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OFFICE OF
ENVIRONMENTAL
CLEANUP

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MEMORANDUM

SUBJECT: Addition of STAR Technology for Quendall Terminal Site

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TO: Site File

The purpose of this technical memorandum is to provide documentation supporting the addition of Self-Sustaining Treatment for Active Remediation (STAR) to the array of potentially viable technologies for use at the Quendall Terminals Superfund Site.[1] STAR will be included to the candidate alternatives assembled for the site given the potential of this technology to treat principal threat waste (PTW) present in the upland soil at the site.

The following sections:

- Describe the STAR technology
- Discuss the Applicability of STAR to the Quendall Site as an enhancement to EPA's Preferred Alternative (Feasibility Study [FS] Alternative 7)[2]
- Identify changes to the CERCLA Nine Criteria Comparative Analysis of Alternative 7 in the context of possible STAR implementation
- Highlight the potential benefits of STAR compared to *In Situ* Stabilization (ISS) for Future Site Development

Description of STAR Technology

STAR is a patented treatment technology that has been developed by Savron Solutions located in Guelph, Ontario, Canada (www.savronsolutions.com). The technology is based on the principals of smoldering combustion. It can be applied *in situ* or *ex situ*, in both saturated and unsaturated conditions. The treatment approach is suited for soil contaminated with coal tar, creosote, and petroleum hydrocarbons including non-aqueous phase liquid [NAPL] under oil-coated or oil-wetted[3] field conditions. STAR is a thermal oxidation process that results in the destruction of the target contaminant through a smoldering combustion reaction. The net products of thermal oxidation are carbon dioxide, carbon monoxide, water, and heat. Smoldering combustion (analogous to charcoal burning in a grill) is a distinct and different form of thermal oxidation which differs from flame combustion. In flame combustion, solid or liquid fuels are initially gasified by external energy input which allows for direct oxidation in the vapor phase. Conversely, smoldering combustion is an oxidation process that occurs at the surface of a solid or liquid fuel. Smoldering combustion is regulated by the diffusion of an oxidant

[1] The FS defines upland PTWs for the Site as dense non-aqueous phase liquid (DNAPL) and DNAPL-impacted soil located east of the shoreline.
[2] Aspect Consulting. 2016. Feasibility Study, Quendall Terminals Site. Prepared for U.S. Environmental Protection Agency, Region 10. December 2016.
[3] The estimated lower concentration limit for STAR application ranges from 3,000 to 5,000 milligrams per kilogram (mg/kg) of total petroleum hydrocarbons (TPH).

into the fuel matrix and for this reason the oxidation process can be readily controlled, especially within a porous media such as contaminated soil.

The basic premise for STAR is as follows:

1. The STAR process begins by inserting a heating element into the target treatment zone. A short duration input of energy is then applied to heat the NAPL adjacent to the heating element to the target ignition temperature.
2. Once this temperature is attained (typically between 200°C and 400°C), air is injected to ignite the NAPL within the porous media. The NAPL is thermally oxidized, releasing heat energy that is retained by the porous medium to pre-heat NAPL farther away from the ignition point.
3. The heating element can then be turned off, and as long as sufficient air is supplied, the combustion process will continue, propagating away from the air injection point. Through this process, NAPL is destroyed by thermal oxidation.

Figure 1 illustrates the *in situ* STAR application (figures follow the text).

Applicability of STAR at Quendall (Alternative 7 Enhancement)

The Quendall FS alternatives currently employ two technologies to address upland PTW: In situ stabilization (ISS) and excavation with onsite treatment or offsite disposal. Alternatives 3 through 9 all include targeted ISS treatment, while Alternatives 4, 9, and 10 also include targeted excavation.

ISS was selected as the primary technology for upland PTW because it was viewed as being a more viable alternative compared to excavation and disposal/onsite treatment. Although the excavation-based alternatives are expected to be more effective at reduction of PTW, implementation will be challenged by several factors including increased cost. For comparison, the FS estimated costs to apply ISS to all of the upland PTW at approximately $26M versus $78M for excavation and onsite thermal desorption.

Conventional *in situ* thermal treatment technologies were <u>not retained</u> in the FS for various reasons. Notable limitations of these technologies projected to the site-specific conditions included:

- Limited effectiveness based on the heterogeneous Shallow Alluvium soils where the PTW is located. In addition:
  - Low-temperature thermal treatment (hot water injection, electrical resistance heating, thermal conductive heating) were viewed to have low to moderate effectiveness given the potential to mobilize DNAPL and given the subsurface heterogeneities, making injection/recovery difficult, potentially leaving residual DNAPL untreated. The FS labeled low-temperature thermal treatment as a developing technology.
  - Mid-temperature thermal treatment (steam injection, electrical resistance heating, and thermal conductive heating) were viewed to be moderately effective, but the subsurface heterogeneities complicate heating and contaminant extraction, potentially resulting in pockets of untreated and unheated soil.[4] The FS labeled mid-temperature thermal treatment as “demonstrated at a few coal tar/creosote sites.”

[4] Note that site conditions are too shallow for steam-enhanced extraction (SEE).

   - High-temperature thermal treatment (thermal conductive heating) was noted as having potentially high effectiveness, but achieving temperatures greater than the boiling point of water would require significant dewatering. The FS labeled high-temperature thermal treatment as "not widely demonstrated".

- More cost-effective methods for in situ treatment of DNAPL are available.

In situ chemical oxidation was also not retained in the FS because:

- It was assumed the quantity of reagent required to oxidize free-phase DNAPL in situ across a large portion of the upland could be difficult and costly to inject.
- Multiple injections may be required to achieve remediation goals.
- More cost-effective methods for in situ treatment of DNAPL are available.

STAR is being proposed as an applicable in-situ treatment technology for the Quendall uplands because:

- STAR can destroy the site contaminants in situ; whereas, ISS only immobilizes site contaminants.
- STAR has lower sensitivity to heterogeneities versus conventional thermal processes.
- Quendall contaminant types and mass are expected to readily support combustion.
- Sufficient subsurface permeability exists to inject air.
- STAR can be readily scaled and implemented using simple, off the shelf, components (air injection + heaters [ignition source]).
- STAR infrastructure requirements are significantly lower than conventional thermal processes.
- Extraction of groundwater and DNAPL during treatment is not required.
- STAR processes include concurrent vapor extraction and will afford for control of nuisance odors during site remediation
- When compared to conventional remediation technologies such as excavation/disposal and ISS, the unit treatment cost for STAR may be as much as 50 and 75 lower, respectively (Grant *et al.*, 2016).

Site investigation has demonstrated that subsurface DNAPL is primarily encountered below residual saturation or associated with small stringers (not pools). Therefore, expectations remain high that ISS will readily immobilize the DNAPL through mixing and distribution within the vertical soil column. Although ISS is assumed to be the primary technology applied to the site, STAR could offer significant advantages over ISS. However, before the efficacy of either technology can be demonstrated under site conditions, additional investigation and development of both technical approaches will be required.

EPA anticipates that treatability testing will be required during remedial design to determine the required performance specifications for ISS implementation at the site. In practice, soil would be solidified *in situ* using large-diameter augers and with concurrent addition of pozzolanic (cementitious) reagents. The actual amendment types and mix ratios are tested in the laboratory to support remedial design and specification then subsequently demonstrated during field implementation. Laboratory testing remains a key element of any ISS operation specifically to confirm that subsurface mixing is complete and that field permeability and strength requirements are achieved. Depending on the concentration of amendments added, it is estimated that the soil volume would increase between roughly 10 and 30 percent as a result of solidification. Because it is anticipated that future site development would require an overall grade increase, no removal or disposal of excess soil is anticipated with ISS.

The potential application of STAR to the site would follow a similar path, however testing efforts would incorporate both laboratory and field based study efforts. Laboratory testing using site soil would be performed to ensure the site related contaminants are capable of supporting a smoldering type combustion. Given successful laboratory testing, a field-scale study of STAR would be commissioned to serve the following objectives:

- Demonstrate the treatment concept under site conditions
- Assess the lateral and vertical influence of combustion front propagation in the subsurface
- Identify boundary conditions for treatment performance to develop full-scale cost estimates
- Obtain site-specific data to support the full-scale design and application of STAR for the treatment of the waste types present in the upland source areas of the site.

The scope and scale of mixing reagent selection would be similar to STAR testing in the laboratory. However, implementation of STAR at the field scale is expected to be significantly smaller in effort and scope than an ISS demonstration. In addition, a field scale STAR demonstration will return net benefit in that contaminants will be destroyed rather than encapsulated and immobilized. Overall, STAR application to the site affords greater flexibility in both remedy implementation and overall protectiveness since PTW is destroyed. STAR will also allow a more precise application of the technology to focus only on PTW versus treating uncontaminated overburden materials.

As shown in Figure 2, STAR and ISS can both be depicted as viable technologies for the upland PTW. Figure 2 includes the identical graphic from the FS for Alternative 7 with an updated legend item for PTW area targeted for ISS (the orange area). Given current understanding of site conditions, STAR could initially be considered for the areas with the greatest contiguous thicknesses of DNAPL. Pending favorable demonstration, expanded treatment areas could be considered. In addition, since supplemental testing of both technologies is required before full-scale design can commence, integration of a field demonstration program for STAR is expected to have little impact to projected implementation schedules for full-scale remediation of the site.

Field Scale Effectiveness of STAR

There have been limited field scale applications of STAR to date, however, pilot and full-scale results from application of STAR for treatment of a former creosol manufacturing site in New Jersey are compelling. A pre-design evaluation (PDE) for STAR commenced at the site in 2013. Using a single well ignition source and air injection, more than 4,500 kg of coal tar was destroyed *in situ* using the STAR process. Post-treatment sampling within the demonstration area revealed the average concentration of total petroleum hydrocarbons was reduced in excess of 99%. Based on results of the field demonstration, a full-scale STAR approach was developed to treat coal tar which is present across large areas of the 37-acre site, in a depositional environment and depth similar to the Quendall site. Full-scale application of STAR at the New Jersey site commenced in 2014 and remains on-going to date.

Under the current field application STAR is implemented and operated in cells composed of 6 ignition points and air injection wells which has been demonstrated capable of destroying subsurface coal tar at a rate of tons per day.

In addition to the full-scale STAR application in New Jersey, PDEs have been performed at three other additional coal tar sites in Europe and the United States. An ex-situ variation of STAR has also been successfully demonstrated for the treatment of refinery separator sludge in the Philippines. Savron Solutions report that under all field evaluations, the application of STAR has resulted in the destruction of the target waste materials under controlled and predictable operating conditions. Unit treatment costs for STAR application to field sites referenced were not cited or reported. However, even if ISS costs presented in the FS for the Quendall site were equal to STAR (a conservative assumption based available references), technology application results in waste destruction, which is an inherent limitation of ISS. Assuming STAR unit costs are equal to ISS provides a conservative basis for technology evaluation and is more than adequate to perform a basic comparative analysis of the technology congruent with the FS. As noted previously, available information suggests that STAR unit treatment costs may be considerably lower than ISS when all elements of a specific remedial technology are considered.

Subsurface contamination at the Quendall site is derived from coal tar and petroleum related compounds. Prior application of STAR to these materials have demonstrated technology efficacy; however, to fully assess feasibility to the site a laboratory-scale study followed by a PDE would need to be completed on site. The purpose of these efforts as previously noted would be to demonstrate the applicability of STAR to site contaminants and to obtain site-specific data to support full-scale design pending favorable performance in the laboratory. The PDE could be completed in an area where cumulative DNAPL thickness is high (e.g., the Railroad Area, see Figure 3) and, pending favorable results, also in an area where DNAPL thickness is lower to better understand the range of conditions to which STAR is applicable for the site. In the event that the laboratory testing or the PDE failed to show feasibility of the STAR technology, implementation of ISS could proceed in all areas of the site currently identified in the FS under Alternative 7.

Impact of STAR on the CERCLA Nine Criteria Comparative Analysis of Alternative 7

Alternative 7 (PTW Solidification [Upland] and Removal [Sediment]) has been identified by EPA as the Preferred Alternative because it satisfied the Threshold Criteria of **Overall Protection of Human Health and the Environment** and **Compliance with ARARs**, and was rated as "high" for **Long-Term Effectiveness and Permanence** and **Reduction of Toxicity, Mobility, or Volume Through Treatment**, as were Alternatives 8 through 10. Alternative 7 was differentiated from Alternatives 8 through 10, being rated higher for **Short-Term Effectiveness** and **Implementability**. **Cost** was also a differentiator, in that Alternative 7 costs were estimated at $82M versus $146M, $280M, and $425M for Alternatives 8, 9, and 10, respectively.

The addition of STAR to Alternative 7 as currently considered, has limited risk of reducing the remedy effectiveness or increasing costs, and will aim to strengthen the alternative's ability to satisfy the statutory preference for the treatment of PTW as stipulated by the National Contingency Plan. Supplemental considerations of STAR integration to Alternative 7 in context to threshold and balancing criteria evaluated by the FS are outlined in the following sections.

Overall Protection of Human Health and the Environment

From the FS: Alternative 7 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. It is rated "moderate" for Short-Term Effectiveness because of the extensive upland and in-water construction activities occurring over a multi-year period; however, the alternative is rated "high" for Long-Term Effectiveness and Permanence because PTWs are removed or treated. Addressing PTWs will have a greater contribution to groundwater restoration. To the extent required, protectiveness would be addressed via institutional controls and monitoring.

Impact of STAR Implementation*: The addition of STAR as a treatment option along with ISS would aim to elevate Overall Protectiveness of Human health and the Environment. An increase in Short-Term Effectiveness would be expected since the remedy implementation can occur with greater control and significantly lower potential for nearby receptors to be exposed to nuisance odor during ISS operations. Long-Term Effectiveness and Permanence would also be increased since more volume of material would be destroyed versus immobilized by ISS.*

Compliance with ARARs

From the FS: Alternative 7 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting maximum contaminant levels (MCLs) everywhere in groundwater. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met 100 years after remedial construction completion.

Impact of STAR Implementation*: The addition of STAR as a treatment option along with ISS will elevate Compliance with ARARs as the contaminant mass is destroyed, eliminating the potential leaching of contaminants that may occur locally from the ISS-treated materials.*

Long-Term Effectiveness and Permanence

From the FS: Alternative 7 is rated "high" with respect to long-term effectiveness and permanence because of its reliance on treatment and removal technologies to address all PTWs.

Impact of STAR Implementation*: The addition of STAR as a treatment option along with ISS will elevate the high rating of Alternative 7 since more volume of material would be permanently destroyed.*

Reduction of Toxicity, Mobility, or Volume through Treatment

From the FS: Alternative 7 is rated "high" with respect to reduction of toxicity, mobility, or volume through treatment because a large fraction of PTWs would be treated. The volume of contaminated groundwater and mass flux of organic chemicals of concern (COCs) to sediments would be greatly reduced over time.[5]

Impact of STAR Implementation*: The addition of STAR as a treatment option along with ISS will elevate the high rating of Alternative 7 since contaminant mass is destroyed versus immobilized.*

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[5] Alternative 7 would reduce the mobility of upland DNAPL, through in situ solidification, by approximately 377,500 gallons or 85 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material would not be reduced.

Short-Term Effectiveness

From the FS: Alternative 7 is rated "moderate" with respect to short-term effectiveness. There is a large increase in the amount of potentially contaminated sediments to be dredged and handled for off-site disposal; however, there are no DNAPL-impacted soils to be excavated and disposed off-site. No unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. EPA believes Alternative 7 should be rated "moderate" to differentiate this alternative from Alternatives 8 through 10 (rated as "low"), which have substantially greater short-term impacts, particularly in the upland area.

Impact of STAR Implementation: The addition of STAR as a treatment option along with ISS could elevate the "moderate" rating to "high" for Alternative 7 since contaminants are not brought to the surface via mixing, and are actively controlled by vapor extraction, eliminating exposure to site workers. In addition, STAR incorporates vapor extraction for the control of nuisance odors. Open mixing or excavation of coal tar and creosote-contaminated materials during ISS operations may directly impact residential and commercial receptors which surround the site. The addition of pozzolanic agents will create heat that can volatilize light-end hydrocarbons further exacerbating the issues associated with nuisance odor generation. Odor-suppressing agents, while effective, cannot eliminate the potential for odor generation that may require active extraction and treatment of vapor during ISS at the site. In the absence of active vapor extraction, the feasibility of ISS operations may be limited to those months (winter) when windows are kept closed in neighboring communities and there are generally fewer people outdoors for extended time periods. The use of STAR however would greatly minimize the generation potential for nuisance odors as treatment operations are performed in-situ, with minimal disturbance of the subsurface. Like previous criteria that benefit from waste treatment and destruction, relative ratings of Alternative 7 including STAR application would be increased over the sole use of ISS.

Implementability

From the FS: Alternative 7 is rated "moderate" with respect to implementability. The much larger scale and volume of materials removed or treated compared to previous alternatives would introduce additional implementability challenges. However, Alternative 7 involves fewer construction elements than most of the previous alternatives. The technologies are well understood and have been used for many years. Environmental dredging is a more recent technique but as experience with environmental dredging has increased, better practices have developed to minimize the generation of contaminated residuals and the management of such residuals, as evidenced in recent local dredging projects, such as the Boeing project in the Duwamish River. Engineered caps are relatively easy to repair or replace compared to reactive core mat (RCM) caps. Monitoring is expected to be relatively simple to implement given that DNAPL-impacted media will be treated or removed, unlike other alternatives that leave more DNAPL-impacted media in place in perpetuity. Lengthy construction schedules may result in more schedule modifications than previous alternatives. However, alternatives with more construction elements could also result in schedule complications because of more complicated coordination of multiple remedial activities sometimes in a short period of time.

Impact of STAR Implementation: The addition of STAR as a treatment option along with ISS would maintain or elevate the "moderate" rating for Alternative 7. Specific benefits of STAR include:

- *Implementation of STAR can be phased to treat smaller areas. This differs from ISS where economics of treatment operations favor contiguous treatment of large soil volumes. The direct benefit is that working in smaller volume areas will minimize the potential for nuisance odor generation. A secondary benefit can be realized in lower mobilization and costs to implement STAR versus a heavy construction activity like ISS.*
- *Completion of a field or pilot scale technology demonstration for ISS would likely be integrated directly with a full-scale remediation approach. Initially, field observations and performance results would be applied in an iterative approach as necessary to guide modification of laboratory established reagent mixtures or mixing strategies to achieve the desired stabilization results.*
- *The full-scale applications of STAR are modular and rely on the reuse of system equipment and infrastructure in the treatment of multiple cells.*
- *Overall the application of STAR may be considered more sustainable since the destruction of the coal tar does not rely on the extensive use or consumption of manmade materials. The production of cement, a critical element of ISS is energy intensive and for every cubic yard of material that can be treated without mixing, STAR would offer demonstrable improvement in context to a sustainable remediation analysis.*
- *Since STAR is targeting treatment of DNAPL source as fuel to support smoldering combustion, a more precise application of the technology to focus only on PTW is feasible. Unlike ISS which must treat potentially uncontaminated overburden to reach a DNAPL zone at depth, STAR can target only the PTW waste interval resulting in significantly lower volumes of media to be treated on site.*
- *Identified limitations:*
  - *STAR may be considered an emerging technology as there are relatively few full-scale applications by which performance can be judged by EPA and project stakeholders.*
  - *STAR is premised on the thermal oxidation of organic materials in the subsurface. Accordingly, contaminants such as coal tar will be combusted by smoldering. In addition, organic material such as peat, wood chips or similar debris that is present in the combustion zone will also be oxidized resulting in the potential for subsidence in areas where thick organic deposits may occur.*
  - *STAR is a proprietary technology developed designed and implemented by Savron Solutions. Use of the technology in any application at the site would require compliance with Federal Acquisition Regulations (FARs) for use of sole source supplier. Acquisition of sole sources while feasible under the FARs can be complicated and subject to additional scrutiny given the magnitude of total project costs considered by this alternative.*
  - *STAR is not applicable for sediment remediation.*

Cost

From the FS: The estimated present worth cost of Alternative 7 is $82M, including a projected $79M for capital construction and $2.9M (present worth) for operations, maintenance, and monitoring.

<u>Impact of STAR Implementation</u>: The addition of STAR as a treatment option along with ISS is not expected to increase cost, and in fact may allow cost savings as suggested by a direct unit cost comparison to both ISS and excavation (Grant et al., 2016). Based on preliminary discussions with Savron Solutions, a conservative unit cost for STAR could be considered comparable to the ISS unit costs estimated in the FS at $70 to $90 per cubic yard. In addition:

- *Mobilization costs would be lower as STAR is not considered a heavy construction activity like ISS. As noted above, the full-scale applications of STAR are modular and rely on the reuse of system equipment and infrastructure in the treatment of multiple cells.*
- *Because mobilization costs for STAR are significantly less than ISS, implementation could be phased around available funding, without significant consequence. Conversely, given the size, complexity and projected capital cost of ISS operations contemplated by Alternative 7, the potential for complete treatment of the site with one mobilization of ISS equipment is highly unlikely. Therefore, if all ISS operations are not completed during a given mobilization effort, supplemental costs must be factored to the total remedy cost projections to remobilize necessary equipment and resources to complete the ISS operations.*
- *Laboratory treatability studies would likely be comparable or lower for STAR versus ISS, as ISS studies may involve several rounds of testing to achieve desired stability and leaching results.*
- *A field demonstration for STAR would be needed to confirm its effectiveness at Quendall. Based on information available from Savron Solutions, a single well PDE costs approximately $325,000. Conversely, because of the significant capital cost investment for ISS, completion of a field or pilot scale technology demonstration would likely be integrated directly with a full-scale remediation approach.*[6]

Benefits of STAR Versus ISS for Future Development

The EPA National Remedy Review Board, as well as EPA Region 10 staff, have expressed concerns that using ISS may create a barrier that could restrict groundwater flow, cause ponding and potential flooding on the site, and may also force groundwater to move north or south into the two neighboring sites, with uncertain consequences. The Board also recommended consideration of how long-term performance could be improved by managing surface water infiltration rather than allowing surface water to come in contact with the treated material.

The use of STAR, even in smaller targeted areas, would help mitigate issues related to groundwater flow restriction and potential ponding or spreading, as it would not appreciably change the hydraulic conductivity of the treated media.

Concerns have also been raised about constraints related to future site development over a large solidified monolith, should ISS be used to address all of the upland PTWs. ISS would constrain future site excavation required for structures, underground utility installation, etc. With STAR, there would be

[6] Initially, field observations and performance results would be applied in an iterative approach as necessary to guide modification of laboratory established reagent mixtures or mixing strategies to achieve the desired stabilization results.

no depth restrictions as the contaminant mass would be destroyed and the fill and native soils would be structurally similar to their current state.

Finally, implementation of STAR can be phased to treat smaller areas, and may allow for incremental development of the site. This differs from ISS where economics of treatment operations favor contiguous treatment of large soil volumes.

Summary

Based on the findings discussed above, the addition of STAR for the Quendall site may prove to be more effective, easier to scale and implement, and no more (possibly less) costly than ISS. It may also allow for phased development and fewer development restrictions than may be realized with an upland remedy that relies solely on ISS.

Reference

Grant, Gavin P., D. Major, G. Scholes, J. Horst, S. Hill, M. Klemmer, and J. Neil Couch. 2016. "Smoldering Combustion (STAR) for the Treatment of Contaminated Soils: Examining Limitations and Defining Success", REMEDIATION, Volume 26, Issue 3, Summer 2016 (June 3, 2016), pp. 27-51.

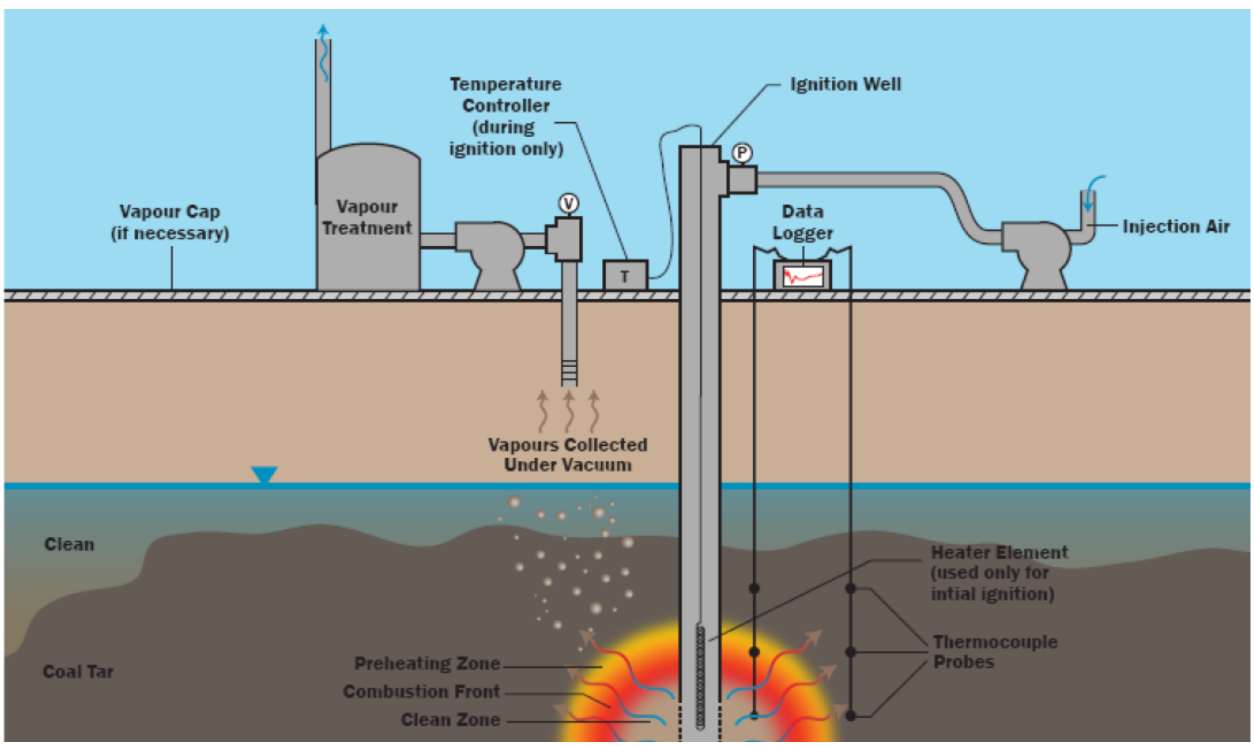

Figure 1. STAR Application In Situ
Graphic by Savron Solutions

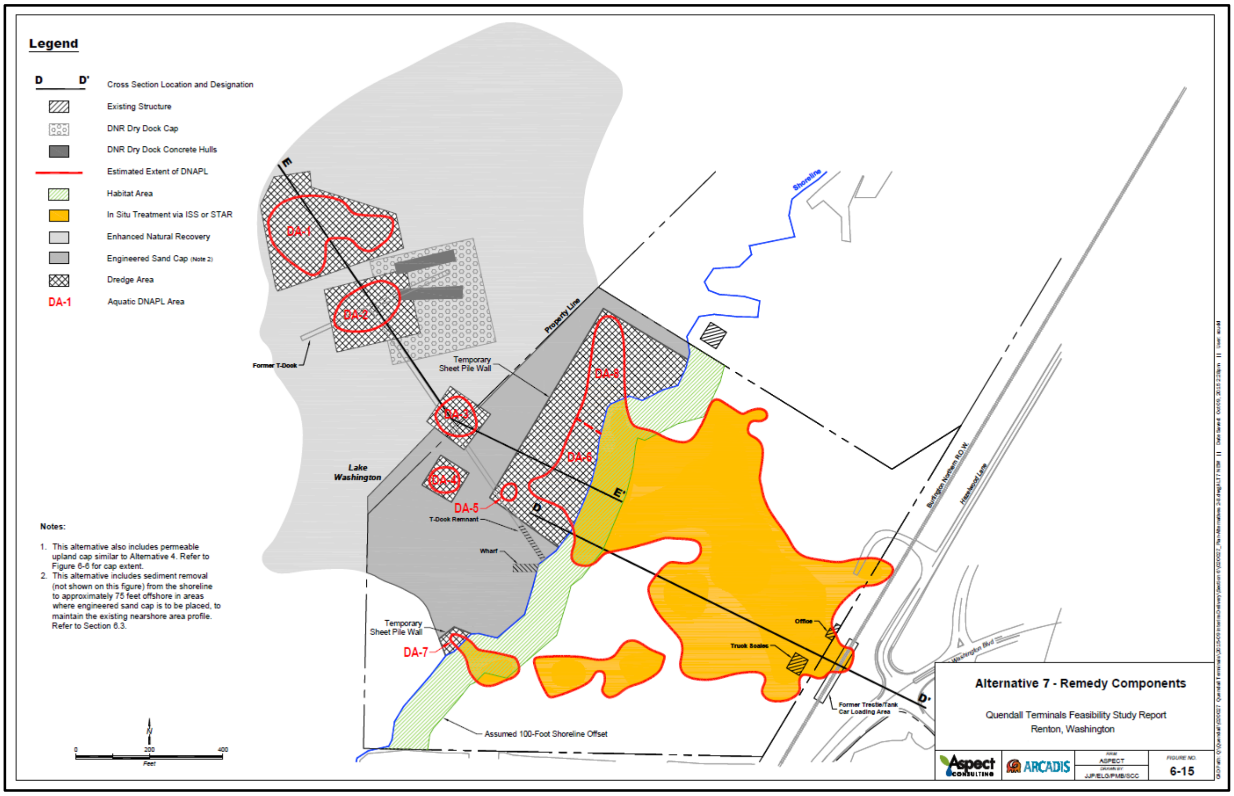

Figure 2. Alternative 7 –Revised Remedy Components
Quendall Terminals, Renton, Washington