonstrating the following goals are met *during the 1,000 year compliance period*" (emphasis added).

- $10^{-5}$ ELCR and HI of 1 based on a human receptor's (direct) ingestion of groundwater from a drinking water well and (indirect) uptake of surface water for the compliance period (to 1,000 years) using a resident farmer scenario, and $10^{-4}$ ELCR and HI of 3 at times exceeding 1,000 year compliance period

- Appropriate AWQC for chemicals (risk-based discharge levels for radionuclides in Bear Creek and tributary surface water are per the *Integrated Water Focused Feasibility Study* (UCOR, 2016)

- MCLs in groundwater present in drinking water well of the resident farmer scenario.

Therefore, the PreWAC as identified in the D4 RI/FS should be consistent with RAOs during the 1,000 compliance period, *but not necessarily thereafter.*

CERCLA 121(d)(1) requires the remedial action "shall attain a degree of cleanup of hazardous substances, pollutants, and contaminants released into the environment and of control of further release at a minimum which assures protection of human health and the environment." RAOs should also include protection of environmental receptors allowing for environmental risk assessment or screening. We found no timeframe in either CERCLA or the NCP that specifies that after a specified number of years it is no longer necessary to assure protection of human health and the environment under CERCLA. CERCLA 121(d)(2) discussed ARARs for any hazardous substance, pollutant, or contaminant that will remain onsite. We found no timeframe in either CERCLA or the NCP that says that ARARs are no longer applicable or relevant and appropriate after a specified timeframe. CERCLA utilizes a review process every 5 years to determine whether remedial actions remain protective.

As a follow-up for the May 3rd meeting discussing changes from the D3 to D4 RI/FS DOE's contractor sent TDEC and EPA the following:

*"For the EMDF D4 RIFS, PreWAC for radionuclides predicted to peak after 2,000 years were based on a risk-informed, 500 mrem/yr radiological dose criterion. The flow and transport model predictions and receptor exposure assumptions utilized were the same as for the risk-based PreWAC, but rather than estimating ELCR with a carcinogenic slope factor (for comparison to a specific target risk level), the peak annual radiological dose was calculated using water ingestion dose conversion factors for each radionuclide. This predicted peak dose corresponding to the assumed unit waste concentration (1 Ci/m3) was then used to estimate the waste concentration limit (PreWAC) corresponding to the 500 mrem/yr criterion. The assumptions underlying this calculation are exactly the same as those made for calculating risk-based PreWAC."*

This methodology developed PreWAC limits for 28 radionuclide with excess lifetime cancer risk (ELCR) in the range from about 2.6E-02 (2.6 per hundred) to 9.8E-4 (9.8 per ten thousand) based on the limited resident farmer scenario. Much of this risk results from drinking from the residential water well. The ELCR may be higher if additional pathways of exposure are considered.

CERCLA and the RAOs reference SDWA MCLs. SDWA MCLs are identified in the RAOs for waters that are a current or potential source of drinking water. The future farmer scenario assumes drinking from a residential water well in the exposure risk scenario and development of the PreWAC. Potential use of groundwater for a drinking water supply does not end at the end of the 1,000 year compliance period and may increase farther out in the future. MCLs for radionuclides include beta/photon emitters (4 mrem/yr), gross alpha particle (15 pCi/L), Radium-226 and Radium-228 (5 pCi/L) and Uranium (30 μg/L). The MCL for uranium limits toxicity of uranium as a heavy metal in addition to effects as a radionuclide. It should be verified that PreWAC limits will result in groundwater concentrations at the residential water well that are less than or equal to the appropriate MCLs irrespective of how far in the future modeling predicts a peak concentration in surface water.

23. Of note is the fact that, for the different proposed disposal sites, there are different lithological and formation contact areas for different sites. This may be more significant than initially appears, particularly when there are formations that contain more carbonate. If the streams on the sites are walked and water quality parameters are measured along them, it is apparent that when, for example, a stream crosses a carbonate unit, say the Dismal Gap Formation (formerly Maryville Limestone), there is a measurable change in electrical conductivity of the water. This means that a higher dissolved load is in the water, which means that channels or conduits are developing in the subsurface.

24. The general groundwater situation in this part of Bear Creek Valley needs to be described in a clearer way. The document is written such that a "pick and choose" method is used to obtain supporting materials to justify the position. Sometimes references are quoted out of context, and previous comments were made about this, but have not been rectified.

## <u>Specific Comments</u>

1. **<u>Page 4-1, RAO 2:</u>** The RAO to protect ecological receptors includes ARARs that may not include radionuclides. Protection of ecological receptors from radionuclides should also be established through ecological risk assessment.

2. **<u>Page 6-9, 2nd paragraph:</u>** *"No known federal- or state-listed T&E species have been identified in the EBCV site area (Option 5), except for Northern long-eared bats, which are listed as threatened. An acoustic bat survey conducted by ORNL personnel in August 2013 at and near Site 5 prior to timber recovery did not detect any Gray or Indiana bats that are listed as endangered species, but did identify Northern long-eared bats (See Appendix E for details)."*

Did DOE previously notify the U.S. Fish and Wildlife Service regarding timber recovery at this site? Given the threatened Northern Long-eared bat was detected onsite, has DOE been in Section 7 consultations with the USFWS regarding the EBCV site (Option 5)?

Under Section 7 of the Endangered Species Act, Federal agencies must consult with the U.S. Fish and Wildlife Service when any action the agency carries out, funds, or authorizes (such as through a permit) *may affect* a listed endangered or threatened species. This process usually begins as informal consultation. A Federal agency, in the early stages of project planning, approaches the Service and requests informal consultation. Discussions between the two agencies may include what types of listed species may occur in the proposed action area, and what effect the proposed action may have on those species.

3. **Page 6-14, last paragraph titled: Ecological/cultural resources:** *"No recent site-specific surveys to identify T&E species have been completed for Site 14. Ecological conditions for the WBCV area were reported in an environmental impact statement data package for the LLWDDD program published in 1988.*

   This study is outdated for the purpose of establishing current T&E species status. TDEC agrees that detailed assessments to evaluate potential impacts to wetlands and to identify T&E species would be warranted at Site 14 if the site is selected for construction, as stated on page 6-15. Furthermore, as NEPA values are to be incorporated into CERCLA, TDEC expects a thorough evaluation of ecological and cultural resources at any candidate site before approval of an alternative that would authorize construction of a disposal facility on the site.

4. **Page 6-20, 3rd paragraph titled: Ecological/cultural resources:** *"Two separate surveys to identify T&E species of vascular plants and fish were completed in 1998 for the EMWMF that included the Site 6b area (see Appendix E for details). Neither survey identified T&E species in the Site 6b area, although recommendations were made to preserve habitats and implement best management practices to protect the Tennessee Dace in downstream areas. ORR ecological surveys mapped a "natural area 28" across and adjacent to the Site 6b area (See Appendix E) that includes wetlands delineated east and west of the site. Wetlands on the east and west sides of Site 6b along the NT-5 and NT-6 tributaries were delineated by Rosensteel and Trettin (1993) that could be impacted by EMDF construction (See maps and details in Appendix E). Surveys to evaluate potential impacts to wetlands and other T&E species may be warranted at Site 6b if the site is selected for EMDF construction."*

   As discussed in comment 3 above, the documents cited in this paragraph are outdated for the purposes of establishing the current status of T&E species. Given that the Northern Long-eared bat was detected in an acoustic survey in Bear Creek Valley as recently as 2013, bat survey data for any candidate site should be collected prior to approval of an alternative that would allow a facility to be constructed on the site.

5. **Page 6-81:** The PreWAC values listed in Table 6-5 do not include the non-carcinogenic PreWAC for uranium of 52.2 mg/kg identified in Table H-12 (page H-81). Presumably, uranium non-carcinogenic PreWAC limits were calculated based on a Hazard Index (HI) of 3. The non-carcinogenic pathway for uranium metal is based on a reference dose of 0.003 mg/kg-day. Since this reference dose is the same for all isotopes of uranium, the PreWAC for the non-carcinogenic threat from uranium metal should be determined by EPA approved analytical methods and reported as total uranium in units of mg/kg instead of speciation into the various uranium isotopes.

6. **Page 6-51. Section 2.2.4.8. Longevity of Engineered Features Cover/Liner Systems:** *Geomembrane liners of the landfill liner system at all sites would control releases of leachate to ground water for their design life reported to extend from 500 to 1000 years or more (Koerner, et al. 2011, Rowe, et al. 2009a, Benson 2014, EPA 2000). Both cap and liner systems contain geomembranes to prevent water infiltration into the waste, reduce contact of water and waste, and minimize leachate production and migration. As described by Bonaparte et al. (2016), it appears that HDPE geomembranes of the type being used in some MLLW disposal facilities are relatively unaffected at total alpha doses of 5 megarad (Mrad), or more. These geomembranes are also reportedly unaffected by radiation from gamma and/or beta sources until total doses reach on the order of 1 to 10 Mrad, which is much higher than what would be expected to be disposed in the EMDF.*

   TDEC agrees that properly designed and installed geocomposite barriers may control leachate releases to groundwater for many decades or even centuries. However, the difference between a service life of a few hundred years and a thousand years might be critical for isolation of an isotope like strontium 90, which would require 30 to 40 half-lives, or about 1000 years to decay from the proposed limit set by the administrative waste acceptance criteria to levels that would be innocuous in leachate.

   TDEC also agrees that disposal of waste that could produce a total dose of 1 megarad to the geomembrane in either cap or liner is unlikely, due in part to the small amount of waste that is likely to be generated with high concentrations of beta/gamma emitters and in part to shielding by clay and drainage layers. However, as the proposed administrative WAC would allow 4600 Curies per cubic meter of Cesium 137 and places no limits on Cobalt 60, it is not clear to TDEC that localized liner damage due to radiation fields would be completely impossible without dose calculations and possibly further WAC restrictions.

7. **Page 7-10. Section 7.2.2.2.3 Action-specific ARAR, first bullet, TDEC 0400-20-11-.17(1)(b) Disposal site shall be capable of being characterized, modeled, analyzed and monitored:** *"All sites selected for consideration meet this ARAR. All sites under consideration in this RI/FS as locations for an on-site disposal facility – EBCV Site, WBCV Site, Dual Site (Site 6b and Site 7a) – are located in BCV, which has been extensively characterized over the last 40-50 years. More than 1,000 groundwater wells have been installed and monitored many of which continue*

*to be monitored, multiple characterization events have been executed and documented, and over 900 acres of the valley are incorporated in the BCV model (see Appendix E and Appendix H). Additionally, an effort is underway within OREM to develop a more detailed groundwater model of BCV outside of this RI/FS.* ***The current BCV model, a porous media model, has been questioned in terms of its ability to adequately predict groundwater movement in Bear Creek. Discrete fracture flow models have been suggested to be more applicable for this area. However, development of a fracture-based flow model would take a large amount of capital and time, without any guarantee of producing a successful accurate model. The scale of fractures compared to the scale of the current porous flow model grid is such that this approximation is appropriate, and modeling calibration efforts and results support that conclusion. See further discussions in Appendix H."***

The approach cited above assumes a porous medium. In other parts of the document the equivalent porous medium approach is promoted.

A porous medium has: areal recharge (no losing or sinking streams), parallel flow lines, with laminar flow, (no convergent flow, no turbulent flow, no troughs, valley or ridges in the potentiometric surface), discharge across the entire downgradient face of the aquifer (no springs or seeps) and a convex profile to the water table (in cross section), or a steepening hydraulic gradient towards the discharge.

So, do any of the proposed sites deviate from any of the ideal criteria? If so, the porous medium assumption is invalid. ASTM (1995) state in fractured rocks the porous medium is poorly approximated, and should be avoided.

It appears that the settings proposed fail for most if not all of these fundamental porous medium test criteria.

An equivalent porous medium is: "a homogeneous setting with parameters chosen to be characteristic of the fissured rock" (Barker, 1993) – essentially an ideal porous medium with the chosen parameters assumed if they are not measured.

The term equivalent porous medium appears quite straightforward. However, further in Barker (1993) there is a discussion and it is such that there are different scenarios to choose from, that involve various characteristics about the transport mechanisms in the rock matrix and the fissures, for example, whether transport is diffusive or advective, whether there is flow in the matrix and fissures or only in the fissures, but still diffusive exchange between the two. When the time scale is small with respect to the diffusion across the fissures and the effects of matrix porosity can be ignored, (conditions he suggests are probably restricted to the laboratory) an equivalent porous medium model might work, using just the fissure porosity. This might also work if diffusive equilibrium exists, with the time scale small, the setting behaving like a homogeneous medium and using the total porosity, with alternatively a double porosity approach (flow in only the fissures). If there is a wide distribution of timescales, then only diffusive double permeability approaches can be envisioned (flow in both the fissures and the matrix and diffusive exchange).

This discussion hopefully shows the complex interactions that have to be determined when using what appears to be a relatively simple: "equivalent porous medium" approach. In reality it involves choosing a complex and interwoven set of assumed conditions, of which most are impossible to validate, unless they are measured directly.

It is often suggested that large scale can allow a better fit to such approaches. This may be the case with general parameters to determine mass balance, but when tested with methods not buried in the same assumptions details emerge that usually result in a model more closely approximating a discrete situation that defies equivalence with anything but reality. There are numerous traces in fractured non-carbonate/clastic rocks that have been done kilometers in length with velocities of > 100 m/day (Worthington et al., 2016 [in review]). When the proportions of flow in different porosity elements (matrix, fissure and channel/conduit) are included, it is obvious that the concept of any type of porous medium is much less likely.

It is overly simplistic to assume that fissured rock can be modeled as a porous medium. One alternative is to use parameters determined directly by groundwater tracing, although tracing is likely to prove that rock is not a porous medium. Another alternative is to apply parameters derived by tracing in similar settings on the ORR (e.g., Gwo et al., 2005) and to assume those values are representative.

Convergent flow to major fissures must be considered and thus the inclusion of channeling must be included in the thought process. Channeling will obviously result in more rapid velocities, which will result in any dissolved solutes or contaminants reaching users more rapidly and in higher concentrations.

8. <u>Page 7-13, TDEC 0400-20-11-.17(1)(f):</u> *"All proposed sites are situated such that upland drainage areas are minimized by locating the footprints as far upslope as possible."*

   TDEC is not sure this statement is true since several of the sites are proposed to be located on knobs separated from Pine Ridge.

9. <u>Page 7-18, Section 7.2.2.3 Long-term Effectiveness and Permanence (On-site):</u> The Residual Risk discussion is limited to the 1,000 year compliance period. Residual risk beyond 1,000 years is not considered in the Long-term Effectiveness and Permanence discussion.

10. <u>Page E-16, Figure E-1, BCV Phase I ROD land use zones...:</u> Symbols displayed on the map are missing from the legend. Please provide a complete legend that describes all map symbology, including existing streams, roads, and gray polygons west of Site 6B.

11. **Page E-18, Figure E-2, Existing contaminant source areas...:** A) Symbols displayed on the map are missing from the legend. Please provide a complete legend that describes all map symbology, including existing streams. B) Acronyms on the map (e.g., HCDA) are not defined on the figure or in the Appendix E acronym list. Please define all acronyms.

12. **Page E-24, Figure E-7, Potential EMDF sites in BCV with respect to the northern DOE site boundary and nearest Oak Ridge residents:** The map is annotated to portray distances between potential disposal sites and existing (current) residences. For protectiveness of future residents, it would be more appropriate to show the distance to the DOE site boundary. Please revise the figure accordingly (and any calculations or estimates based on these distances). At a minimum, revise the figure title to accurately reflect that the map only addresses *current* residents.

13. **Page E-26, Paragraph 2:** *"... the proposed sites (Option 5) and physically and hydrologically separated from this community by Pine Ridge."* Freeze and Cherry (1979) and Fetter (1980) show the effect of topography and geology/hydrogeology on groundwater flow nets. Without tracer test information, it cannot be stated or claimed in this type of topographic setting in fractured rocks that the site is hydrologically separated from the (scarp side of the ridge) i.e., Scarboro community side of the ridge. Tracer testing from both sides of the ridge must be done to prove that there is a groundwater divide. This would be considered a common practice in carbonate settings and would be prudent in clastic and other similar settings also (Worthington et al., 2016 [in review]). Note: the higher up in the dip slope of the ridge the proposed site is increases the probability that the assumption that no groundwater will pass beneath the ridge is more likely to be incorrect.

14. **Page E-30, 2.8.1 Hydrogeological Conceptual Model for Bear Creek Valley:** The concepts of the hydrogeology of fractured rock settings used in this document have not moved with the progress made within the discipline and throughout the profession in general across the globe through the decades. For example, it is now acknowledged that it is not possible to assume that carbonate or fractured rocks behave as a porous medium (ASTM, 1995). Many papers through several decades have been written that describe rapid flow of recharge, groundwater flow and discharge in non-carbonate clastic rocks. They assume the characteristics of carbonate rocks, because there are obviously preferential flow paths, i.e., channels, the only difference being that the diameters of the channels in clastic rocks are probably less than those in carbonate rocks, because the dissolution rates are less (Worthington et al., 2016 [in review]).

    Fractured rocks have relatively long groundwater flowpaths and relatively deep flowpaths because the specific surface area contacted by water and other dissolved solutes is low as compared to the specific surface area of a well-sorted sand or gravel. This means that fractures tend to alter (or weather) along their length. With a positive feedback loop where in an open fracture within which water moves, if it becomes widened, it will take more water and thus will widen more and so on. This is one of the few reasonable explanations for deep contamination of classic rock settings. In addition the mineral assemblages of sandstones and shales dissolve incongruently, where a relatively insoluble clay mineral is formed after, e.g., feldspar minerals dissolve, which is different that when a carbonate rock dissolves and almost all the existing rock is transported away in solution. These scenarios in clastic rocks cause miscalculations in groundwater velocity, underestimations in contaminant transport, and other potentially problematic modeled predictions.

At the end of the first paragraph therein (Section 2.8.1) a differentiation is made between karst and clastic rocks, evaluate the comments here and that statement, and in particular with regards to Worthington et al. (2016 [in review]).

15. **<u>Page E-32, Section 2.8.2, Hydrogeological Conceptual Models for EMDF Sites in Bear Creek Valley:</u>** *"Groundwater and surface water flow paths along and adjacent to the NT valleys adjoining the proposed sites ultimately lead downgradient toward the base level elevations imposed by Bear Creek which drains the entire valley toward the southwest."*

    As shown on Figure E-3 and other diagrams, the karstic Maynardville Limestone outcrops and dips steeply to the southeast along both sides of Bear Creek. As noted on page E-76:

    > Stratigraphically and physically above the Maynardville, the Copper Ridge Dolomite dips to the southeast under the north flank and crest of Chestnut Ridge. Cavities in the Copper Ridge are generally larger than those in the Maynardville.... Uncontaminated groundwater from the cavity/fracture network below Chestnut Ridge drains northward and discharges to Bear Creek and probably commingles with groundwater in the Maynardville karst.

    In karst settings such as this, groundwater has been demonstrated to flow beneath surface streams, and surface streams may have losing reaches, as Figure E-32 shows for Bear Creek. If the intent is to communicate that Bear Creek is a hydrogeologic boundary to groundwater flow, please include supporting evidence or cite a document where this is documented.

16. **<u>Page E-33, 2.8.2 Hydrogeological Conceptual Models for EMDF Sites in Bear Creek Valley:</u>** *"As shown in Figure E.11, Solomon et al (1992) defined hydrologic subsystems for areas underlain by predominantly clastic (non carbonate) rocks referred to on the ORR as aquitards. ...The subsystems include...an aquiclude at great depth where minimal water flux is presumed to occur."*

    Given that 1) releases of radioactive constituents from EMDF have the potential to impact human health and the environment for thousands of years and 2) groundwater flow is one of the most significant potential transport pathways, reliance on general statements made more than a quarter century ago should be supported with site-specific data from a thorough hydrogeological investigation of the candidate sites. It is not sufficiently protective to refer to predominantly clastic rocks as aquitards or to presume minimal groundwater flux at depth.

In a region with a significantly more stable tectonic history than the ORR, Anthony Runkel, Chief Geologist of the Minnesota Geological Survey, has demonstrated that conceptual hydrogeologic models used for decades are indefensible (Bradbury and Runkel, 2011; Runkel, 2010). In particular, he finds little support for historical assumptions that groundwater flow in siliciclastic strata is primarily intergranular and that "aquitards" have uniformly low conductivity. Specifically, he finds that discrete intervals of exceptionally high conductivity, commonly bedding-plane fractures and fractures perpendicular to bedding, can dominate the hydraulics of siliciclastic strata previously presumed to be aquitards. If intervals of high conductivity dominate groundwater flow in the relatively undeformed strata of Minnesota, such intervals are more likely to influence flow in the highly deformed bedrock of Bear Creek Valley.

17. **Page E-33, 2.8.2 Hydrogeological Conceptual Models for EMDF Sites in Bear Creek Valley:** *"Detailed water budget research on ORR watersheds that are similar to those of the EMDF sites..."*

    Please cite the reference(s) supporting similarity between the candidate EMDF sites and watersheds where detailed water budgets were developed. As written, the paragraph containing the quoted statement is confusing, as it presents different findings from two studies and then speculates about groundwater flow conditions at various depths and future impacts of landfill construction on groundwater flow.

18. **Page E-43, Figure E-18, Key changes to surface and groundwater hydrology from pre-construction through EMDF construction, capping, and closure:** It is not clear how the relatively shallow upslope diversion channel will divert upgradient groundwater around the landfill. The diagram does not indicate how groundwater flow will be prevented from crossgradient (along-strike) areas into the area beneath the landfill, where the water table is predicted to be lowered.

19. **Page E-46 and Figure E-19, Water table contour map for Site 5 representing the highest groundwater levels for the winter/spring 2015 wet season:** *"Of the proposed EMDF sites, the hourly water level data from the Phase I monitoring at Site 5 provides the only complete record of water table fluctuations over a full year of record. Figure E-19 illustrates the Site 5 seasonal high water table measured on April 21, 2015, reflecting the annual wet season peaks observed each year during periods of relatively heavy winter/spring precipitation (see Attachments A and B for details)."*

A single year of water level data cannot adequately represent the potentiometric surface range over 1,000+ years. Describe any adjustments or safety factors that were applied to address this discrepancy.

20. <u>Pages E-46 and E-52:</u> *"If Site 5 is selected for the EMDF, additional hydrogeological data will be needed to more completely establish baseline conditions for groundwater in, adjacent to, and upgradient of the Site 5 footprint...."* and *"Additional site characterization and water table monitoring at Site 5 in conjunction with more detailed engineering analysis are envisioned to resolve whether the conceptual base elevations would need to be raised in this area or whether dewatering before or during construction would be required."*

    Such fundamental baseline groundwater conditions should be characterized before selecting candidate sites and developing conceptual designs.

21. <u>Pages E-72 and E-76:</u> *"Geologic structures provide the fundamental pathways for groundwater flow and contaminant transport. Structures most relevant to the site conceptual model and fate and transport modeling include...macropores and relict fractures within saprolite...."*

    *"Descriptions and detailed systematic analyses of fracture sets are generally not provided in site investigation reports or in boring log or test pit descriptions, so that the nature of fracture systems and the detailed geometry of fracture networks remain nebulus [sic] and undefined at most sites. This is true for the EMWMF and for the proposed EMDF sites.... These uncertainties and limitations are necessarily reflected in fate and transport simulations in fractured media on the ORR."*

    If geological structures provide the fundamental pathways for groundwater flow, understanding of those fracture systems should be defined to a higher standard than "nebulous" to reduce uncertainties and limitations of the fate and transport modeling.

22. <u>Page E-72, Section 2.12.3.2 Bedrock Fractures in Predominantly Clastic Formations of the Conasauga Group:</u> It should be recognized that the flowmeter readings are from boreholes that may not be connected to macrofeatures, as is often the case, simply because there is a low probability of these zones being intersected by chance (Benson and LaFountain, 1984). The only way to reliably demonstrate that hydrogeology from boreholes correctly represents a site is to test the conceptual model with tracers.

23. <u>Page E-73, Section 2.12.3.2 Bedrock Fractures in Predominantly Clastic Formations of the Conasauga Group:</u> First paragraph, last sentence: How do you corroborate a notion? It is more logical to rationalize that, since the water table has not been in the same place, it settles in the zone of maximum porosity and permeability. It is also likely that there is more flow parallel or aslant the strike as in other locations that have been tested with injected tracers. The remaining and previous discussion about groundwater flow should consider that there will be convergent flow in larger fractures simply because of a positive feedback

loop that develops. This could easily lead to small diameter channeling (a few mm to cm) that can be missed by boreholes, but that carry leachate or groundwater + dissolved solutes related to the waste cell to impact users probably many kilometers (miles) away.

24. **<u>Page E-74:</u>** The text cites Lutz and Dreier (1988). Please list the associated reference in Chapter 7, along with any others that are missing.

25. **<u>Page E-76, Section 2.12.3.3, Karst Hydrology in the Maynardville Limestone and Copper Ridge Dolomite:</u>** There is a discussion about karst, karstification, etc., which segregates karstification into only these two formations. A modern approach to this should be considered. Worthington et al., (2016 [in review]) show that dissolution actually occurs in non-carbonate rocks, because of geological time, almost as commonly as it does in carbonates. They cite many examples of tracer tests that show rapid velocities (>150 m/day [~500 ft/day] ) and long pathways (> 3 km [~2 miles]) e.g., in arkosic sandstones (quartz, feldspar and some mica minerals). Other examples they cite show similar parameters and suggest that at the scale of contaminant groundwater and migration (dissolved solutes and colloids) in narrow channels that can permit turbulent flow at 0.001 m/s (about 90 m/day [~300 ft/day]) (Quinlan et al., 1996) there is comparability between clastic and carbonate rocks. Lowe and Waters (2014) state that there are lithological conditions that promote development of subsurface channels, conduits and karst. These are: shale beds, faults and unconformities. The first of these is because sulfide minerals are often present in shales and thus can be oxidized after being in contact with meteoric waters to produce a groundwater that contains sulphuric acid, which can significantly enhance dissolution. Faults and unconformities always have some sort of void spaces formed along them, and thus can allow groundwater or formation water and thereafter meteoric water to penetrate. This can have the effect of pre-conditioning the setting so that when it is subjected to uplift and subaerial exposure and attacked by meteoric water, dissolution processes can proceed at higher rates. Degrees of karstification are hard to quantify. Quinlan et al., (1996) provide the only numerical basis for describing the minimum size for conduits (a few mm [a few fractions of an inch] in diameter).

26. **<u>Page E-78:</u>** *"The maximum thickness of this unsaturated zone between the top of the waste and the post closure water table is in the range of 100-150 ft thick at Site 5 (See conceptual design cross sections in Chapter 6 of the EMDF RI/FS Report)".*

    Please rephrase this sentence to state the minimum predicted thickness of the unsaturated zone between the bottom of the waste and the post-closure water table, which is the relevant thickness.

27. **<u>Pages E-80 and E-81:</u>** *"The hydraulic characteristics of unsaturated (and saturated) in-situ materials can be currently estimated based on available data at and near the proposed EMDF sites but most field investigations have not involved any direct measurements of unsaturated zone hydraulic parameters."*

*"If unsaturated zone characteristics are required to support modeling, engineering design, or other project needs, they can be addressed in future work plans for site characterization."*

If most investigations have not involved direct measurement, does this mean that some direct measurement data are available? If so, how are those data factored into the evaluation? If not, collection of such data is warranted to support a defensible evaluation of site suitability even before it is needed for detailed engineering design.

28. **Page E-94, Hydraulic Conductivity in Relation to Equivalent Porous Media Modeling, Third Paragraph, 9th line:** A reference by Worthington (2003) is incompletely used in the D4. The reference is also missing from the references list (note the corrected reference is included below). The original reference that should be used is Worthington (1999) below. In that paper the discussion by Worthington (1999) as used in the D4 is only partially represented and does not advocate assuming that the setting can be assumed to be an equivalent porous medium and can be modeled as such. It is part of a discussion of several techniques typically used.

29. **Page E-102, Section 2.13.4 Groundwater Geochemical Zones, Fourth complete paragraph:** TDEC comment TDEC.S.066 discusses deep groundwater circulation on the ORR and points out that Nativ et al. (1998) reply to the rebuttal of their original paper by Moline et al. (1998). The D4 version still does not quote the reply by the original author to the rebuttal. In rocks that have been faulted such as those on the ORR, TDEC would not presume, as stated in the RI/FS, that a finite number of borehole tests would be adequate to determine that permeable fractures at depth were absent or of minimal consequence.

30. **Page E-103, Section 2.13.4 Tracer Tests, First paragraph, 10th line, "informal unpublished document":** The results of tracer tests done in Bear Creek Valley are included in the TDEC Environmental Monitoring Report (2001).

31. **Appendix E, Attachment A, page 1:** *"The conceptual design for the EMDF includes the installation of underdrain systems beneath the landfill to ensure surface water and groundwater diversion, drainage, and lowering of the water table below the waste cells. The results of the Phase I site characterization are presented in relation to the existing site topography and proposed conceptual design for the landfill and underdrain system. The results support the concept that the water table can be effectively managed and lowered during and after construction to ensure that the water table does not encroach on the geologic buffer or waste materials placed above the buffer and liner systems."*

The document should indicate any lessons learned from the failure of groundwater modeling to predict post-construction groundwater levels at the EMWMF with an acceptable level of certainty, as well as how any such lessons are incorporated in the EMDF conceptual design to ensure that the water table does not encroach on the geologic buffer or waste materials.

32. **<u>Appendix E, Attachment A, Figure 1, Phase I Monitoring Locations at the Proposed EMDF Site:</u>** The Rome formation symbol defined in the legend does not match the symbol shown on the map. Please correct the legend or map for accuracy and consistency. This discrepancy should be resolved on other figures throughout the RI/FS report components (e.g., Appendix E, Attachment B, Plates 5 and 6).

33. **<u>Appendix E, Attachment B, Cut/Fill Thickness Map:</u>** Symbols displayed on the map are missing from the legend. Please provide a complete legend that describes all map symbology, including existing streams and roads.

34. **<u>Page G-13:</u>** Part of the discussion to justify a waiver of TSCA requirements is that all onsite disposal of PCB waste at EMWMF and future EMDF is limited to < 50 ppm. A PCB limit of 50 ppm should be established in the WAC for the future EMDF.

35. **<u>Page F-20, Chapter 3. NATURAL PHENOMENA HAZARDS:</u>** *"Two natural hazards, tornados and earthquakes, are considered in this evaluation, since these are the most likely potential natural phenomena that could affect the EMDF."*

    DOE is to be commended for evaluating an air dispersion scenario. However, the source is modeled as being equivalent to waste disposed in EMWMF. While this might be reassuring that risks will be low if waste inventory in a future disposal facility is similar to EMWMF waste, it does not provide a basis for setting limits on concentrations of radionuclides that might contribute to either on-site or off-site risk during a tornado.

36. **<u>Page H-24, Paragraph 3, Second Bullet:</u>** *"...composite barrier layer that consists of a 40 mil thick high density polyethylene (HDPE) geomembrane layer..."* **<u>and Page H-26, Item 8, First Bullet</u>** *"... proposed geomembrane (40 mil) ..."* **<u>and Page H-28, Table H 2, column 'Layer' (#5) and column 'Thickness'</u>** *(80 mil)*.

    The specified thickness of the composite barrier layer is inconsistent between the text and the table, with the text indicating 40 mil and the table indicating 80 mil. This needs to be corrected. Further, the barrier thickness in the cover layer should normally be the same as that in the liner (as indicated by the thickness of 80 mil shown for Layers 5, 12 and 15 in Table H-2; it is not clear if that is the case here.

37. **<u>Page H-30, Table H-3, Amended Clay Hydraulic Conductivity, Stage 4:</u>**

    The basis for adjusting the hydraulic conductivity of the amended clay layer by a factor of 2 should be provided.

38. **Page H-32, Section 4.2.1.2 Model Boundary Conditions:** *"The UBCV Model has a no-flow boundary at the top of Pine Ridge to the north of the proposed facility..."* **and Page H-38, Figure H-9:**
The no-flow boundary assigned north of the proposed facility in the MODFLOW model appears to be only a few hundred feet away from the unit. Assigned boundary conditions should be tested to demonstrate that the boundary assignment does not have a significant influence on the calculated water levels – especially when the model boundary is in relatively close proximity to the area of interest in the model. This is particularly important since the model is used to estimate post-construction water level declines at the EMDF for comparison to the base of the landfill liner system. A no-flow boundary can enhance calculated declines by inhibiting flux into the model area. The assumption of a no-flow boundary underlying the ridge is a theoretical guideline, but field data has not been presented to support the boundary definition.

39. **Page H-43, Section 4.2.1.4 Model Calibration:**

Since the numerical model is used as the basis for establishing pre-design components of the landfill facility as well as PreWAC values, knowledge of specific calibration results is warranted to gage the suitability of the model for the applications. Calibration details, however, are not presented in this RI/FS. Information normally required includes the distribution of calibrated heads, minimum/maximum residuals, calibration statistics (such as root mean square error, absolute error, mean error) and the spatial distribution of the head residuals. It is not clear if any of this information, specific to this model for the proposed EMDF, is presented in other reports; nonetheless, some of the basic calibration information should be included in the RI/FS to allow confirmation that the model calibration is adequate for this application.

40. **Page H-50, Section 4.3.2 MT3D Model Assumptions:**

The MT3D model setup includes withdrawal of water from Layers 3-6 – presumably with one well node assigned in each of the 4 model layers representing the pumping of a water supply well. However, the summary of MODFLOW parameters for the Future Condition scenario (Table H-4, page H-41) lists 8 well nodes used in the model. Please clarify the representation of the pumping and number of well nodes assigned.

41. **Page H-64, second complete paragraph:** *"...dilution factors for the creek (surface water source) and residential well (see Section 4.3.3) were used for scaling the constituent concentrations in the creek to corresponding well concentrations."*

The surface water concentrations and the residential well (groundwater) concentrations used in the scaling calculations have each been developed using different modeling approaches and assumptions (the surface water concentrations are developed using PATHRAE with consideration of advection, dispersion, and sorption, while the groundwater concentrations are developed based on advection only). The comparability of the modeled values for use in scaling calculations is questionable.

42. **Page H-69, Table H-7:**

Response to TDEC comment TDEC.S.106 stated that differential settling is assumed post-1,000 years and is accounted for by clogging the drainage layer of the cap (decrease in hydraulic conductivity of 100). HELP model sensitivity analysis presented in Table H-7 includes a 2 order of magnitude reduction of hydraulic conductivity in the lateral drainage layer post-1000 years. TDEC does not understand the technical basis for postponing differential settling to greater than 1,000 years after closure.

43. **Appendix H, Attachment B, Table 1:** Some of the Peak Effective Risk, $PR_{eff}$, (ELCR) included in Table 1 appear to be $PR_{well}$ instead of $PR_{eff}$. In other words, some of the $PR_{eff}$ in Table 1 was derived from drinking from the groundwater well only and does not appear to include the risk from livestock watering and consumption of meat and produce grown on the farm.

44. **Appendix H – Attachment B, Page 7, Section 2.1.3 General Design and Evaporative Zone Data:**

The SCS runoff curve number of 49.3 seems low when compared to curve numbers presented for Pasture, grassland, meadow or brush in Table 2-2c of the US Department of Agriculture Technical Release 55 (Natural Resources Conservation Service, *Urban Hydrology for Small Watersheds*, 210 VI TR-55, June 1986). In that document, the majority of the runoff curve numbers are greater than 60, with values less than 50 associated with good hydrologic conditions in generally sandy soils.

Additionally, the assumption of 100% runoff for the 'Fraction of Area Allowing Runoff' in the HELP model seems optimistically (and non-conservatively) high.

45. **Appendix H – Attachment B, Page 7, Section 2.2 HELP Model Output, Paragraph 1:**

The text indicates HELP model results for the long-term scenario are presented in Section 2.2.2; however, no Section 2.2.2 is provided in Appendix H – Attachment B. Further, output data for at least one run should be provided for some confirmation of the HELP model output.

46. **Response to Comment TDEC.S.001:** TDEC should clarify that the purpose of TDEC comment S.001 was to identify problems with the current disposal facility that have not been resolved to TDEC's satisfaction. The comment response focuses on debating or denying the significance of these problems, and the D4 does not incorporate any major changes that reflect progress on outstanding EMWMF issues. During the five previous years since the FFS was scoped with the regulators, little consideration has been given to issues at

EMWMF. DOE has only recently initiated discussions on the problems of elevated groundwater discussed in the comment and there has been little discussion on modifications to the approach to waste acceptance.
To address the response to this comment, TDEC first notes that unregulated discharges of radioactive wastewater to Bear Creek occurred very early in EMWMF operations prior to facility expansion. The problems resulted primarily from excessive runoff from a large working face and water ponding on a low permeability protective layer in cell 1 of EMWMF rather than the inability of the leachate collection system to convey water.

With regard to the second individual comment response, it is true that releases occurring during waste generation and transportation are not directly the results of on-site disposal. However, these releases, such as the contamination of Highway 95 and the contamination of sewage sludge at the Rarity Ridge wastewater treatment plant, were, in part, the result of having abundant on-site disposal capacity and flexibility in the approach to waste characterization, which favored en masse removal actions rather than a more surgical approach to risk reduction.

With regard to the groundwater intrusion into the EMWMF buffer and liner, TDEC's concerns were never strictly based on the pneumatic piezometer readings, as DOE has surmised, but on the apparent intrusion of groundwater into the liner prior to underdrain construction and persistent elevated water levels around the northeast end of EMWMF. The hypothesis that elevated piezometer readings resulted primarily from the increase in pore pressure due to the overburden weight of added waste is not consistent with the data that was presented in the referenced UCOR report, or with data collected subsequent to its publication. Pressure in pores under confined conditions increases almost instantaneously (at the speed of sound in water) and decays as consolidation occurs. In clay barriers, this decay may require months or years. The piezometer readings below cell 3 did not rise quickly during the time when cell 3 was most rapidly loaded, and the pressure recorded in the years since loading shows seasonal changes rather than decay.

Finally, while the karst system in the Maynardville Limestone in Bear Creek Valley was documented in the BCV RI, as DOE states in the response to comment, no travel times were available except an arrival time for the short trace reported by Geraghty and Miller (1989). The Bear Creek RI does not reference the several tracer studies in west Bear Creek Valley after 1995 or tracing done in similar rocks in Melton Valley, many of which are now summarized in Appendix E of the D4 version of this RI/FS. These studies did provide insight concerning the range of first-arrival times and center-of-mass travel times in Conasauga Group rocks such as those underlying the proposed sites. Changes to the fate and transport modeling made in the D4 are seen by TDEC as positive and significant, but still don't necessarily provide a conservative assessment of risks to water resources from all contaminants of concern that are of interest. TDEC anticipates working to expand the scope of the risk assessment and ensure that on-site waste disposal can be done compliantly and cost effectively and welcomes the opportunity to work with DOE on improving the analysis of water pathway risk in the D4.

As DOE states in the response, TDEC approval of and comments on the work plan (TDEC letter dated November 27, 2013) for the investigation of site 5 did not indicate that the site would be rejected on the basis of its location across the upper NT-3 valley or make any recommendations for avoiding Site 5 on the basis of its footprint across a "blue line" stream. However, TDEC believes that both discussions with DOE and the content of the approval letter made it clear that the site investigation would be made at risk.

The letter states, on page 2, *"We appreciate DOE's cooperation with TDEC's request to perform this screening evaluation prior to the proposed plan and it should be understood that TDEC's acceptance of this Limited Phase 1 Site Characterization Plan for the Proposed Environmental Management Disposal Facility Site does not constitute an endorsement of the proposed EMDF location. It should also be understood that where the screening level evaluation should assist in understanding the hydrogeology and characteristics of the site, there are also other concerns that will have to be resolved prior to TDEC acceptance of the RI/FS."*

TDEC regrets any miscommunication and has discouraged DOE from further characterization at this site and at other proposed sites until more progress can be made on resolving outstanding issues at EMWMF and agreement reached on issues concerning characterization and acceptance of waste at any future on-site facility.

**Editorial Comments**

**1. Page E-32, Paragraph 2 (first full paragraph), Line 11:** *South* is misspelled.

**2. Page E-76, Paragraph 1, Line 3:** *Nebulous* is misspelled.

**3. Page E-81, Section 2.13.1.4, Line 12:** It appears the word *and* should be removed from *"remolding and of bulk soil materials"*.

**4. E-124, Paragraph 1, Line 4:** *Taxa* is the plural of *taxon*. Where an individual species is spoken about, *taxon* should be used (e.g., *"one taxa"* should be *one taxon*).

**5. Page E-131, Paragraph 2, Line2:** The genus name for ovenbird should be *Selurus* instead of *"Seirus"*.

**6. Page E-135, Paragraph 4, Lines 1-4:** *Quercus prinus* is included twice in this sentence.

**7. Page H-4, List of Figures:** Figure H-3 is omitted from the list of figures.

8. <u>Page H-10, Line 1, partial sentence:</u> *Ridg* should be *Ridge*.

9. <u>Page H-13, Line 6, middle of partial paragraph:</u> Extra period – "*...NT-2 and NT-3 at the EBCV site.. The modeling and PreWAC development ...*"

10. <u>Page H-17, Table H-1 Title:</u> "*Risk and DoseHI-based*"

11. <u>Page H-17, Last sentence:</u> "*Detailed description of thess methods ...*"

12. <u>Page H-53, Figure H-17:</u> "*...Model Layers 53-86...*"

## References

ASTM, 1995, D5717-95, *Standard Guide for the Design of Monitoring Systems in Karst and Fractured Rock Aquifers*, Annual Book of ASTM Standards Volume 04.09 Soil and Rock (II) D-4943-latest American Society for Testing and Materials, Philadelphia, PA, p. 451-468.

Barker, J.A., 1993, *Modeling groundwater flow and transport in the Chalk*, (in) Downing, R.A., Price, M., and Jones, G.P., (eds.) The Hydrogeology of the Chalk of Northwest Europe, Oxford Science Publications, p. 59-66.

Benson, R.C., and LaFountain, L.J.,1984, *Evaluation of subsidence or collapse potential due to subsurface cavities*, in, Beck, B.F., (ed.) Proceedings, of the First Multidisciplinary Conference on Sinkholes, Their Geology, Engineering and Environmental Impact, Orlando, Florida, p. 201-216.

Birchfield, J.W. III, and Albrecht, L., 2012, *Successful Characterization Strategies for the Active High Risk Y-12 National Security Complex 9201-5 (Alpha-5) Facility, Oak Ridge, TN – 12164*, WM2012 Conference, February 26-March 1, 2012, Phoenix, Arizona, USA (retrieved from http://www.wmsym.org/archives/2012/papers/12164.pdf).

Bradbury, K.R., and Runkel, A.C., 2011, *Recent advances in the hydrostratigraphy of Paleozoic bedrock in the Midwestern United States*, GSA Today, v. 21, no. 9, p. 10-12 (available online at http://www.geosociety.org/gsatoday/archive/21/9/pdf/i1052-5173-21-9-10.pdf).

Fetter, C.W., 1980, *Applied Hydrogeology*, Merrill, New York, p. 161-163.

Freeze, J.A., and Cherry, 1979, *Groundwater*, Prentice-Hall, p.195-199.

Geraghty & Miller, Inc., 1989, *Tracer study of the hydrologic system of upper Bear Creek, Y-12 Plant*, Oak Ridge, Tennessee, Y/SUB/89-00206C/4.

Giroud, J., and Bonaparte, R., 1989, *Leakage through liners constructed with geomembranes - Parts I and II*, Geotextiles and Geomembranes, 8 (2): 71-111.

Gwo, J-P., Jardine, P.M., and Sanford, W., 2005, *Effect of advective mass transfer on field-scale fluid and solute movement: Field and modeling studies at a waste disposal site in fractured rock at Oak Ridge national Laboratory, Tennessee, USA*, Hydrogeology Journal, 13, p. 565-583.

Lowe D.J., and Waters, C.N., 2014, *Geological influences on cave origin and development in the Yorkshire Dales*, Cave and Karst Science, v. 41, no. 1, p. 13-35.

Moline, G.R., Rightmire, C.T., Ketelle, R.H., and Huff, D.D., 1998, *Discussion: Evidence for ground-water circulation in the brine-filled aquitard, Oak Ridge, Tennessee*, Groundwater, v. 36, no. 5, p. 711-713.

Nativ, R.A., Halleran, A., and Hunley, A., 1997, *Evidence for ground-water circulation in the brine-filled aquitard, Oak Ridge, Tennessee*, Groundwater, v. 35, no. 4, p. 647-659.

Nativ, R.A., 1998, *Author's Reply by Ronit Nativ*, The Hebrew University of Jerusalem, Faculty of Agricultural, Food, and Environmental Science, POB 12, Revohot 76100, Israel, p. 712-713 (final reply to comments by Moline et al., as referenced above).

Quinlan, J.F., Davies, G.J., Jones, S.J., and Huntoon, P.W., 1996, *The applicability of numerical models to adequately characterize ground-water flow in karstic and other triple-porosity aquifers*, Subsurface Fluid-Flow (Ground-Water) Modeling, ASTM STP 1288, J.D. Ritchey and J.O. Rumbaugh, (eds.), American Society for Testing and Materials, 1996, p. 114-133.

Rosensteel, B.A., and C.C. Trettin, 1993, *Identification and Characterization of Wetlands in the Bear Creek Watershed*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Y/TS-1016.

Rowe, R.K., 2012, *Short- and long-term leakage through composite liners. The 7th Arthur Casagrande Lecture*, Canadian Geotech. J., v. 49, no. 2, p. 141-169.

Runkel, A.C., 2010, *Southeastern Minnesota Paleozoic Hydrostratigraphy: Fractures in Aquifers, Aquitards, and Aquitardifers*: AIPG Luncheon Presentation (abstract available online at http://aipgmn.org/meetinginfo.php?id=27&ts=1368160930).

Solomon, D.K., Moore, G.K., Toran, L.E., Dreier, R.B. and McMaster, W.M., 1992, *Status Report: A Hydrologic Framework for the Oak Ridge Reservation*, ORNL/TM-12026.

Spalding, B.P., 1987, *Environmental Data Package for the ORNL Seepage Pits and Trenches Waste Area Grouping*, ORNL/RAP-10, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

TDEC, 2001, *Environmental Monitoring Report*, Tennessee Department of Environment and Conservation, DOE Oversight Division, p. 6-32 to 6-40.

UCOR, 2016, *Focused Feasibility Study for Water Management for the Disposal of CERCLA Waste on the Oak Ridge Reservation, Oak Ridge, Tennessee*, DOE/OR/01-2664&D2.

USGS, 1978, *Suggestions to Authors of Reports of the United States Geological Survey*, U.S. Government Printing Office, Washington D.C., p. 192.

Worthington, S.R.H., 1999, *A comprehensive strategy for understanding flow in carbonate aquifers*, Proceedings of the symposium, Karst Modeling, Charlottesville, Virginia, Karst Waters Institute Special Publication No. 5, p. 17-37.

Worthington, S.R.H., Davies, G.J., and Alexander, E.C., Jr., 2016 (in final review), *Enhancement of bedrock permeability by weathering*, Earth Science Reviews, 16 p.