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December 17, 2013

**Sent VIA E-MAIL and OVERNIGHT DELIVERY**

Mr. Rusty Lundberg  
Director  
Division of Radiation Control  
Utah Department of Environmental Quality  
195 North 1950 West  
P.O. Box 144850  
Salt Lake City, UT 84114-4820

**Re: Transmittal of Source Assessment and Literature Search Report, Tetrahydrofuran in MW-01  
White Mesa Mill Groundwater Discharge Permit UGW370004  
Conditional Approval of September 17, 2013 Plan and Time Schedule**

Dear Mr. Lundberg:

Enclosed are two copies of Energy Fuels Resource (USA) Inc.'s ("EFRI's") Source Assessment and Literature Search Report for Tetrahydrofuran ("THF") in MW-01 at the White Mesa Mill. THF in MW-01 exceeded its Groundwater Compliance Limit ("GWCL") in the fourth quarter of 2012 and first quarter of 2013. As required by Part I.G.4(d) of the Groundwater Discharge Permit ("GWDP"), EFRI submitted a Plan and Time Schedule for the assessment of THF in MW-01 on August 27, 2013. Conditional approval of the Plan and Time Schedule was received by EFRI on September 17, 2013. Pursuant to the Plan and Time Schedule, EFRI has prepared this Source Assessment and Literature Search Report.

This transmittal also includes two CDs each containing a word searchable electronic copy of the report.

If you should have any questions regarding this report please contact me.

Yours very truly,

A handwritten signature in blue ink that reads "Kathy Weinel".

**ENERGY FUELS RESOURCES (USA) INC.**  
Kathy Weinel  
Quality Assurance Manager

CC: David C. Frydenlund  
Harold R. Roberts  
David E. Turk  
Jo Ann Tischler

# **SOURCE ASSESSMENT AND LITERATURE SEARCH REPORT FOR TETRAHYDROFURAN IN MW-01 WHITE MESA URANIUM MILL**

**Blanding, Utah**



***Prepared by:***



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**December 17, 2013**

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## EXECUTIVE SUMMARY

This report is an assessment and an investigation of the potential source for tetrahydrofuran (“THF”) in MW-01 at the White Mesa Mill, which has exhibited two consecutive exceedances of the applicable Groundwater Compliance Limit (“GWCL”). This report provides documentation from published studies and papers that indicate that THF is persistent over many years in monitoring wells due to solvents and adhesives used for well construction.

Water level and elevation data indicate that the perched groundwater elevation in MW-01 is approximately 9 feet higher than perched groundwater elevations beneath the Mill’s Tailings Cells and therefore MW-01 cannot be impacted by Mill activities. Additionally, MW-01 is more than 2,200 feet (0.4 miles) upgradient of the Mill facilities. THF concentrations which exceed the GWCL are likely the result of well construction practices in older monitoring wells that used adhesives and glues to join the casings.

Several US Environmental Protection Agency (“EPA”), United States Geological Survey (“USGS”) and consultant studies have produced data which indicate that THF in older wells is the result of construction practices. THF has never been used as a reagent, solvent or additive to the Mill’s processes but is found as an additive in kerosene, which is used in the Mill’s solvent extraction circuit. THF is therefore expected to be a constituent in the Mill’s tailings system and tailings wastewater analyses have confirmed that it is present in the tailings system. However, its presence in tailings does not explain the detection of THF in wells as far up-gradient as MW-01. As previously stated MW-01 is far upgradient and cannot have been impacted by Mill activities.

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## ABBREVIATIONS AND ACRONYMS

Director DRC	Director of the Division of Radiation Control State of Utah Division of Radiation Control
EFRI	Energy Fuels Resources (USA) Inc.
GAMA	Groundwater Ambient Monitoring and Assessment
GWCL	Groundwater Compliance Limit
GWDP	State of Utah Ground Water Discharge Permit UGW370004
GWQS	Groundwater Quality Standard
µg/L	micrograms per liter
mg/L	milligrams per liter
Mill	White Mesa Uranium Mill
Notice NTIS	Notice of Violation and Compliance Order, Docket No.UGWII-02 National technical Information Service
PVC	polyvinyl chloride
SAR SRLs	Source Assessment Report Study reporting levels
THF	Tetrahydrofuran
USEPA USGS	United States Environmental Protection Agency United States Geological Survey
VOC	volatile organic compound

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## 1.0 INTRODUCTION

Energy Fuels Resources (USA) Inc. (“EFRI”) operates the White Mesa Uranium Mill (the “Mill”), located near Blanding, Utah under State of Utah Groundwater Discharge Permit UGW370004 (the “GWDP”). This is the Source Assessment Report (“SAR”) required under Part I.G.4 of the GWDP relating to violations of Part I.G.2 of the GWDP with respect to tetrahydrofuran (“THF”) in groundwater compliance monitoring well MW-01.

Part I.G.2 of the GWDP provides that out-of-compliance status exists when the concentration of a constituent in two consecutive samples from a compliance monitoring point exceeds a groundwater compliance limit (“GWCL”) in Table 2 of the GWDP. The GWDP was originally issued in March 2005, at which time GWCLs were set on an interim basis, based on fractions of State of Utah Ground Water Quality Standards (“GWQSS”) or the equivalent, without reference to natural background at the Mill site. The GWDP also required that EFRI prepare a background groundwater quality report to evaluate all historical data for the purposes of establishing background groundwater quality at the site and developing GWCLs under the GWDP. As required by then Part I.H.3 of the GWDP, EFRI submitted the following to the Director (the “Director”) of the Utah Division of Radiation Control (“DRC”) (the Director was formerly the Executive Secretary of the Utah Radiation Control Board and the Co-Executive Secretary of the Utah Water Quality Board):

- A Revised Background Groundwater Quality Report: Existing Wells for Denison Mines (USA) Corp.’s Mill Site, San Juan County, Utah, October 2007, prepared by INTERA, Inc. (the “Existing Wells Background Report”).
- A Revised Addendum: Evaluation of Available Pre-Operational and Regional Background Data, Background Groundwater Quality Report: Existing Wells for Denison Mines (USA) Corp.’s Mill Site, San Juan County, Utah, November 16, 2007, prepared by INTERA, Inc. (the “Regional Background Report”).
- A Revised Addendum: Background Groundwater Quality Report: New Wells for Denison Mines (USA) Corp.’s Mill Site, San Juan County, Utah, April 30, 2008, prepared by INTERA, Inc. (the “New Wells Background Report,” and together with the “Existing Wells Background Report” and the “Regional Background Report,” the “Background Reports”).

Based on a review of the Background Reports and other information and analyses, the Director re-opened the GWDP and modified the GWCLs to be equal to the mean concentration plus two standard deviations or the equivalent. The modified GWCLs became effective on January 20, 2010.

In the October 10, 2012 SAR for multiple wells at the Mill site, EFRI recommended that GWCLs be removed from up-gradient wells MW-01, MW-18, and MW-19. EFRI reiterated in the SAR that MW-01, MW-18, and MW-19 are far upgradient from the Mill site and cannot be impacted by Mill activities, therefore it is not appropriate to establish compliance monitoring standards under the GWDP for those wells.

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In a letter of April 25, 2013, DRC concurred with EFRI's determination that constituents in those wells were not from Mill sources, and that GWCLs in those wells could be removed. Per discussion with DRC in July 2013, DRC planned to remove the GWCLs from the up-gradient wells in an interim revision of the GWDP.

The identification of two successive exceedances of the THF GWCL of 11.5 ug/L in MW-01 occurred in fourth quarter 2012 and first quarter 2013, after EFRI's assessment, and DRC's concurrence that, the GWCLs should be removed from MW-01, and before any revised GWDP had been published.

The Director issued a Notice of Violation and Compliance Order, Docket No. UGW13-05 (the "Notice"), dated July 23, 2013, based on the State of Utah Department of Environmental Quality ("UDEQ"), DRC findings from the review of the Mill's 1st quarter 2013 Groundwater Monitoring Report. The Notice cited one violation of the Permit under Part I.G.4 of the Permit for failing to provide to the Director a Plan and Time Schedule for assessment of the source(s), extent, and potential dispersion of the monitoring well MW-01 THF contamination.

Section E.2 (d) of the Notice ordered EFRI to prepare and submit within 30 calendar days of receipt of the Notice, a written plan and time schedule for assessment of THF out-of-compliance status at monitoring well MW-01 in compliance with the Permit Part I.G.4.c. In response to the Notice, EFRI submitted a Plan and Time Schedule on August 27, 2013.

This SAR addresses THF in MW-01 as described in the DRC-approved August 27, 2013 Plan and Time Schedule.

## **1.1 Source Assessment Report Organization**

An overview of Sections 2.0 through 5.0 of this Report is provided below.

A description of the approach used for analysis is provided in Section 2.0, and the results of the analysis are presented in Section 3.0. Conclusions and recommendations are provided in Section 4.0, and references are included in Section 5.0.

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## 2.0 CATEGORIES AND APPROACH FOR ANALYSIS

Generally, out-of-compliance constituents and wells can be grouped into five categories:

1. Constituents in wells with previously identified rising trends.
2. Constituents in pumping wells.
3. Constituents potentially impacted by decreasing trends in pH across the site.
4. Newly installed wells with interim GWCLs.
5. Other constituents and wells.

This SAR addresses THF in MW-01 which falls into category five: other constituents.

### 2.1 Approach for Analysis

The first step in the analysis is to perform an investigation of the potential source of the exceedance. EFRI will provide documentation from published studies and papers that indicate that THF is persistent (over many years) in monitoring wells constructed using solvents and adhesives. Section 2.2 recaps the history of prior studies and correspondence. Section 2.3 provides results of the literature review.

### 2.2 Prior Studies and Correspondence

THF is the most common solvent used for commercial Grignard reactions such as the Grignard reaction used by refineries to produce alkane hydrocarbons for fuels, including kerosene and is used as a solvent for PVC manufacture (US EPA 2012). Furans and alkoxyethyl furans are known to be added as conditioners for anti-wear properties and freeze prevention in the formulation of fuels, including kerosene, diesel and jet fuel. Therefore, although the Mill does not use THF as a reagent or solvent in the Mill's process, the kerosene used in the Mill's uranium and vanadium solvent extraction circuits likely contains THF residuals from the refinery kerosene synthesis or blending process. The Mill's annual tailings characterization data since approximately 2010 indicate it is present in the Mill's tailings system. Historic information on chemical and reagent use in the Mill laboratories and circuits do not identify any other use of THF on the Mill site. Used oils on site are controlled within lined secondary containment systems consistent with the Mill's Stormwater Pollution Prevention Plan and are, if they contain any THF, not a source of THF in groundwater.

However, as discussed in EFRI's letter of March 26, 2012 and subsequent correspondence, there is no plausible scenario that would explain the presence of THF in a perched groundwater monitoring well (completed in the Burro Canyon Formation) that is more than 2,200 feet (0.4 mile) up-gradient of the tailings system. Perched groundwater elevations in MW-01 are approximately 9 feet higher than those beneath the upgradient portion of the tailings system, precluding the possibility that perched groundwater could migrate from the tailings system to MW-01. Since there is no other source of THF as a reagent, solvent or constituent/contaminant

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of reagents or solvents at the Mill, there is no plausible way that Mill operations could release THF into perched groundwater and that THF could subsequently migrate 2,200 feet up-gradient.

An October 2003 letter from the supervising hydrogeologist who installed the Mill's initial monitoring wells MW-1 through MW-13, confirms that those wells were constructed of schedule 40 polyvinyl chloride ("PVC") pipe, utilizing the solvent and adhesive coupling method which was standard practice during the period from 1979 to 1982 when these 13 wells were installed. This letter was provided to DRC as part of a submittal from EFRI on October 17, 2003 and is not reproduced here. The wells constructed by this method include MW-01, addressed by this SAR and Literature Review.

As discussed in detail in the literature review in Section 3, below, the most common solvents used in adhesives or cements for PVC piping are ketones (2-butanone or "MEK", and methyl isobutyl ketone ["MIBK"]), and THF. THF is used as a softener and carrier for the monomer component of the glue which hardens and sets in air after application to the prepared pipe joint surfaces.

THF has a Henry's Law Constant of  $7.05E-5$  atm  $m^3$ /mole, very low compared to other ketones, and most aromatic solvents, indicating that THF is not readily volatilized. As a result, any solvent contained in the glue or cement applied to a PVC well pipe joint is not vaporized out of the cement before hardening, and may remain trapped in the pores of the hardened cement. Due to its solubility in water (up to 1,000,000 mg/L), it may leach from the cement over time as changing water levels bring the joint into contact with formation water.

The 13 wells indicated above were constructed over a period of 4 years. A number of factors can vary during the multiple construction dates and conditions under which these first 13 monitoring wells were installed, specifically:

- Different installation personnel may have used widely differing amounts of adhesive.
- Solvent content of the adhesive may vary from batch to batch.
- Adhesive setting conditions (ambient temperature and humidity) vary the speed at which the adhesive sets and therefore the quantity of THF and other solvents trapped in the hardened cement.

Therefore, even wells constructed by the same technology may vary widely in their residual THF concentration in the adhesive, and in subsequent water samples. As a result, some wells from that time period may exhibit elevated THF levels in groundwater samples, while others do not.

In December of 2005, EFRI conducted a study of MW-02 to evaluate PVC cement as the source of THF in a number of the Mill's older monitoring wells constructed with glued PVC. The study results, submitted in a report on June 26, 2007 were inconclusive because:

- a) the trip blank provided by the contract laboratory contained THF at 36 ug/L and
- b) THF which was typically present at elevated levels in MW-02 was not detected in well samples during that December 2005 test event.

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As discussed above, the presence or absence of THF in samples from any one sampling event from any one well from the MW-01 to MW-13 series does not mean it was not present in the well cements of that or any of the other wells in the series. As explained in Section 3.0 below, given the study demonstrating persistent presence of THF in laboratory water following installation of glued PVC plumbing (Wang and Brickner, 1979) , and the widespread presence of THF in quality control samples in the USGS Study (USGS 2012) the presence of THF in laboratory-originated samples is also explainable and not unexpected.

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### 3.0 RESULTS OF LITERATURE SURVEY

As committed in the Plan and Time Schedule, EFRI has pursued a literature survey of research and field studies by US EPA, USGS, and private organizations addressing water quality analyzed in samples from wells constructed with PVC pipe cemented with adhesives and/or primers known to contain THF. The results are enumerated below.

#### Soseby Laboratory Simulation

(Soseby 1983) In hazardous and Solid Waste Testing (Soseby, 1983.) the authors state, regarding wells constructed with PVC cements that:

“Standard well construction techniques may lead to the introduction of contaminants into the groundwater and can lead to incorrect conclusions concerning water quality.” With respect to THF in PVC cements, they stated as a result of their laboratory trials with six different PVC adhesives and one PVC primer that “PVC constituents added to the well during construction can be quite tenacious.” Every PVC adhesive or primer tested leached THF. (Most of the adhesives also leached MIBK, MEK among other volatile organic compounds [“VOCs”]). More importantly, the percent composition of the organics remained remarkably constant with successive washes with distilled water, intended to represent repeated well purging.

Other laboratory studies on cements used to join PVC pipe systems also showed leaching of ketones and tetrahydrofuran (Wang and Brickner 1979) (US EPA 1982), demonstrating an unexpected persistence of these solvents over time. The Wang and Brickner study was initiated after high concentrations of 2-butanone and THF continued to be present at high concentrations in laboratory supply water 6 months after installation of glued PVC laboratory water supply piping. Samples taken at 6 months and 8 months, at multiple residence times, indicated that MEK and THF concentrations increased with residence time over 48 hours to an equilibrium concentration. The samples taken at 8 months had generally higher THF concentrations than those at 6 months.

#### Martin and Lee Field Study on Frequently Purged Wells at Waste Disposal Site

William Martin and C. Chow Lee (Martin and Lee, 1989) evaluated groundwater samples from monitoring wells with glued PVC well casings, which were known to have extremely slow rates of recharge, at a chemical waste management facility. The wells evaluated had undergone repeated development and sampling over a seven year period. They repeatedly detected no THF during well purging, but increasing THF levels over a period of 2 to 4 days after purging. They concluded that:

“The further increase in THF concentration in 2 to 4 days after purging suggests that THF may be rapidly diffusing from the PVC glued joints into fresh formation water entering the well.”

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They found that after the initial increase, and 20 days ongoing purging, the THF concentrations still remained somewhat higher than before the initiation of purging. They concluded that the source of the THF was within the well casings.

#### *U.S. Geological Survey Study for National Water-Quality Assessment*

While developing protocols and standards of practice for the National Water-Quality Assessment (“NAWQA”) Program, the USGS noted as early as 1995, that well materials, design and installation can result in bias in analytical results for certain VOCs, which leach from PVC well casing glues. These included THF, MEK, MIBK, and hexanone (USGS 1995).

#### *U.S. Geological Survey Study Reporting Levels*

For a six year study on over 2,000 groundwater quality control samples for the California Water Resources Control Board (USGS 2012), the USGS determined that there is no concentration of THF above which detection in groundwater represents “real” aquifer conditions, as discussed below.

From May 2004 to September 2010, the USGS study attempted to develop Study Reporting Levels (SRLs) for VOCs for the Groundwater Ambient Monitoring and Assessment (GAMA) Program. For eighteen VOCs, including THF, regularly detected in field blanks or source-solution blanks. The object of the program was to determine whether there were concentration levels above which a groundwater sample could be considered to represent groundwater quality rather than sampling-related contamination. The highest concentration of three VOCs, including THF, occurred in groundwater samples and field blanks collected at sites where contamination of the methanol used to clean field equipment or the cement used to join PVC piping was documented.

“The observations that field blanks can contain high concentrations of acetone, 2-butanone and tetrahydrofuran, and that contamination from PVC cement at well sites can produce high concentrations of these three VOCs in groundwater samples, indicate that it is not possible to define a threshold concentration above which detections in groundwater have an acceptable possibility of being representative of aquifer conditions rather than due to contamination.”

Further, USGS determined that because it is not possible to establish a threshold level of acetone, 2-butanone, and THF above which detection actually represents aquifer conditions, analytical results data for these three constituents should be discounted and reported detections should be defined as “having no data available for these three VOCs” by changing the data quality indicator code to “reviewed and rejected.”

#### *Other Studies*

The literature review presented above focuses on THF from the cements used on PVC well casing. These and additional studies, not summarized here, also indicate that:

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- Cements used on PVC well casing also leach methyl ethyl ketone (2-butanone) and methyl isobutyl ketone into groundwater at levels comparable to THF (USGS 2012), and
  - PVC piping itself leaches its stabilizers, calcium, zinc, antimony, and tin, into groundwater samples (US EPA 1981/1982), (US EPA 1991).

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## 4.0 CONCLUSIONS AND RECOMMENDATIONS

Water level and elevation data indicate that the perched groundwater elevation in MW-01 is approximately 9 feet higher than the perched groundwater elevation beneath the upgradient portion of the Mill's Tailings Cells and therefore MW-01 cannot be impacted by Mill activities. Additionally, MW-01 is more than 2,200 feet (0.4 miles) upgradient of the Mill facilities. THF has never been used as a reagent, solvent or additive to the Mill's processes. THF is used by the petroleum industry as the solvent for the Grignard reaction used to produce alkane hydrocarbons such as the kerosene used in the Mill's solvent extraction circuits. THF is therefore expected to be a constituent in the Mill's tailings system, and tailings wastewater analyses have confirmed that it is present in the tailings system. However, its presence in tailings does not explain the detection of THF in wells as far up-gradient as MW-01. As previously stated MW-01 is far upgradient and cannot have been impacted by Mill activities.

THF concentrations which exceed the GWCL are likely the result of well construction practices in older monitoring wells that used adhesives and glues to join the casings. The US EPA, USGS and consultant studies summarized in Section 3 and cited in the references below have produced data which demonstrate that wells constructed with glued PVC casings continue to leach THF and other VOCs for months to years after installation, development and repeated purging of the wells. The reports and studies also conclude that:

- Repeated purging does not reduce the concentration of THF over time in leached from PVC wells with glued joints.
- THF levels in PVC wells with glued casings may increase for hours or days after purging/flushing prior to sample collection.
- THF is so ubiquitous in cemented PVC wells that there is no concentration at which detection of THF can be considered with certainty to represent aquifer conditions.
- Laboratory PVC piping is an additional contributor of THF and 2-butanone to analyzed samples.

Further, EFRI has identified contamination in at least one THF VOC trip blank (in Q3 2011), far above the GWCL for THF in MW-01 (as well as the GWCLs for most other wells). This finding is also consistent with the USGS findings above, that THF is not uncommon in laboratory supplied blanks and other QC samples, and render positive THF results from field sampling questionable.

As discussed above, EFRI requested in the October 10, 2012 SAR, that GWCLs be removed from up-gradient wells MW-01, MW-18, and MW-19. In a letter of April 25, 2013, DRC concurred with EFRI's determination that constituents in those wells were not from Mill sources, and that GWCLs in those wells could be removed. Per discussion with DRC in July 2013, DRC planned to remove the GWCLs from the up-gradient wells in an interim GWDP revision. The

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identification of two successive exceedances of the THF GWCL of 11.5 ug/L in MW-01 occurred after EFRI's assessment, and DRC's concurrence, that the GWCLs would be removed from MW-01, and before any GWDP revision was published by DRC.

Given that:

- the THF detected in samples from MW-01 is suspect, and most likely due to influences of solvent from the glued joints,
- MW-01, along with other up-gradient wells addressed in the October 2012 SAR are too far up-gradient to be influenced by Mill activities, and
- DRC has already concurred with removal of the GWCLs from MW-01, along with other up-gradient wells, then

EFRI believes that no corrective action is necessary or appropriate for THF in MW-01. EFRI proposes to do the following:

EFRI will continue to monitor THF in MW-01 quarterly beginning from the third quarter of 2013 through the second quarter of 2014, which is consistent with the accelerated schedule for this semi-annual well. EFRI will re-evaluate the status of THF in this well after those four quarters of monitoring data are collected. A discussion of the results will be included in the 2<sup>nd</sup> quarter 2014 quarterly groundwater report due to DRC on or before September 1, 2014.

If THF levels remain below the GWCL during the four quarters ending the second quarter of 2014, EFRI will resume semi-annual monitoring of MW-01 for THF. If THF exceeds the GWCL during these four quarters, EFRI will continue accelerated (quarterly) monitoring for THF in MW-01 until removal of the GWCL occurs with the publication of the revised GWDP.

**Table 1**  
**Summary of Findings**

<b>Well</b>	<b>Out-of-Compliance Constituent</b>	<b>Summary</b>	<b>Path Forward</b>
MW-01	THF	MW-01 is located approximately 2,200 feet (over 0.4 miles) up-gradient of Mill operations.	Continue to monitor THF in MW-01 for four quarters. Remove from accelerated sampling if THF concentration does not exceed the GWCL. Remove GWCL (revise GWDP).

## 5.0 REFERENCES

- Energy Fuels Resources (USA) Inc. (EFRI), 2010-2013. White Mesa Uranium Mill Groundwater Monitoring Reports
- Hurst, T.G., and Solomon, D.K., 2008. *Summary of Work Completed, Data Results, Interpretations and Recommendations for the July 2007 Sampling Event at the Denison Mines, USA, White Mesa Uranium Mill Near Blanding Utah*. Prepared by Department of Geology and Geophysics, University of Utah.
- Martin, William H. and C. Chow Lee *Persistent pH and Tetrahydrofuran Anomalies Attributable to Well Construction*. Woodward-Clyde Consultants, Oakland, California 1989
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- Soseby, J. P. Geiszler, D. Winegardner, and C. Fisher. 1982 Contamination of Groundwater Samples with PVC Adhesives and PVC Primer from Monitoring Wells. Environmental Science and Engineering, Inc. Gainesville, Fla.
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- U.S. Environmental Protection Agency. EPA 160014-891034. *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*. March 1991
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- U.S. Environmental Protection Agency. EPA 635/R-11/006F *Toxicological Review of Tetrahydrofuran (CAS No. 109-99-9) In Support of Summary Information on the Integrated Risk Information System (IRIS)* February 2012.
- U.S. Geological Survey. Open File Report 95-398 *Ground-water Date-Collection Protocols and Procedures for the National Water-Quality Assessment Program: Selection, Installation, and Documentation of Wells, and Collection of Related Data*. 1995.
- U.S. Geological Survey. *Water Resources Investigation Report 96-4233 Guidelines and Standard Procedures for Studies of Groundwater Quality: Selection and Installation of Wells, and Supporting Documentation* 1996.

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Wang, T. and J. L. Brickner. 1979 2-Butanone and Tetrahydrofuran Contamination in the Water Supply. *Bulletin of Environmental Contamination and Toxicology*. 23:620-623