SECTION THREE

<u>ABANDONED</u> <u>SHALLOW</u> <u>OIL</u> <u>WELLS</u>-DECONSTRUCTION, GEOPHYSICAL EVALUATION, SHOOTING, CEMENTING, AND PLUGGING METHODOLOGIES

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Author Note

This report is intended to be a basic field guide for on-site personnel when proper and permanent plugging methods are needed for addressing orphan wells which are discharging or threatening Surface Waters of the United States.

BASIC TEMPLATE FOR PLUGGING OIL WELLS THAT HAVE NOT BEEN PREVIOUSLY PLUGGED

STEPS:

1. Prepare the lease with heavy equipment. These activities include: excavating soils to locate the buried/obscured well (s), building roads, leveling out the site (s), and excavating the containment pits.
2. Move-in the single pole cable tool rig (also known as a workover rig and/or gin pole rig) and center it over the surface/production casing. Assure that the well site is completely level and properly graded. These units have a single drum and are used to service shallower (i.e. less than 800 feet deep) wells. The cable tool rig is small enough that it's possible to run it with just a crew of two people, however, an extra hand is recommended. The draw-works consists of five main parts:

   - the drum,
   - the motor,
   - the reduction gear,
   - the brake, and
   - the auxiliary brake.

   The draw-works are often attached to a diesel engine. The number of speeds could be one, two or three speed combinations. The main brake, usually operated manually by a long handle, may be a friction band brake, a disc brake, or a modified clutch. It serves as a parking brake when no motion is desired. The auxiliary brake is connected to the drum, and absorbs the energy released as heavy loads are raised or lowered. Draw-works can be used to hoist or lower tens of thousands of pounds of weight. Accordingly, horsepower ratings for the draw-works can also have a wide range. **Refer to Appendix: 1 for a detailed discussion of the guidelines for an oilfield gin pole truck.**

3. Raise the mast and secure it, using all the associated guide wires and anchors. Mark these wires with bright flagging for clear visibility. **See Appendix: 2 for OSHA requirements.**
4. Stage neatly all associated rig equipment, (especially work-strings (including, but not limited to: one-inch and two-inch diameter tubing for well cleanout); swedges (aka swages or reducers); drilling bits for removing scale/debris from the inside casing surfaces; rig bales; lifting bails; air slips; tools (especially hammers, wrenches, cheater bars, and cutting torches); elevated work racks; and so forth. A swedge (also known as a swage) is a short crossover joint used between two sizes or specifications of casing and/or tubing. Because of its cupped shaped, it may be used on the inside of the production casing to remove scale. **The reader** is **referred to Figure: 1 to facilitate his understanding of the configuration of a swedge** (a.k.a, swage nipple). FYI- Most drillers refer to a "swage" as a "swedge." While rig-up activities are occurring, take time to review the NIOSH Rig Inspection Forms, MSDS Sheets for Crude Oil,

Hydrogen Sulfide, and NORM (TENORM) Advisory Documents. **See Appendix: 3, Appendix: 4, Appendix: 5, Appendix: 6, and Appendix: 7.** Establish Health and Safety monitoring.

5. Place the (i.e. filled) water truck/storage tank, pumps, and associated hoses proximal to the rig to facilitate downhole flushing activities.
6. After assuring that the well is not under pressure, remove the well head assembly (if present) to ascertain whether the well contains injection tubing, production tubing, and/or sucker rods. Note: When both the tubing and the pumping rod string are to be removed from the well at the same time, it's called stripping the well. **See Figures 2A and 2B.**
    a. **If the rods and tubing are present, proceed to Step 7.**
    b. **If there are not any sucker rods, but the well has tubing, proceed to Step 8.**
    c. **If there are no rods or tubing in the well, proceed to Step 8 and then immediately to Step 22 and then Step 49.**
7. When pumping rods (a.k.a. sucker rods) are pulled from the well, they need to be unscrewed from the rod below it to be removed. This unscrewing process is referred to as "breaking the box," with the box being another name for the female side of the screw. The rod string is broken when the individual rods are turned enough times in the counter-clockwise direction. The upper part can be pulled and this is repeated until the entire rod string has been pulled from the well. **See Figure: 2, Figure: 3, and Figure: 4.** (Note: A sucker rod is a steel rod between 25 and 30 feet in length, threaded at both ends, and is used in the oil well to join the surface pump jack and its components to downhole elements of a reciprocating piston pump installed at the bottom of an oil well). The use of a set of sucker rod air slips is mandatory during this step to lock and hold the remaining sucker rod string at land surface while individual rods are being removed. If the individual rods cannot be disassembled by hand, a cutting torch may be needed. As the production rods are disassembled from the inside of the production tubing, begin pulling and tallying them at land surface to determine the approximate depth of the well. Continue extracting the individual rods until all sections are removed from the production tubing. Stage the afore-mentioned rods in a neat and tidy fashion on elevated storage racks. It is highly recommended that once the production string is extracted from the well, a Naturally Occurring Radioactive Material (NORM) survey be undertaken to preclude any unnecessary exposure to any of the onsite personnel to Radium and/or its associated daughter decomposition products. If elevated readings are detected (i.e. above health-based action limits), the rods will need to be moved to a secure and isolated location and marked clearly with CAUTION tape. NORM contamination can be infrequent and sporadic within the Country, so radiation surveys are recommended on all well plugging sites. Individual personal dosimeters are also recommended to be worn by onsite personnel for the duration of the job. Air monitoring is necessitated throughout all work activities.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

8. Measure the INSIDE diameter of the production casing. (It is often between 4.5 and 6.5 inches in diameter). Record this information and communicate this information to the lead driller and/or vice versa). The inside diameter of this pipe determines the size and width of the drilling bit, scraper, and/or swedge (a.k.a. reducer or swage)) needed to remove the scale and debris from the inside of the production casing (once wash-down activities are initiated). The purpose of taking this measurement at this step is to assure that one has the proper sized bit or scraping apparatus on site and/or to allow time to rent specialty tools (when necessitated) to perform this task. Note: If surface casing (often 8 inches or more in diameter) is present on the outside of this, no actions are necessitated. Hook up the fresh water truck to the water circulation hoses and the circulation pump (via pump truck or stand-alone pump) in anticipation of loading the well with water. **Proceed to Step 50.**
9. Assemble a one-inch diameter work string (a.k.a. circulation tubing) at land surface and insert it into the production/injection tubing (approximately 2.375-inch tubing) in the well and begin pumping the fresh water. At about the same time, fill the well annular space between the outside of the production tubing (2.375 inch and the production casing). Continue to circulate fresh water throughout to prevent the well from flowing oil and gas at land surface. This will help "kill" the well and dissipate any downhole pressures. Before a workover can begin, the well must be killed. This means that the pressure of the oil production formation must be equaled by the pressure of the water column above. Keep inserting the one-inch work string into the production/injection tubing to ascertain whether the latter remains continuously open vertically throughout. Note and record any problematic depths (i.e. partings or places where the circulation tubing experienced difficulties advancing down the well). Once on bottom, record the total depth of the well. Extract the work string from the production tubing once the well is in equilibrium.
10. Remove the production tubing batten clamp (if present) at land surface by loosening the associated bolts and nuts or by cutting it off with a torch.
11. Begin assembling a (1 or 2- inch diameter) work string (i.e. circulation tubing) at surface for insertion into the annular space (i.e. between the production and/or injection tubing and the inside of the production casing). Continue to run it downward until it reaches refusal or preferably at or near the top of the packer (which secures the tubing to the production casing). If refusal is encountered, begin circulating fresh water via the work string to dislodge any scale or to obstructions and/or to dissolve any mineral residue. Work the tubing up and down (at surface) to facilitate washing down the well and hopefully to reach the top of the packer. (Note: The top of the packer can be estimated by tallying up the total length of the rods extracted from the well, associated well completion records, well records from nearby units, or by tallying up the work string in the well. Bridges in the production casing may be caused by

corrosion, parting of the individual strands of pipe, the build-up of salt (mineral deposits) over time, and scale. There is no way to know which condition may be causing the problem.

12. Continue to circulate water via the annular space (i.e. between the casing and the tubing) to land surface for a few hours (as prescribed by the driller) hopefully to reach the top of the packer and/or the total depth of the well.
13. Once the work string reaches the top of the packer (or total depth of the hole when there is no packer), load the inside of the production casing and production (or injection) tubing with fresh water. The column of water on the inside of the casing and the inside of the production or injection tubing is intended to dissipate any down hole pressures that may exist associated with the petroleum reservoir.
14. When the pressures are properly normalized, extract the work string from the annular space (between the outside of the production tubing and the inside of the production casing). Disassemble the work string and neatly stack it adjacent to the well where it will not impede all associated work with operating the cable tool rig and its associated draw- works.
15. Assemble and attach the lifting bales (if appropriate) and the air slips to the cable to enable the extraction of the production and/or injection tubing in the well.
16. Place the air slips directly below the first exposed collar of production tubing (at land surface) and secure them tightly to ensure that it remains closed. The production tubing (a.k.a. pipe) may become stuck downhole (for reasons previously specified in Step 11). The driller will begin to manipulate the cable tool draw works (up and down) at a low speed to break the tubing and/or associated packer loose from the well. Continue to pump fresh water into the well at land surface. These extraction activities may continue for 1-2 hours (or more) and are up to the discretion of the drill rig supervisor and crew. **If one is successful in removing the production tubing, proceed to Step 24 and continue following steps.**
17. If after several hours of manipulating the draw works up and down, and the production tubing (and packer) remain stuck in the well, reassemble a one-inch diameter work string (a.k.a. circulation tubing) at land surface. Insert it into the production/injection tubing (approximately 2.375-inch tubing) in the well and begin pumping the fresh water again to remove oil, debris and scale from the well. Based on the packer depth information obtained in Step 11, continue to advance the circulation tubing past this depth and tag the bottom of the well with the one-inch diameter work string. Circulate fresh water via the pump at land surface and through the work string to properly clean out the portion of the well below the packer. Continue flushing activities for approximately 6-8 hours and/or until the discharge water remains mostly clear.
18. Record the following information to assist (later) in calculating the volume of Class-A Portland Cement needed to plug the well below the packer: the diameter of the borehole and/or the inside diameter of casing (below the stuck packer), the outside diameter of the production

tubing, the depth of top of the packer, and the total depth of the hole. Since the tubing is stuck in the hole, the intent will be to kill the well using cement being circulated from land surface via the one inch diameter tubing that is being run to total depth on the inside of the 2.375-inch diameter production tubing.

19. Calculate the annular capacity and the annular volume using several formulas as shown below:

a) Calculate annular capacity in barrels per foot: (bbl)/ft

Annular capacity in bbl/ft = $(Dh^2 - Tp^2) \div 1029.4$

Example: Hole size (Dh) = 6 1/8 inches or 6.125 inches

Production tubing (Tp) = 2.375 inches outside diameter

Annular capacity in bbl/ft = $(6.125^2 - 2.375^2) \div 1029.4$

Annular capacity = 0.0310 bbl/ft

b) Calculate annular capacity in ft/bbl

Annular capacity in ft/bbl = $1029.4 \div (Dh^2 - Tp^2)$

Example: Hole size (Dh) = 6.125 inches

Production tubing (Tp) = 2.375 inches (outside diameter)

Annular capacity in ft/bbl = $1029.4 \div (6.125^2 - 2.375^2)$

Annular capacity = 32.295 ft/bbl

Note: One barrel (bbl) equals 42 gallons.

Calculations (Continued)

c) Calculate annular capacity in gallons per foot (gal/ft)

Annular capacity in gal/ft = $(Dh^2 - Tp^2) \div 24.51$

Example: Hole size (Dh) = 6.125 inches
Production tubing (Tp) OD = 2.375 inches

Annular capacity in gal/ft = $(6.125^2 - 2.375^2) \div 24.51$

Annular capacity = 1.300 gal/ft

d) Calculate annular capacity in ft/gal

Annular capacity, ft/gal = $24.51 \div (Dh^2 - Tp^2)$

Example: Hole size (Dh) = 6.125 inches

Production tubing (Tp) = 2.375 inches

Annular capacity in ft/gal = $24.51 \div (6.125^2 - 2.375^2)$

Annular capacity in ft/gal = 0.769 gal/ft

20. Once the above calculations are made and the volume of cement (needed for filling the annular space below the packer) is determined, instruct the driller to begin mixing the Class A Portland Cement to a weight of 18 pounds per gallon. To obtain 18 pounds per gallon slurry, one must mix about 5.2 gallons of fresh water per 94 pound (dry weight) sack of cement.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

The user is referred to *Appendix* 8. (The Author and Publishing Date are unknown). This same Appendix provides the reader with pertinent background relating to the American Petroleum Institute (API) Classes of Cement, including but not limited to: density, fluid loss, differences between the different types of cement, factors affecting cement, primary cementing, etc.

Example Description:

Assume that one is preparing to plug the Royal Heirs # 2-W (Enhanced Recovery Well) located in Ohio County, Kentucky. The well has been determined to be 715 feet (Total Depth) below land surface. This determination is made based on the original well log provided by the Commonwealth of Kentucky and by inserting the 1.00-inch diameter circulation on the inside of the 2.375-inch diameter injection tubing through the packer until it tagged bottom. The top of the packer has been determined to be 650 feet below land surface. The well is open hole below the packer, and the hole diameter below that point is 7.5 inches. The injection tubing runs through the packer at 650 feet to 715 feet. The production casing directly above 650 feet is 5.0 inches in diameter.

NOTE: It is recommended that one draw the well to scale on a piece of paper to facilitate a better understanding of its overall construction.

Calculate the volume of cement (in gallons) needed to plug the well between 650 feet and 715 feet.

Example: Hole size (Dh) = 7.50 inches
Production tubing (Tp) = 2.375 inches

Annular capacity in ft/gal = $(7.50^2 - 2.375^2) \div 24.51 = 2.06$ gal/foot (**i.e. Gallons of Cement per Vertical Foot of Hole).**

Open hole below stuck packer: (715 feet – 650 feet) = 65 vertical feet of hole

Cement needed to be mixed and below the packer = 65 feet x 2.06 gal/ft = 133.9 gal

Number of 94-pound sacks of dry cement needed to obtain 18 lbs/gal slurry = 133.9 gal cement slurry x 18 lbs/gal of cement slurry x 1 sack cement/94 lbs of dry weight cement = 25.6 sacks

Note: Mix an additional 10-15 percent of cement (ABOVE AND BEYOND THE CALCULATED VOLUME) because some of the pumped volume will be lost to the geologic formations.

An alternative method for calculating the volume of cement needed is for the user to refer to the Halliburton Cementing Tables found in *Appendix 9*. **These are printed with permission of the company.

21. With the work string (i.e. one-inch diameter tubing) inserted through the 2.375-inch diameter tubing and through the packer (i.e. hanging proximal to the total depth of the well), pump the calculated volume (including the added volume as specified above) of Class A cement into the portion of the well that is below the packer.
22. Once the cement has been spotted at the bottom of the hole, begin extracting the work string from the well tubing. As the circulation tubing is being pulled at land surface, rinse the component sections (inside and out) with fresh water to remove the cement slurry from the impacted surfaces. Continue to rinse, pull and disassemble the work string from the well until the entire span is removed. Neatly organize and stack the individual sections on elevated work racks to preclude a trip hazard. Allow the cement to harden overnight.
23. Contact the **QUALIFIED** Downhole Geophysical Well Logging Company to request their services on the following day(s). Requested services will include any (or all) of the following tasks: Cement (Variable Density) Bond log, (VDL), Natural Gamma-Ray Log, Neutron-Neutron Log, Casing Collar Locater (CCL) summary Log, Radial Explosive-Based Tubing Cutters, and/or High Explosive (such as RDX) Perforating Guns. The uses of each are presented below:

TYPES OF DOWNHOLE GEOPHYSICAL LOGS USED FOR WELL PLUGGING

Ofwana, 2014, provides a succinct description for the Cement Bond Log (VDL), the Natural Gamma-Ray Log (G), the Neutron-Neutron Log (N), and the Casing Collar Locator (CCL) for the reader. It is as follows:

Cement Variable Density Bond Log (VDL)

Cement Bond Logs use sonic tools that work by transmitting a sound wave through the casing, cemented annulus into the rocks of the borehole wall. A basic sonic tool consists of two parts. One contains the transmitter and the other contains two or more receivers. The two parts are normally separated by a rubber connector to reduce direct transmission of acoustic energy along the tool from the transmitter to the receiver.

Types of Downhole Geophysical Logs used for Well Plugging: (Continued)

VDL (continued)

The transmitter injects a sinusoidal wave-train of acoustic energy into the formation. The detectors receive the signals whose arrival time will depend on the density of the media the signal has traversed. **The VDL is used for determining the cement bond quality between the cement and the casing and between the cement and the geologic formation for zone isolation. A Cement Bond Log is run to inspect the integrity of the cement sealing the outside of the production casing and the borehole at a series of geologic formations. This good bonding of cement ensures that undesired formation fluids (i.e. oil, gas or brine) will not flow into the well up or down the outside annulus (i.e. space between the casing and the wellbore), especially when the well is plugged permanently.**

Natural Gamma Ray Log (G)

Natural Gamma (G) is the simplest type of geophysical logs. The logging tools record the level of naturally occurring gamma ray releases from rocks around the borehole. The signals comprise gamma ray emissions at different energy levels from the radioactive isotopes of Potassium-40, Thorium-232, Uranium-238, and the associated daughter products of the decay series. The distribution of Potassium, Thorium, and Uranium varies widely in the crust and as a result, logging of gamma ray signals emanating from the rocks around the borehole can provide considerable information about the geology (lithology) of the borehole.

Neutron (N)

Neutron (N) and Natural Gamma Ray (G) tools are usually run together. The Neutron sensors measure the water content of the rock because hydrogen atoms deflect Neutron particles emitted from the tool. Porosity is a function of rock type and slow neutron count. **When run in conjunction with one another, the G and the N logs are invaluable because they provide rapid, economical, and detailed information on the thicknesses, lithologic characteristics, fluid content, correlation, depth of strata, and identification of geologic formations by their established signatures for all formations penetrated by the well. Most geophysical Logs are recorded at a scale of 1- inch equals 20 feet. There are ten subdivisions per inch on the printed graphs which represent 2- foot intervals.**

Casing Collar Locator (CCL)

The CCL responds to changes in metal volume, such as pipe collars, perforation depths or intervals, locations of casing damage, well construction with respect to individual pipe

Types of Downhole Geophysical Logs used for Well Plugging: (Continued)

CCL (continued)

lengths comprising the well, and depth control in casing. The CCL, run in combination with a cased hole Gamma Ray, establishes the link between the individual geologic formations and the interval of pipe being scrutinized (as it pertains to perforations needed to successfully plug the well with cement on the inside and outside of the casing).

The CCL is an electric logging tool that detects the magnetic anomalies caused by the relatively high mass of the casing collars. The distortions are amplified within the tool and sent up hole as pulses that are recorded in millivolts of amplitude.

Note: For the reader who requires additional information regarding downhole geophysical surveys, Ofwana's article can be found in **Appendix** 9. **See Figure :5.**

DOWN-HOLE HIGH EXPLOSIVES: VARIETIES

Radial Explosive-Based Tubing Cutters

Explosive cutters use various explosives that are characterized by extreme energy release in a very short time. Some of the explosives used have a front movement on the order of 20,000 or more feet per second. The explosive and the liner are arranged in a wedge so that the associated explosive front of the device will push out on all sides and sever the tubing. Often the tubing that is cut is left with an outward oriented flare at the cut surface.

Perforating Bullet Guns

Perforating is a process used to establish a flow path between the annular spaces of the production casing and the well bore. Most commonly, RDX, HMX, PYX, HNS and other high explosives are used in the oil industry. For wells that are being plugged in the Commonwealth of Kentucky, an interval of four shots per foot is acceptable for poorly cemented and/or uncemented intervals portions of the well. Multiple shots are often required. Decision-making and characteristics for these will be provided later in this document.

In no instance, would one choose/implement the perforation of production casing at an identified collar (i.e. where two individual pipes are joined together). This will likely damage the well such that plugging the well could prove to be impossible. If the rods and tubing were removed in Step 6 (c), proceed to Step 25.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES (Continued)

24. Once the cement has hardened overnight, two actions must be accomplished prior to the arrival and setup of the Geophysical Well Logging Truck and its representatives. First, begin assembling a (1 or 2-inch diameter work string (i.e. circulation tubing) at surface for insertion into the 2.375 inch-diameter production/injection tubing. Continue to run it downward until it reaches refusal (a.k.a. top of cement circulated inside the production/injection tubing. **Record the approximate depth**. Circulate fresh water inside the tubing back to land surface. Remove the work string from the hole and stack it neatly on nearby on the dedicated pipe racks. The second step requires flushing and filling the annular space between the outside of the production/injection tubing and inside the production casing. Circulate fresh water back to land surface and confirm that it remains static and clear. Keep the water level at land surface throughout logging operations.
25. Once the Downhole Geophysical Logging Company arrives on site, **IMMEDIATELY instruct all onsite personnel to TURN OFF all radios and cell phones. The associated high explosives are susceptible to detonating (without blasting caps) in the presence of electromagnetic energy waves associated with the afore-mentioned devices. They may also be set off by static electricity.**
26. A truck mounted Geophysical Logging System consists of four basic parts. They are as follows:
    - Probes (the sonde or tool);
    - Cable and Wench (including the vertical depth measuring system);
    - Analog Logging Control Modules, and
    - Recording Systems; and Digital Logging System.

    The logging cable is an important an integral part of the logging system which suspends and holds the sonde in the borehole at the desired depth and continuously moves it along the length of the borehole and/or well. The cable also acts as a conductor for electrical signals to and from the sonde to land surface.

    A cable-winch is provided with an associated mechanism for winding the cable. Most winches are powered by AC electric motors that are driven mechanically or hydraulically from a power take off on the truck. The wench has enough pulling power to break the cables if necessary.

    Logging probes, also called sondes or tools, enclose the down the hole sensors, radiation sources, power sources, and the electronics for transmitting and receiving signals. Probes need to be stored and transported with care. Large probes are often stored horizontally in a probe rack. Logging probes are stored in a strong, well-padded box to prevent damage.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

27. There are generally 2-3 personnel (including the Geophysical Logging Engineer) associated with the geophysical logging crew. The Geophysical Logging Engineer (GLE) is the key representative who assures that the well is properly evaluated, and the tools are recording at accurate and representative conditions. The remaining person(s) prepare the well for the proper insertion of the logging tools and explosives into the well and that the pulleys (hooked to the cable tool rig) are allowing the cable to spool smoothly down into the well.
28. Assist the geophysical logging truck in properly positioning the cable spool and wench (which are situated on the rear of the vehicle) directly in line and adjacent to the well that is being evaluated. Spool out the cable from the spool to the well and insert logging probe blank into the top of the 2.375 inch- diameter production remaining on the inside of the production casing. **If the rods and tubing were removed in step 8, one should proceed to Step 50.**
29. Communicate the approximate depth (below land surface) of the top of cement (i.e. measured on the inside of the 2.375 inch-diameter production tubing) to the Geophysical Logging Engineer (GLE) prior to spooling the tool downward. **This depth was recorded previously in Step Number 23.** The GLE will then 'zero out' the depth counter (while measuring the distance which the casing and/or tubing) spans vertically above land surface. This is also known as the casing or tubing stick-up length.
30. While the GLE is calibrating his onboard instruments, the geophysical logging crew is attaching the Casing Collar Locator (CCL) to the logging probe blank on the end of the wireline. This step will enable the GLE to identify the individual collars comprising the 2.375-inch diameter tubing and to determine the TOC inside the tubing.
31. The GLE begins unwinding the cable over a measuring sheave between the winch and the well. Electrical signals from the optical encoder, or speed meter type cable is used to transmit the rotation of the measuring sheave to record the precise depth downhole. Using the information communicated from Step Number 23, the logging engineer will continue to spool out the cable until he tags the top of the cement (TOC). He will then compare this (more accurate) measured depth to the top of the cement with the measured depth as previously determined by the driller. The GLE will identify the relative individual tubing lengths by examining the systematic magnetic anomalies identified on the CCL. Generally, production tubing varies between 20-30 feet in length. The corresponding tick marks (associated with the juncture of two joined tubing pieces) found on the associated print out will provide valuable construction data, especially as it pertains to the individual lengths of the tubular goods spanning from the TOC to land surface. Once the depths of the three lowermost collars are identified, the GLE will record these depths prior to extracting the sonde from the tubing.

BASIC TEMPLATE OF PLUGGING

(Continued)

32. The GLE records and communicates the previously determined TOC and the depths of the two lowermost collars to EPA and its Contractor Representatives as determined by Step Number 30.
33. The cable tool rig crew continues to periodically top off the annular space between stuck tubing and the inside of the production casing with fresh water. This water level **must** remain static (at or near land surface) to absorb the (eventual) percussion created when the production tubing is shot off above the stuck packer.
34. **Reconfirm that all radios and cell phones are off to prevent accidental explosions at land surface.**
35. The GLE and his helper(s) begin to assemble (on elevated racks adjacent to the well) the indicated Radial Explosive-Based Tubing Cutter (REBTC) at the end of the logging probe blank and assure that all electrical connections are properly established and working. All power is then shut off until the actual shooting begins.
36. Using a free hanging spool secured to the cable tool rig and adjacent to the well, the GLE helper(s) feed(s) the REBTC inside the 2.375-inch diameter production tubing at land surface.
37. The GLE slowly lowers the REBTC downward into the (stuck) 2.375-inch diameter production tubing using the onboard cable and spooling wench (located on the inside of the Geophysical Logging Truck).
38. Continue advancing the REBTC vertically until it tags the top of the cement, as established and recorded in Step Number 30. Immediately, cease spooling once this depth is reached. Compare the depth measured in Step Number 30 with the pre-established depth obtained from Step Number 28. Assure that these numbers agree with one another.
39. Once this accomplished, slowly begin to spool up the REBTC to a minimum depth fifty (50) feet above the TOC and cease to rotate the onboard wench. This fifty-foot spacing is required to preclude damage downhole while the REBTC. Record this depth as noted on the onboard geophysical logging equipment situated in the Shooting Gallery of the truck. Identify the casing collar which is a minimum of fifty feet or more from the top of cement.
40. Spool up the REBTC to the nearest collar (approximately 50 feet or more) located in Step Number 38 because it is preferable to separate the tubing at a joint.
41. Identify the depth of the joint which is 50 feet or more above the TOC. Readjust the depth of the REBTC to the same depth of this joint in preparation for detonation.
42. Top off all fluid levels in the well back to land surface one last time prior to shooting off the 2.375-inch diameter tubing. Place a properly sized set of free slips around the production tubing at land surface. This will preclude the loss of the tubing downhole after the REBTC is detonated, and the tubing is sheared off.

BASIC TEMPLATE FOR PLUGGING
(Continued)

43. Evacuate all personnel a safe distance (i.e. 50-100 feet) from the well prior to the GLE detonating the REBTC downhole. Verbally warn all workers immediately prior to detonation.
44. The GLE Initiates the REBTC using the associated electronic switches located in the shooting gallery positioned on the inside of the geophysical logging truck. Confirm that the discharge is successful prior to allowing onsite personnel to approach the well. The power is re-established immediately prior to shooting off the tubing.
45. Once the production tubing is shot off, the GLE extracts the cable (including the remnants of the REBTC) using the onboard draw works (i.e. cable spool and wench). When the cable reaches land surface, the geophysical logging worker(s) disconnect the remnants of the explosive cutter from the logging spool blank located at the end of the cable. **Assure that all radios and cell phones remain in the off position.**
46. Continue to wind the wireline cable until it is returned to the spooling mechanism situated on the rear of the geophysical logging truck.
47. The cable tool rig crew refills the well with fresh water back to land surface and assure that it remains there throughout the forthcoming steps.
48. The cable tool operator and his worker(s) then begin extracting the production tubing from the well (while leaving the slips in place to preclude the tubing from slipping vertically back into the well).
49. As the production tubing is extracted from the well, the cable tool operator pauses every 20-25 feet (average length of tubing) to allow the crew to disassemble (or cut off with a torch) the individual strands of tubing comprising the string. Each removed component piece of tubing is stacked neatly on nearby stands outside the working area of the wellhead to preclude trip and fall obstacles. **A Naturally Occuring Radioactive Material (NORM) Survey is performed continuously throughout this step until the tubing is extracted in its entirety. If elevated levels of radioactivity are detected, it is necessary that the tubing be isolated to preclude unnecessary exposure to onsite personnel.**

Example Description: The reader is referred to well description provided for the Royal Heirs #2W Well provided in Step Number 19. To more fully understand and comprehend the steps thus far, one may wish to develop a cross-section of the well. The construction features are as follows:

- Well Depth 715 feet;
- 7.5-inch diameter borehole;
- 5.0-inch (inside) diameter production casing set to 653 feet;
- (Assumed) Top of 5-inch diameter tubing packer 650 feet;

BASIC TEMPLATE OF PLUGGING

(Continued)

Well Example (Continued):

- Top of Cement inside 2.375-inch tubing 630 feet; and
- (Assumed) Top of 2.3755-inch tubing (shot-off) 580 feet.

The associated schematic for this well is provided in **Figure**: 6.

50. Completely fill the inside of the diameter production casing with fresh water and continuously maintain the fluid level at or near land surface. The reason for this step is to maintain the well in static equilibrium.
51. The cable tool rig crew assembles a work string, (which most likely consists of a scraper type bit or a swedge, which is nearly equal in size as the inside diameter of the production casing; a drilling sub for added weight; and heavy tubing). This workstring is meant to be inserted into the production casing to remove any scale or corrosion from top of the cut off tubing to land surface. This step will assure the proper bonding of cement on the inside of the production casing when the well is eventually plugged in the forthcoming steps.

IF THE READER IS PROCEEDING FROM STEP 28, (i.e. WHERE ALL THE RODS AND TUBING ARE EXTRACTED OR REMOVED FROM INSIDE THE PRODUCTION CASING), THE WORK STRING (INCLUDING THE SWEDGE) WILL BE USED TO SCRAPE THE INSIDE OF THE PRODUCTION CASING FROM THE TOTAL DEPTH OF THE WELL TO LAND SURFACE.

52. While the fresh water is being pumped downhole, the work string is lowered slowly on the inside of the production casing to remove the scale and debris. Eventually, the work string will be lowered to an appropriate depth. There are two different approaches based on whether the tubing was successfully removed from the well or not.The options are as follows:

- It will be lowered to a depth approximately 20 feet above the top of the at or near the top of the severed production tubing if the tubing was shot off.

<u>OR</u>

- It will be lowered to the total depth of the hole if the rods and tubing were removed). Fresh water that is being pumped from downhole will remove the dislodged debris. This flushing activity should last approximately two or more hours. After flushing the well for several hours. the cable tool rig crew removes the work string from the production casing. In so doing, the scraper bit or swedge will further expose and clean the **INSIDE** of the casing surfaces as it is extracted back up the well to land surface. As the work string tubing is disassembled at land surface, the cable tool rig crew will stack and organize each component string on elevated racks outside the immediate work zone. In so doing, all trip and fall hazards are eliminated or minimized. The cable tool rig crew will again top off the well with fresh water in anticipation of well logging activities.

The reader is now referred to Step Number 23 to refresh his memory and to provide a checklist of the available/necessary downhole geophysical logging tools needed for the successful plugging of an oil production/injection well. The GLE will request direction from the EPA onsite Representative(s) regarding which sondes are required for evaluating the well. To properly evaluate an abandoned well properly, especially with respect to:

a. the well construction;
b. the quality of cement between the borehole and casing, tubing and casing-collar locations with respect to depth;
c. the relative quality of the production casing (with respect to casing corrosion and corrosion holes); and
d. the differentiation of the associated geologic formations, (including thicknesses and depths);

NOTE: It is recommended that, (at a minimum), one use a Natural Gamma Ray (G), Casing Collar Locator (CCL), and a Cement Variable Density Log (VDL) suite be run on all wells. This is most important when it comes to the protection of individual ground water formations that are otherwise endangered or impacted by migrating oil, gas, and brine which are not otherwise contained within their respective geologic formations. *By Federal Law* (i.*e. the Safe Drinking Water Act*), *all ground water with 10,000 ppm or* less *Total Dissolved Solids* (*TDS*) *must be protected with cement*.

53. The GLE requests and records the following information from the EPA representative:
- the name of the well,
- the oil well field name or designation,
- the inside diameter of production casing,
- the types of geophysical logs to be run on the well,
- the Carter Coordinate location,
- the County, and
- the State.

Other information included is:
- the date of downhole survey,
- the person logging the well,

- the equipment number,
- the location of equipment,
- the elevation where (i.e. top of casing or land surface) the log was measured from, <u>and</u>
- the name (s) of the client and/or the witnesses.

All information is recorded on the onboard computer and will be printed out on the log header when the well is evaluated. **See Figure**: 7.

54. Confirm that the GLE has transported the proper sized cast-iron bridge plug to fit the inside diameter of the production casing. Ideally, **the EPA representative <u>must</u> contact the GLE a *day* or two <u>in</u> <u>advance</u> to confirm that he has the proper sized unit in stock** or to assure that he can special order the plug. It sometimes takes several days to obtain non-typical sized bridge plugs. Setting of the cast-iron bridge plug will be discussed later.
55. Once the EPA representative identifies the geophysical logging suite to be run downhole on the well to the GLE, the GLE and his crew begin assembling the various probes (also called sondes or tools) in anticipation of logging the well. As specified earlier in this document, these probes need to be stored and transported with care. Large probes usually are stored horizontally in a probe rack. Logging probes stored in a strong, well-padded box is less likely to sustain damage. The reader is referred to Figure: ____ to familiarize himself with the typical appearance of a fully assembled sonde.
56. Probes are then connected to (geophysical logging truck) cable by a cable head connected on to the top of the tool. Sondes are made of stainless steel or other non-corroding materials and are made to withstand thousands of pounds per square inch while downhole.
57. The GLE (while spooling out the cable) directs his crew to carefully carry the assembled probe to the well. The crew will inserts the probe on the inside of the production casing in preparation of evaluating the well while the cable is slowly descending. The cable is riding on a sheave on a tripod adjacent to the well to assure that the cable speed remains constant during the evaluation.
58. Lowering the cable is carried out at a constant speed which is checked with a speedometer located in the shooting gallery of the truck. If the sonde is held up due to some downhole occurrence, the GLE raises and lowers the cable about 25 to 50 feet until it breaks free and continues down the well.
59. Assure that the well is topped off with fresh water throughout logging operations.
60. The sonde is slowly lowered down the well by the GLE until the top of the (shot off) tubing is encountered. The GLE spools up the cable (approximately 20 to 30 feet above the top of the shot off tubing) and stops spooling one las time in preparation of running the NGR, CCL, and the VDL on the inside of the production casing. As a rule, these aforementioned- geophysical

parameters are measured while the sonde is being drawn up at a preset and constant rate as specified by the GLE. **If THE TUBING WAS SUCCESSFULLY REMOVED FROM THE WELL EARLIER, THE WELL IS LOGGED FROM THE TOTAL DEPTH OF HOLE TO LAND SURFACE.**

61. Before the well is logged back to land surface, all of the external connections are made within the shooting gallery of the logging truck. Also, the operation of the main measuring units are verified by the GLE. The most important among these are as follows:

    - Verification of the transmission from the cable sheave to the chart or the tape drive;
    - Checking the signal system;
    - Checking the depth markers on the charts; and
    - Assuring that the paper drive mechanism is calibrated and working properly.

62. Most geophysical logs are recorded at a scale of 1- inch equals 20 feet. There are ten subdivisions per inch on the printed graphs which represent 2- foot intervals. Now that the tubing has been shot off and removed from the well, it is now time to evaluate the production casing. The GLE begins spooling the downhole sonde upward while he is evaluating well construction (with respect to casing collar lengths), geologic (lithology) units, and the quality of cement (with respect to depths) behind pipe.
63. The reader is referred to **Figure 8**. There are six (6) of the most common Classic Architypes of the geophysical logging suite examples that one will encounter. By providing these expected signal associated with the VDL, CCL and G, it is the author's hope that the reader may properly evaluate an individual well or group of wells with time and experience. Careful scrutiny of a well's construction, provides crucial information, as it relates to:

    - the location and the lengths of the individual casing collars comprising the well,
    - the quality of cement between the production casing (or pipe) and the borehole with respect to depth , and
    - the geology, as it pertains to various confining layers and ground water zones.

    These parameters are essential information which must be gathered prior to deciding of the methodology of plugging the well (s) from total depth to land surface.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

NOTE: Based on my 36 years experience in plugging oil and injection wells in the Commonwealth of Kentucky, the life expectancy of uncemented production casing is approximately 8-12 years. This means that older wells with little or no cement will lack internal and external mechanical integrity.

<u>**TRANSLATION**</u>: THE CASING IS ROTTEN AND LEAKING BEHIND THE PIPE AND OIL IS MIGRATING BETWEEN THE PRODUCTION CASING AND THE BOREHOLE!!!! IT CAN AND WILL EASILY FLOW UPWARDS FOR HUNDREDS OF VERTICAL FEET!!! THIS DISCHARGE ALLOWS THE POLLUTION OF GROUND WATER AND FLOWS OF OIL AND BRINE AT LAND SURFACE.

64. Top off the well with fresh water back to land surface to maintain the static equilibrium. Continue to replenish this supply throughout the geophysical logging evaluation.
65. Once the GLE successfully logs the well, the geophysical logging tools are removed from the well and placed on elevated racks for disassembly by his crew. Once the probes are properly cleaned and wiped down, each component sonde is carefully returned to its secure storage container on the truck. The GLE rolls up the remaing cable spanning from the back of the truck to the wellhead. His helpers clean the cable with rags to remove all oily residues from the well.
66. The GLE prints out two paper copies of the logging suite (CCL, VDL and Gamma) for evaluation by himself and the EPA representative. The purpose of this step is to allow both parties to scrutinize the the overall quality of cement with respect to depth and geologic formations comprising the well. **It is highly recommended that the EPA representative scrutinize the six sample Architypes presented in Step 63 for comparison to the newly run logs for the well in question. Refer to Appenndix 10 for an introduction to geophysical logging.**
67. Examination of the logging suite is always performed from the lowest vertical point (i.e. the top of shot off tubing or the total depth of the well, if the tubing was removed). The reason for this approach is to assure that all avenues of crude oil migration are sealed properly to prevent flow upward. Emphasis is given here because so called depleted reservoirs have oil, gas, and brine that will compromise the overall quality of cement which will be circulated to plug the well. This is especially important when one is examing the various zones that have little or no cement on the backside of the production casing. In other words, if the bottom-most cement plug fails, there are multiple continuous plugs(i.e. which extend on the inside and outside of the pipe) to keep the oil vertically isolated as far down the well as possible, such that all ground water zones are protected. Also, there are no avenues on the outside annulus because these zones have been squeezed with cement to seal them off) to preclude migration.

68. Should the EPA representative be rusty or unfamiliar with the art of interpreting a geophysical logging suite (consisting of a CCL, VDL, G, and/or a N), he absolutely must consult with the GLE for a strategy forward. The GLE is a wealth of knowledge when it comes to identifying the following on the current well evaluation:

    - the depth (s) of the localized fresh water aquifers and confining layers which when properly sealed with cement would prevent the upward migration of oil,gas and brine;
    - the portions of the well which lack cement bonding to the production casing, but may or may not have cement adhering to the associated geologic formation (s);
    - the uncemented portions of the pipe and its relative condition based on the CCL;
    - the portions of the well which have cement bonding to the production casing, but may not have cement adhering to the associated geologic formation (s); and
    - the properly cemented intervals of the well which serve as a barrier for the vertical migration of petroleum-related fluids and gases into or between other geologic formations.

69. When discussing the observed downhole conditions of the well, it is highly recommended that the EPA representative and the GLE, concentrate on identifying and marking the paper working copies of the log suite according to the five (5) criteria listed above in Step 69.
    Remember, ALWAYS interpret the individual geophysical logs from the bottom-up!
70. After the paper copies are marked up in their entirety to land surface, highlight those sections of the well which have competent cement. (i.e. properly bonded to the outside of the production casing and to the adjacent geologic formation (s)), such that vertical migration is not likely. Concentrate on areas exceeding fifty (50) vertical feet or more. The oil industry historically has recommended that a cement plug must be 50 feet or more to properly serve as a migration barrier. Also, mark the lowermost Undergroundd Source of Drinking Water (USDW), as defined by 10,000 ppm Total Dissolved Solids (TDS). The GLE and/or State Oil and Gas Inspector (OGI) can assist you in designating lowermost USDW for your well location. The OGI often times comes equipped with a field portable computer (PC) which has thousands of drilling logs from the localized area and may span more than 75 years or more for well drilling information. More than not, the OGI must be on location to witness the eventual permanent plugging of the well.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

The purpose of marking up the working logs,as specified, serves three specific purposes. They are as follows:

- First, it allows one to identify those portions of the well which will subsequently require perforations prior to plugging the well from total depth of the well to land surface.

- Second, it determines the lowermost interval where the cast-iron bridge plug must be set for wells that have no tubing in the well.

- Third, if on the rare occasion that the VDL indicates that there is Good Cement Quality from the total depth of land surface, one can forgo any perforating activities and set the cast-iron bridge plug directlt above the oil reservoir at the overlying confining layer. For now, a discussion of how the associated perforating guns and bridge plugs work and when they should be utilized is discussed below.

Casing Perforating Bullet Guns

The primary objective of a perforating gun is to provide effective flow communication between a cased wellbore, through the outside annulus, and into the adjacent geologic formation. The perforating gun has four (4) components and they are as follows:

- A conveyance for the shaped charge(s);
- The individual shaped charge(s);
- Detonating cord; and
- A detonator.

There are numerous varieties of explosives used for shaped charges which are used with the detonator cord. Three of the most common types are:

- RDX (Cyclotrimethylene Trinitramine);
- HMX (Cyclotetramethylene Trinitraamine); and
- HNS (Hexanitrosilbene).

Each shaped charge will contain contain between 3 to 60 grams of explosives. Their characteristics are as follows:

- When detonated, the perforating guns go off instantaneously;
- The leading tip of the jet has a velocity of 25,000 to 30,000 feet/second;
- The impact pressure is approximately 10 to 15 million psi; and
- This pressure overcomes the casing and the (geologic) formation strength and forces;

Casing Perforating (Perf) Bullet Guns (Continued):

- Explosive material moves radially away from the jet axis.

REMINDER: **Explosives will detonate unexpectantly** due to static electricity, radio or cell phone transmissions.

When using perforating bullet guns, there are numerous options, as it pertains to the explosive type and the number of shots utilized for the application. Their common characteristics are the following:

- Most perforating guns punch holes from 0.23 inches to 0.72 inches in diameter;
- Typical perf guns have penetrations of six (6) inches to forty-eight (48) inches;
- Most perforating guns shoot from four (4) to twelve (12) shots per vertical foot; and
- Perf guns come in different pressure and temperature ratings.

Cast-Iron Bridge Plugs

BACKGROUND: Generally, when an oil well is first drilled for production, the operator will circulate Class A Cement behind the production casing to keep all crude oil and fractions therof, confined on the inside of the pipe. This allows for the efficient extraction of oil and brine through the downhole pump and back to surface via the rods and production tubing. Sometimes, cement behind pipe is circulated in the outside annulus directly above the oil production zone and may or may not be circulated back to land surface. The quality of this cement varies with depth and from well to well. **See Figure 9.**

As I have presented earlier, when plugging an oil well, one prefers to have all production related goods extracted from the well. In this way, the well is open from total depth of hole (where the oil reservoir is situated) to land surface. The bridge plugs are high performance tools which are set on the inside of the production caing for the zonal isolation of reservoir fluids (i.e. oil, gas, and brines) prior to the circulation of cement during permanent to plugging operations.

IMPORTANT: As a general rule of thumb, a bridge plug is generally set on the inside of the pipe directly above the oil reservoir at the very first interval which exhibits Good Quality Cement for fifty (50) or more feet between the borehole and the casing and at or near the bottom of the well. In so doing, the cast-iron bridge plug precludes the reservoir fluids and gases from compromising the cement slurry while it is hardening. The cement on the backside of the pipe (and which is directly adjacent to the bridge plug) precludes the migration of oil into the outside annulus. This will provide for the isolation of the resevoir fluids.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES (Continued)

Cast-Iron Bridge Plug (Continued)

These mechanical plugs consist of four parts:

- The body of the plug which can be made of steel, cast-iron and composite material;
- The slips that are metal parts that grab the casing to hold the plug in place;
- The packing material which is a rubber or vinyl ring that is squeezed outward (when the plug is expanded by an explosive); and
- The on/off tool that allows the plug to be set and then releases the wireline from the plug to allow the extraction of the wireline and tool from the well.

The plug is designed to be set on the inside of the production casing and then have cement set on top to provide a complete seal of the oil reservoir below. In cases where there is a potential for moderate or high pressure to be flowing from an area below the setting depth, a bridge plug is set to seal the inside of the casing prior to plugging the well with cement. In so doing, one is reducing the chances of pressurized brine, oil, and gas to compromise and/or contaminate the cement slurry while it is hardening. The reader is refered to **Figure: 9**.

Should the cement be contaminated by the oil reservoir fluids while it is hardening and the plug leaks, the cement slurry intended for plugging the well will be compromised. This will cause the well to continue to leak at land surface. Because of this, the well will need to drilled back out with a rotary rig and milling bits. Not only is this time consuming, it is extremely expensive. Once on bottom, the well will require plugging a second time.

71. Based on the observed results of the geophysical logging suite and the interpretation by the EPA representative and the GLE, two critical decisions must now be made with regards to the well. They are as follows:

    - The lowermost (presumably directly above the petroleum reservoir and adjacent to the overlying confining layer) depth where the cast-iron bridge plug must be set to preclude fluids from compromising the cement; and
    - The depth (s) where the perforation gun (unless there is GOOD CEMENT from the total depth of the well to land surface) is necessitated to squeeze cement behide the production casing.

Proceed to Step 81 if the cement behind the pipe and in the wellbore is of Good Quality from the toal depth of the well to land surface.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

72. The reader is referred to Step 69 for the three (3) criteria of sub-par cementing conditions which have been established for perforations to occur. Also, when the bridge plug is set, it must be at a depth where there is a minimum of fifty (50) feet of GOOD CEMENT in the outside annulus of the well (I.e. between the outside of the casing and borehole).
73. The GLE and the EPA representative must establish all zones (by specific depth) which require perforations in the production casing in advance of initiating actual shooting activities. This is accomplished by marking up the two paper working copies. This establishes a comprehensive plan and memorializes it for both the EPA representative and the CCL. The CCL refers to his copy continuously to assure that all subpar cement zones are completely addressed as planned. The EPA representative utilizes his copy to track the ongoing progress at any one time in the process of perforations. **NEVER SHOOT A WELL AT A CASING COLLAR!**
74. Choosing where to perforate a well properly (in terms of total number of shots, frequency of perforations throughout larger sections of pipe, and the locations needed to remediate sub par quality cement); requires great knowledge and know-how. The reader is greatly encouraged to defer his decision-making to the GLE. The GLE has had extensive experience in the methods of remediating wells (especially as it pertains to the perforating and squeezing of cement), so its prudent to defer to his recommendations and decision making. One should not be shy to admit that he or she has had limited experience with regards to this activity.
75. Should a well lack any cement behind pipe, it is highly recommended that the casing be shot at its lowest point and continue perforations at a minimum of every fifty (50) feet. This should continue upward until all uncemented intervals are properly shot.
76. All POORLY CEMENTED wells (i.e. as detailed in Step 69), are also recommended to be shot at fifty (50) foot intervals from the bottom upward.
77. For those wells that have POOR QUALITY CEMENT and/or are uncemented behind the production casing, the reader must assure that the well is perforated twice (i.e every 50 feet) at a depth which is 100 feet below the base of the lower-most Underground Source of Drinking Water (USDW). **SHOOTING A WELL AT A CASING COLLAR MAY DESTROY THE WELL!**
78. Consult with the OGI in advance as to the approximate depth of the base of the lowermost USDW. He has been a field COMPUTER (PC) which contains numerous drilling logs from the well in question or nearby wells which will aid in this determination.
79. When all of the decision-making has been finalized, specify to the GLE that all perforations (using RDX) will be shot at four (4) shots per foot. Each shot is oriented ninety degrees off of the previous vertical shot. As such, the four perforations will encompass the entire 360 degrees of the casing and borehole.
80. Prior to perforating the well casing, the GLE and his crew will spool out their wireline cable from the truck to the well and prepare the bridge plug and associated setting tool (with explosives) for setting above the petrolem reservoir and/or the upper confining zone.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

81. The cable tool rig crew continuously tops off the well with fresh water from here on out.
82. Once the mechanical bridge plug is properly configured on the releasing portion of the tool, the crew carefully places water into the inside of the production casing.
83. The GLE begins lowering the plug down the well from the shooting gallery of the truck. During this process, he is dutifully watching the depths to assure that all onboard instruments are accurate and operating properly. All power switches are in the OFF position to preclude the plug from being prematurely set at an incorrect depth.
84. Once at the desired setting depth, the GLE will move it up or down vertically to prevent from setting the plug at a casing collar. **NEVER SET A BRIDGE PLUG AT A CASING COLLAR BECAUSE THE EXPANSION WILL LIKELY PART THE CASING AND DAMAGE THE WELL.**

85. Once the GLE has positioned the bridge plug at the proper depth, he re-establishes the power in the shooting gallery. He trips the switch and in so doing, the associated explosives will detonate and the plug will expand on the inside of the production casing. Once set, all oil, gases and brines will be isolated below the plug. This ensures that once the well is permanently plugged with cement, the slurry will not be compromised while it is hardening and/or curing.
86. The GLE begins reeling up the cable on the spool while paying careful attention to the tension. The purpose of this scrutiny is to assure that the setting tool has completely separated from the cast-iron bridge plug. Occasionally, the steel pin does not properly shear off from the plug. As a consequence, the GLE must sustain extra pressure on the cable to effect this separation.
87. When the tool is returned to land surface, the geophysical logging crew will place the tool on a set of racks adjacent to the well. The purpose of this is to allow the crew to loosen the pressure release valves on the tool. When the plug was set with the explosives, all emissions from the blast are channeled into a pressure tight container to preclude an accidental fire or explosion downhole.
88. While the pressure release valves are being loosened on the setting tool by the Geophysical Logging Crew, one must avoid being in close proximity to the tool because it is under extreme pressure. Once opened, the off gassing will emit a very large hissing noise and black acrid vapors. This noise has startled many a visitor because of its loud and violent escape to the atmosphere!
89. The tool is then disassembled, cleaned and stored properly back on the truck.

Proceed to Step 101 if there is Good Quality Cement behind pipe from the total depth of the well to land surface.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

90. The GLE has numerous perforation guns assembled in advance to proceeding to the well location. It is standard in Kentucky, that each unit will be configured with four (4) shots of RDX on a one foot interval. As specified earlier, they are comprised of four parts, namely a conveyance for the shape charge, the individual shape charges, detonating cord and a detonator. Shooting the production casing requires numerous trips up and down the well and always begins at the lowermost intervals.
91. All radios and cell phones must be in the OFF position during all subsequent activities. The GLE maintains all onboard electronics in the same OFF position to ensure there are no accidental detonations at land surface.
92. The GLE works on elevated racks adjacent to the well while he is assembling the conveyance, detonator cord, detonator and electric lines on each indivual perforation gun. He only fully assembles one gun at a time and that is done immediately prior to its deployment down into the well.
93. Once all of the connections are made and the gun is made ready for lowering to the proper depth, the crew inserts the tool (which is fastened to the wireline cable) while the GLE spools out the cable from the shooting gallery of the logging truck.
94. Top off the well with fresh water to suppress the upcoming detonations.
95. Spooling of the perf gun continues until it reaches the lowermost interval where the production casing and geologic interval is to be opened up (prior to squeezing the cement). The GLE reconfirms that the perforation gun is properly positioned and then re-establishes the appropriate electrical connections in the shooting gallery of the truck.
96. All personnel are evacuated 50-75 feet from the well for safety immediately prior to the perforation activities.
97. The GLE triggers the downhole detonations via the electric circuitry in the shooting gallery of the logging truck. Once the gun is fired, the GLE shuts off all electrical connections in anticipation of fully assembling the needed perforation guns.
98. The spent gun is reeled back to land surface, and the GLE disconnects the remaining portions after its destruction.
99. Perforating the well from here on out is repetitive and redundant. Once the lowermost zone is successfully shot with the perf gun at an interval of four shots per vertical foot, the GLE will follow Steps 91 through 99 at the next lowermost zone. Once this second zone is opened up, he then moves up to the next higher interval and so forth until all of the identified horizons are shot as specified on the two paper working copies. Be sure to keep the well loaded with fresh water to prevent schrapnel and debris from exiting the well at land surface.
100. Once the GLE has successfully perforated the well from the bottom to top, he spools up his wireline cable.

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

101. It is customary for the GLE to print out about ten (10) paper copies of the logs. Two copies are provided to the KY OGI for his records. The remaining duplicates will be filed away and maintained in the official site files for future reference.
102. Once the logs are copied, the GLE presents the EPA representative with the itemized field invoice for all of the services provided on the subject well. The GLE will then depart the well site for transportation to another site and/or back to his home office.
103. Upon the departure of the Geophysical Logging Crew from the site, all cell phones and radios may be turned back on.
104. The cable tool rig crew assembles a two-inch diameter work string for insertion into the the inside of the production casing to remove any scale or corrosion from top of the cast iron bridge plug to land surface. It will also flush out any oily residue which may remain in the well. Fresh water is continuously circulated for several hours to assure the proper bonding of the cement slurry on the inside of the production casing when the well is plugged in the forthcoming steps. Keep this work string approximately 3-4 feet off of the top of the cast-iron bridge plug while circulating the well with fresh water.
105. Notify the appropriate Kentucky Oil and Gas Inpector (OGI) of the contractor's intent to plug the well with cement, if he is not already on location. He will require the following information for his records. They incude:
    - Size of production casing;
    - Total depth of well;
    - Depth of the top of the bridge plug;
    - Perforation intervals; and
    - Two copies of the Geophysical Logging Suite.

106. The reader is now referred to the Halliburton Cementing Tables which are found in **Appendix 9** of this manual. They are very self explanatory as to determining the amount of cement by volume needed for any and all well construction methodologies. It is recommended that the reader take a few moments to calculate the approximate gallons of Class A Portland Cement will be needed for plugging the well. A good rule of thumb is to add twenty-five (25) to thirty (30) percent more to the calculated volume because cement will be lost to the outside of the pipe and the various geologic formations.
107. **Class A Portland Cement must be mixed up to a weight of 18 pounds per gallon. To obtain an 18 pound per gallon slurry, one must mix about 5.2 gallons of fresh water per 94 (dry weight) pound sack of cement.**

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

108. Prior to preparing the associated equipment (i.e. pump truck, water truck, dry cement bulk truck or the trailer that is transporting the bags of cement) needed for plugging the well, confirm with the lead driller that he has a swage (not to be confused with the drilling swage) that is of equal diameter to the outside diameter of the production casing, such that it can be securely screwed onto the casing. Confirm also that the production pipe has adequate threads to accomplish this task. The important role of this swage will be explained in the forthcoming steps. **This is a crucial step and must not be overlooked.**

109. Re-orient all of the needed equipment for plugging actions in close proximity to the well in order to manage all upcoming activities efficiently. Check all hoses and fittings for any signs of being compromised. Remember that these same pieces of equipment will be withstanding enormous pressures while the cement slurry is being circulated into the well. Any equipment failures can and will get someone injured.

110. The lead driller begins to prepare the pump truck for the proper mixing of the cement. Prior to adding the cement, he will mix an appropriate amount of Calcium Cloride (depending on the amount of cement being mixed) to the fresh water being circulated in the pumps. The Calcium Cloride acts as an accelerant for the cement slurry and will speed up its hardening to green cement. Do not add more than two percent Calcium Chloride to the water or the cement will not set properly and will develop dessication cracks. This will lead to the loss of its integrity with respect to its ability to hold back oil, brine and gas.

The reader is referred to Appendix 8 for further information regarding oil well cement types and properties. Should he/she require additional information, there is an exhaustive reference list at the very end of the document.The reader is highly encouraged to familiarize himself with this subject when he/she has some down-time away from the field. Cementing a well is very complicated and will vary according to downhole conditions. Refer to Appenndix 11 for a discussion and bibliography references relating the plugging and abandonment of oil wells.

111. Cement is mixed by jet mixers that combine cement and fresh water in a single pass operation or the more precision batch mixers that mix by circulating in a large tank but only mix a limited volume at a time. Although an acceptable slurry can be achieved in a jet mixer by an experienced operator, the batch mixer allows closer control in critical, small jobs. Besides specifying the desired density of the cement to be circulated, the EPA representative must rely on the operator's expertise to achieve the desired results. **Do not micro-manage this step! Mixing cement properly is a highly complex science and it takes many years of experience to acquire this expertise. The driller knows what he is doing!**

112. In all plugging jobs where a well has been perforated in order to allow the cement slurry to be circulated and/or squeezed on the backside of the pipe and into the exposed borehole, this technique is referred to as a **Bull-Head Squeeze**. A Bull-Head squeeze is accomplished when a bridge plug is set to create a false bottom and is set just below the squeeze target depth (s). The procedure seals off the oil reservoir from other portions of the wellbore and precludes the compromising of the cement slurry while it is hardening.

A Bull-Head Squeeze is performed by running the 2 inch diameter work string down to the top of the packer and circulating the cement slurry back to land surface while pulling the workstring out of the well. A swage is then be screwed onto the top of the production casing to facilitate the pumping/circulation of cement through the production pipe. The circulation hose will be secured to the smaller diameter (the top) nipple on of the swage. The driller squeezes the cement through the swage and into the production casing and then into the backside of the casing via the perforations. He constantly is monitoring the pumping pressures on the pump truck during this step. **Low pumping pressures of the cement slurry are often in the 500 to 600 pounds per square inch (psi) range. Medium pressures range between 1,000 and 1,500 psi. Higher pressures are those values between 2,000 and 2,500 psi. Anyting in the high pressure regime indicates that the cement slurry is backed up or not flowing freely. Exhibit extreme caution at these high levels.** Excessive pressures emanating from the cement pump can result in the failure of the casing down hole which further complicates the ongoing plugging process. These extreme ranges should be avoided at all times.

113. If there are uncemented portions higher up in the well and they extend to land surface, one wil find that the cement slurry will be returned in the outside annulus between the pipe and the borehole. This will continue for awhile because the cement will displace water and debris from the hole. Eventually, it will return cleanly to surface and the pumping can be ceased once competent cement is flowing behind pipe at land surface. In so doing, one is sealing off all parts of the well to preclude further discharges.

Record the total amount of cement (recorded as sacks of cement) used to plug the well. Provide this information to the OGI because he needs it for his records.

114. If the well has GOOD QUALITY CEMENT for the entire annular space between the outside of the casing and the bore hole **and** is properly bonded to the geologic formations, the driller may circulate cement on the inside of the production casing through a two-inch diameter work string. The work string will be run into the well until it is at or near the top of the cast-iron bridge plug. The work string will be extracted from the well as the cement is circulated back to

BASIC TEMPLATE FOR PLUGGING ACTIVITIES
(Continued)

land surface. The cable tool crew will disassemble the tubing individually, rinse them with fresh water, and stack them neatly to preclude any trip hazards.

115. The crew disassembles all hoses and lines to circulate fresh water into the mixing tanks and cement pumps. This flushing activity continue for a considerable amount of time to ensure that all cement is removed and that all associated valves and equipment will work properly on the next well location.

116. The cement is then allowed to harden overnight. If on the following day, the cement slurry has settled downward in the production casing, the driller may top off the well with cement. This precludes contaminants from percolating from land surface and into shallow fresh water aquifers.

117. Even though the cement has hardened into GREEN CEMENT overnight, it may take several weeks or months before it completely cures.

118. Remove all plugging-related equipment (i.e. cable tool rig, work strings, sucker rods, water truck, pump truck, tools and so forth) from the well location to allow for site restoration activities to occur.

119. Cut off (with a torch) the surface casing and production casing to an approximate depth of three to four feet below grade. This is considered the average plow depth and is required by law when a well is properly abandoned. The cut-off casing is layed in the pit which is adjacent to the plugged well and buried when the site is restored. This burial of pipe assures that if someone at a later date needs to identify the exact well location, he can utilize a magnetometer or metal detector to find it easily.

120. If NORM contaminated debris is identified while plugging the well, all removed tubing and/or sucker rods must be safely segregated and stored until such time that they are properly disposed of in accordance with the regulations. They often cannot be sent to a metal recycling facility because their radioactivity.

121. Complete the retirement and leveling of all containment pits and spillage areas, as necessary. The general guidance on retirement and leveling of the earth works are presented below:

- Remove all free liquids above the solids in the pits to the maximum extent practicable and coordinate disposal or recycling as needed;
- Stiffen the pits and spill areas prior to encapsulation and/or solidification with cement to assure physical stability and support for pit covering activities;
- Slope and grade the soils to prevent the erosion of clean soils overlying the pits;
- Bury the pits greater than four feet below grade to prevent any exposure to wildlife or vegetation; and

BASIC TEMPLATE FOR PLUGGING ACTIVITIES

(Continued)

- If NORM is present in the soils and requires disposal pursuant to State regulaions, sample and analyze the impacted media to determine disposal criteria for on-site or off-site disposal.

124. Conduct restoration activities as required in order to protect the site from erosion and/or ponding. Typical activities are provided below:

- Recontour the well site and access road to a sufficient grade that allows for the shedding of water from the location; and
- Revegetating all impacted/exposed soils with a proper amount and type of pasture mix seed to provide for rapid and sustainable coverage of the site. Straw bales may be required, as necessary.