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Well Construction Information for In Situ Uranium Leaching

By **Daryl R. Tweeton and Kevin Connor**



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WELL CONSTRUCTION INFORMATION FOR IN SITU URANIUM LEACHING

by

Daryl R. Tweeton¹ and Kevin Connor²

ABSTRACT

This Bureau of Mines publication describes present practices of making injection wells for in situ uranium leaching. Casings, screens, drilling fluids, coring, logging, cementing, and developing are discussed with the objective of aiding those who are starting an in situ leaching operation. Improper choices of materials or techniques can result in wells that are either useless or wells that have an undesirably high resistance to injection. Important factors include careful selection of screen slot size, use of logs for choosing the cementing basket depth, proper cementing techniques, and careful choice, use, and flushing of drilling fluids. The information was obtained through observation of well construction and through discussion with in situ leaching companies, drillers, and suppliers.

INTRODUCTION

In situ leaching consists of injecting chemicals (lixiviant) into an ore body, dissolving the desired mineral, and pumping the lixiviant and dissolved minerals out of the ore body. Usually separate wells are used for injecting and recovering the lixiviant. In situ leaching has the following advantages over conventional mining: smaller capital cost for small or deep deposits, shorter lead time before production, minimum surface pollution, lower labor costs, and improved safety for workers. It thus can make feasible the recovery of uranium from deposits that are too small or too low-grade to profitably recover by conventional mining.

Despite the potential benefits, in situ leaching contributes only a small fraction of our national uranium production. Therefore, the Federal Bureau of Mines is conducting research to improve technology with the anticipation that in situ leaching will contribute more to the Nation's uranium production and reserves.

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Research at the Twin Cities (Minn.) Mining Research Center began in 1975, in cooperation with a private company at an experimental test site in Wyoming. The study demonstrated the importance of properly constructing injection wells. The first set of wells had a high resistance to injection despite several attempts at acid flushing. So little lixiviant could be circulated that the leaching test was not a reliable basis for planning commercial operation; therefore, the test was repeated the following year with better wells. Discussion with other leaching companies showed that well clogging was a common problem, and that the degree of clogging was strongly influenced by well construction techniques. Without good injection wells, not enough lixiviant contacts the ore to provide good uranium recovery.

There is little public literature on injection wells for in situ uranium leaching. However, some literature on other types of wells was found to be useful. Reference (7)³ discusses planning and constructing water wells, ground water movement and chemical characteristics, testing wells, screen selection, drilling and developing wells, and pumps. However, techniques that are suitable for water production wells are not necessarily suitable for injection wells. Lixiviants are far more corrosive than ordinary water. Also, wells usually have more fluid resistance to injection than to recovery.

Brown and Silvey (2) described some of the causes and cures for clogging in certain recharge wells. They concluded that clogging was largely caused by dispersion of interstitial clay, and that suitable clay stabilizers such as calcium chloride could minimize clogging during injection. White, Baptist, and Land (9) also concluded that clay dispersion, not clay swelling, was the dominant factor in reducing the water permeability of certain cores.

The lack of public literature on wells for leaching makes it difficult for companies that are just beginning in situ uranium leaching to avoid repeating mistakes made by others, so the Bureau prepared this circular describing current practices. A future report will describe investigations into improved methods. An overview of Bureau research on this and related topics is given by Olson, Larson, and Tweeton (4).

ACKNOWLEDGMENTS

Much of the information relating specifically to in situ leaching wells was obtained in discussions with Intercontinental Energy Corp. (IEC), Denver, Colo., and Tep-Cor, Inc., Alice, Tex., as a result of a cooperative agreement between IEC and the Bureau of Mines.

WELL DESIGN

Important considerations in the design of the well include the type and diameter of the casing and the type and slot size of the screen.

³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Casing

Although some companies use 5- or 6-inch-diameter casing to allow a larger pump to be installed, the most common casing diameter is 4 inches, which allows 4-inch screens to be used and provides adequate screen area for fluid flow. This diameter allows small submersible pumps to be used. The option of installing a pump in an injection well is useful during well development and during postleach restoration of the water quality, even though the pump is not left in the well during leaching. This option also permits later conversion of an injection well to a recovery well.

The most common casing material is polyvinyl chloride (PVC) plastic which has replaced stainless steel because PVC is much cheaper. A disadvantage of installing PVC during Wyoming winters is that the glue does not set properly when colder than 4° C (40° F).

An alternative which makes glue unnecessary is Yelomine⁴ PVC pipe manufactured by Certain-Teed Products Corp., St. Louis, Mo. It uses a patented connector in which a nylon strap is slipped around the joint in a special groove to hold the coupling secure. An O-ring inside the coupling prevents leaking. Yelomine is slightly more expensive than standard PVC, but it is claimed to be stronger. Wells deeper than 500 feet are sometimes cased with fiberglass which is stronger than PVC.

Screens

Just as for casings, plastic screens have replaced stainless steel because of its cheaper cost. There are several manufacturers of plastic well screen each claiming advantages. All of the screens have tapered slots with the narrowest part of the slot to the outside which minimizes plugging with sand grains (fig. 1). A grain small enough to enter the

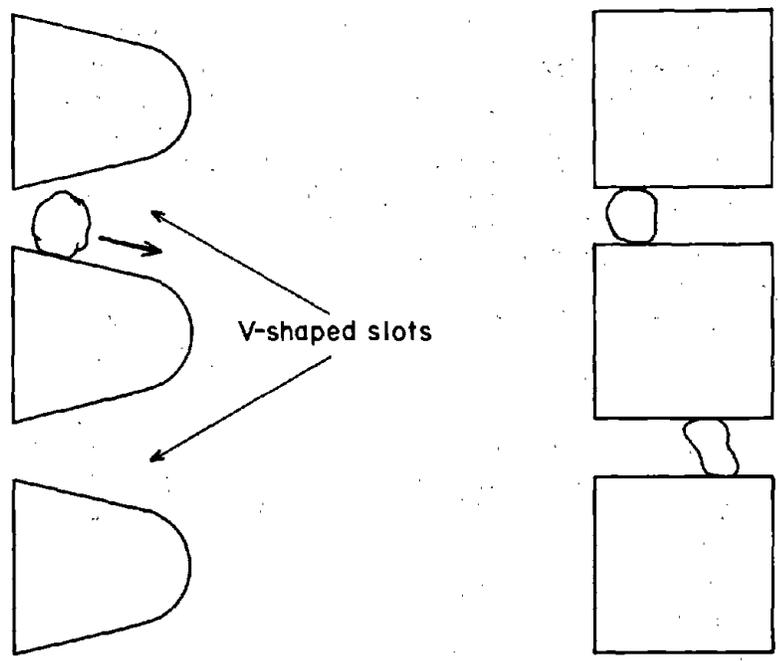


FIGURE 1: - Tapered screen slots minimize plugging from sand grains.

⁴Reference to specific equipment (or trade names or manufacturers) is made for identification only and does not imply endorsement by the Bureau of Mines.

narrowest part of the slot is unlikely to be trapped in the wider parts of the slot. If the slot is not tapered, grains are more likely to be trapped part way through. The type of screen having the greatest open area is wound over thin plastic ribs, and it is sold by Johnson Div., Universal Oil Products, St. Paul, Minn. A different design, which gives less open area but more strength, is wound over a plastic pipe containing closely spaced holes and it is available from Well Supply, Inc., and Wesco, Inc., both of Houston, Tex.

The slot size should be chosen carefully to allow optimum well development. Too small an opening will not allow enough of the fine material from near the well to be flushed through the screen and pumped out. Too large an opening will allow material from the formation to continue to flow through the screen. A common recommendation is to choose a slot size that allows 60 wt-pct of the material to pass through. This slot size is usually from 0.008 to 0.025 inch (0.20 to 0.63 mm). Thus, cores must be taken for grain-size analysis (7, p. 179) before selecting the slot size.

An alternative to conventional screens is to case and cement the well to the bottom of the deposit, then use a water-jet device developed by the Bureau of Mines to perforate the casing and cement. This method has the advantage that the perforation pattern can be tailored exactly to the deposit. The perforator, described in a Bureau publication by G. A. Savanick (5), uses a 10,000-psi water jet to make small holes through the casing and cement that are small enough to provide sand control.

Another alternative is to case and cement to the bottom of the deposit, then remove the casing and cement by underreaming at the desired depths. If the formation is sufficiently consolidated, no screen is necessary. If the formation is poorly consolidated, a telescoping screen of smaller diameter than the casing is slid into position after underreaming.

DRILLING

Of the several methods of drilling, the most common is hydraulic rotary drilling where the drilling fluid is liquid. Foam and air drilling have also been used successfully.

Foam and air drilling are similar in many ways to hydraulic rotary drilling, except the drilling fluid that carries the cuttings up is foam or air instead of liquid. Since hydraulic rotary drilling is much more common, this circular will emphasize drilling with liquids.

Hydraulic Rotary Drilling

Hydraulic rotary drilling is well-known and described in reference (7, p. 47). The choice, use, and flushing of drilling fluid is very important. Any drilling fluid that is not removed during development will be forced into the formation during injection and hence it will contribute to clogging. Drilling fluids made from bentonite are especially prone to cause clogging because bentonite is hard to remove and swells.

Drilling fluids made from guar gum are less likely to cause clogging than bentonite, and they are often used in drilling injection wells. Examples of such fluids are Revert (8), sold by Johnson Div. of Universal Oil Products and Loloss (3), sold by Baroid Services Div., NL Industries, Inc. The advantage claimed is that guar gum drilling fluids can be broken down to a fluid having the viscosity of water by enzymes or chemicals after drilling is completed. However, there are conditions where guar gum fluids will gel and resist breaking down. The literature describing Revert states that a combination of certain chemical constituents in the water such as boron, copper, aluminum, and calcium, coupled with a pH over 8, can cause gelling. The same literature suggests methods for treating the water to avoid gelling. The amount of the chemical constituents that can be present at a given pH before gelling occurs has not been published. When using the fluids it is important to follow all the manufacturer's directions including the warnings of the effects of trace chemical constituents and improper pH. This seemingly obvious advice is stated because the Bureau has encountered several instances of clogging where failure to pretest the water and insure its suitability may have been a contributing factor. In hot weather it may be advisable to preserve guar gum drilling fluids with formaldehyde to prevent them from breaking down before the drilling is completed.

Newer fluids are being recommended by some manufacturers. For example, Baroid now recommends Drispac or Quik-trol rather than Loloss for drilling injection wells. Drispac is a polyanionic cellulose polymer (3) which has been used successfully for drilling injection wells. Quik-trol is an organic polymer (3). Baroid indicates that these two drilling fluids are more effective than guar gum fluids at encapsulating clays and hence preventing the buildup of a fine clay suspension on the borehole wall.

Baroid stresses the need to control the solids content of the fluid by removing clay particles during drilling. Equipment is available for this purpose, and some of it is small enough to be used during injection well drilling. The buildup of solids was a problem at the IEC site which was attributed to the portable mud pits being too small to allow adequate settling of the suspended particles. It would have been preferable to use larger pits, but this was prevented by extremely wet conditions.

Drilling wells straight and vertical is important for several reasons. A crooked hole makes it difficult to lower the casing especially with a cementing basket. Casings have broken when excessive force was used. A crooked hole also makes it difficult to lower a submergible pump down the casing if the pump is long and its diameter is only slightly smaller than the casing. If the holes are not vertical, the well pattern at the ore depth will differ from the surface pattern. This may lead to poor distribution of the lixiviant.

Using as small a downward thrust (pulldown) as practicable at the top of the drill string will help insure a straight hole. Applying part of the necessary force downhole with two drill collars worked well for Tep-Cor at the IEC site. Downward thrust applied at the top of the drill string tends to make the drill go crooked, but weight applied near the bottom of the string helps the drill go straight and vertical. Most companies do not try to drill

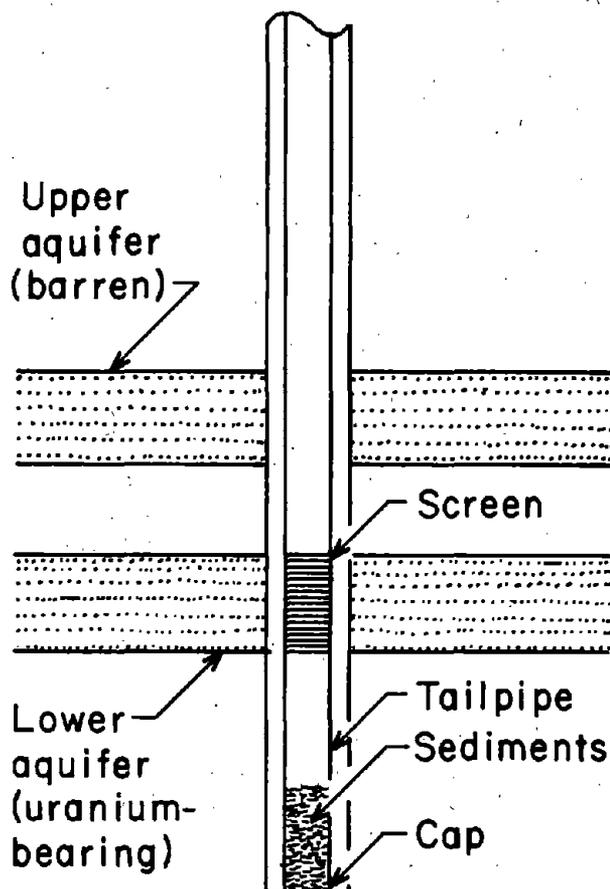


FIGURE 2. - Tailpipe with sediments accumulation.

The hole must be drilled deeper than the screen bottom to allow for some material sloughing to the bottom of the hole and for a tailpipe to extend below the screen. The tailpipe is a piece of casing, usually 5 to 10 feet long, attached to the bottom of the screen and capped at the bottom end. This allows material to settle in the tailpipe without blocking the screen as shown in figure 2. Placing about a foot of plaster of paris in the cap helps prevent drilling through it.

Foam and Air Drilling

Foam or air drilling offers the promise of minimizing the low-permeability skin on the borehole wall. However, it provides less support for the borehole wall and hence increases the risk of collapse.

Air drilling was used successfully in a Wyoming operation. The wells were drilled to a competent layer above the uranium-bearing zone using a guar gum based drilling fluid. A 6-inch-diameter casing was installed and cemented. Then a hole for a 4-inch-diameter screen was drilled through the uranium-bearing zone using compressed air as the drilling fluid. The hole was full of

the full-diameter hole in one pass. Drilling a pilot hole a little more than half the final diameter requires less downward thrust and yields a straighter hole. However, one company has found that using more drill collars and a high bit rpm allows straight holes up to 6-3/4-inch diameter to be drilled in one pass. The Bureau's experience suggests that, in an ordinary formation, a careful driller can avoid being more than about 6 feet out-of-vertical at a depth of 250 feet when using a pilot hole.

The final diameter must be large enough to accommodate the casing with its couplings and cementing basket if used. This is considerably larger than the nominal inside diameter (ID) casing size. For example, a 4-inch ID casing requires a borehole diameter of at least 6-3/4 inches. Tep-Cor preferred 7-3/8-inch-diameter boreholes to facilitate installing the casing. The outside diameter (OD) of the couplings is about 5 inches. There must be room for the cement to flow up the annulus between the casing and the formation to allow a good seal.

water, and the air and water made a froth that carried up the cuttings. A 4-inch-diameter screen was slid down the 6-inch casing to the desired depth. The screen was capped at the bottom and had a packer at the top to seal the space between the screen and casing.

This method produced wells having a low resistance to injection. Those who try this method should keep in mind that a poorly consolidated formation may collapse before the screen can be installed. Various manufacturers offer foam drilling fluids that provide better wall support than air and water.

CORING

Coring poorly consolidated deposits is difficult. Part of the core may be washed out of the barrel during drilling. Also, the core may stick in the barrel so hard that forcing it out breaks it up. Double-tube core barrels (1, p. 181) prevent the drilling fluid from flowing over the core in the barrel and hence help keep the core from washing out. Split-tube core barrels have an inner tube that is in two parts allowing the core to be lifted out when the tube is open and thus eliminating the need to force the core out the end of the barrel.

Excellent core recovery was obtained by Tep-Cor Drilling Co. at the IEC site with a simple solid-core barrel. The drilling fluid was Revert at a Marsh viscosity (7, p. 222; 3) of 50 sec. This is slightly thicker than the 40-sec Marsh viscosity used during drilling, but it is near the viscosity range recommended for Revert (8, p. 4). Core drilling was done slowly to avoid forcing the core tightly into the barrel. Coring 10 feet took 1 to 2 hours. Essentially no pulldown force was applied, so the force on the NX-size bit was from the weight of two drill collars, each weighing 300 to 400 pounds, and 250 feet of drill string. To minimize core washout, the mud pump was slowed until it was just adequate to bring up the cuttings. Most of the 10-foot core sections could be pushed out of the barrel with a rod. If more force was needed, the mud pump was connected to the barrel and the core was pumped out. This step had to be done carefully because once the core started to move, it moved easily. If excessive pressure was used, the core could be ejected so rapidly that it went over the core table and fell on the ground.

For those who are new to coring, Acker (1) is a useful reference. Most types of coring and related drilling are discussed, and previous experience is not assumed.

LOGGING

Well logging is performed on the uncased hole. Three logs aid in deciding the exact depth to set the screen and cementing basket. These logs are natural gamma, resistivity or resistance, and caliper.

The natural gamma log helps in deciding where the highest uranium grade is and hence where to set the screen as shown in figure 3. Uranium decay products emit gamma rays and, if the uranium has not moved away from its decay products, the areas of highest natural gamma rays correspond to the areas of

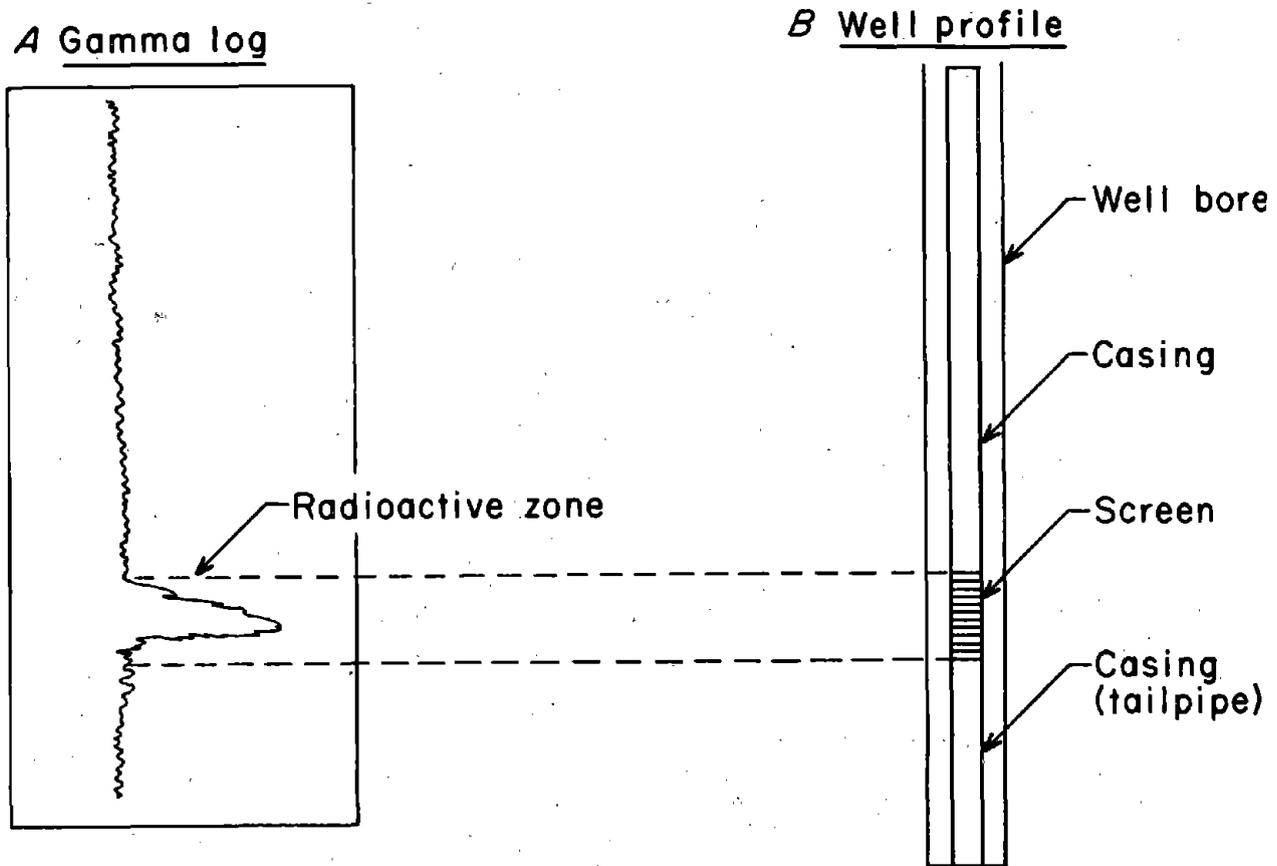
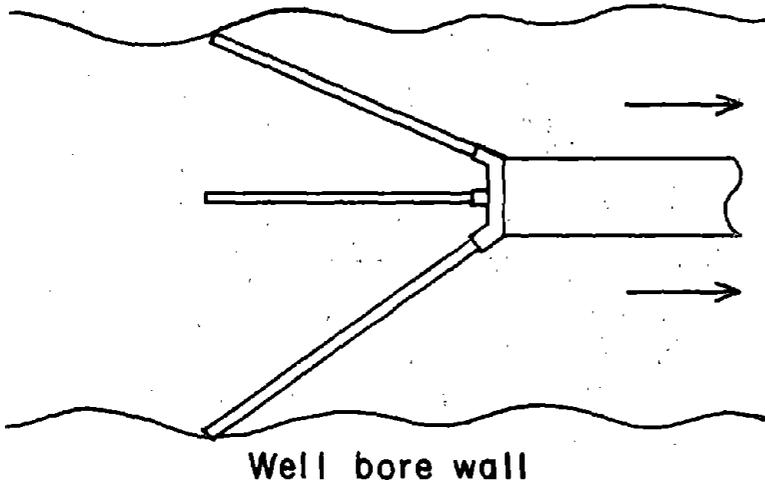


FIGURE 3. - Gamma log-well profile comparison.

highest uranium content. The gamma log is referred to as a "natural" log to distinguish it from induced gamma logs, where a radioactive source is in the probe and gamma rays from the artificially produced nuclides are measured.

A resistance or a resistivity log is used in deciding where to set the cementing basket, which must be set in a competent zone of shale or other well consolidated material to prevent seepage into the screened zone. A resistivity log measures the resistivity of the formation between the ends of the probe. A resistance log, which is more common, measures the resistance from a point on the surface to the downhole probe. These logs can help indicate the proper place for the basket because the resistivity of fine-grained material such as shale and clay is lower than that of coarser grained material such as sand.

The caliper log indicates the diameter of the hole, and it also indicates if sloughing has occurred. The caliper has spring loaded fingers that are extended once the tool has been lowered to the bottom of the hole (fig. 4). The caliper is then brought up the hole constantly measuring the hole diameter. The cementing basket must not be placed in a zone that has sloughed.



Well bore wall
FIGURE 4. - Caliper logging probe.

INSTALLING CASING AND SCREEN

After logging is completed, the casing and screen are installed. The first step is to measure and cut the casing so that the screen and cementing basket will be at the chosen depths. The tailpipe is then capped and attached to the bottom of the screen. Small holes should be drilled in the casing just below the cementing basket plug to allow air to escape as the assembly is lowered

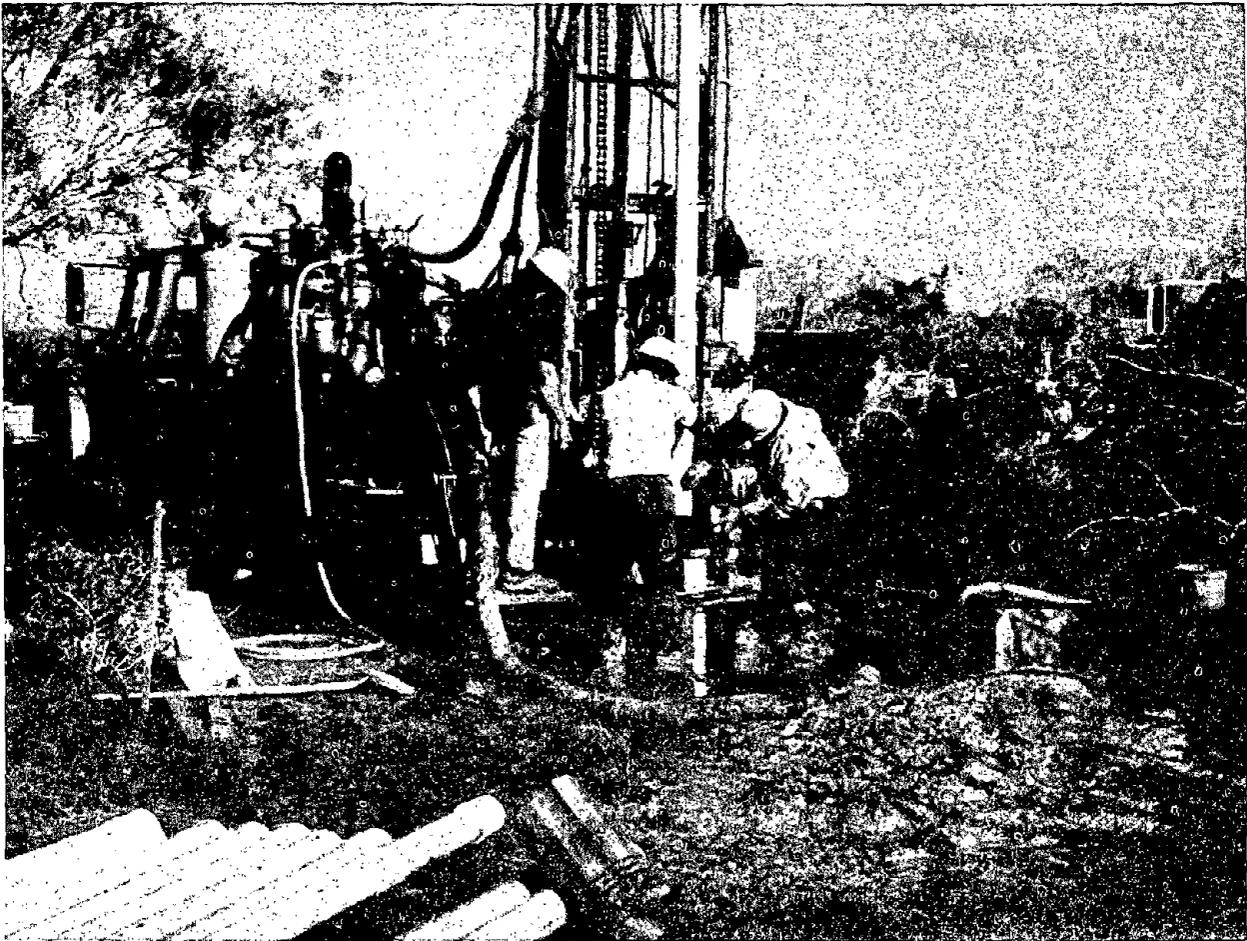


FIGURE 5. - Casing operation using PVC pipe.



FIGURE 6. - Centralizer.

into the water. "Weep holes" of 1-inch diameter are drilled above the plug.

The hoist on the drill rig holds the screen and casing as they are lowered into the hole and connected as shown in figure 5. If glued casing connections are used, screws are also put through the couplings for extra strength.

A centralizer (fig. 6) is slipped over one or more of the casing sections to keep the casing centered in the hole permitting the cement to seal all sides. The centralizers as purchased have six staves (sidebars). At the IEC site, alternate staves were removed, because the staves were quite stiff and a large amount of force was required to push them down the hole with all six staves attached.

One should be careful not to overshoot the depth when lowering the casing. The basket may be ruined if the casing is pulled up more than the distance, about 2 feet, that the basket can slide on its section of casing.

The casing and screen should be installed as soon as possible after drilling and logging are completed. If installation is delayed, the risk of clay swelling and sloughing are increased. In one instance, a caliper log showed that clay swelling reduced the diameter of a 6-3/4-inch hole at one point to 5-1/2 inches. Instead of reaming out that point, the driller forced the casing down the hole. The cementing basket stuck at the narrow point, and so much thrust was applied to force the casing down that it broke below ground. The casing could not be retrieved, and the well was lost (fig. 7).

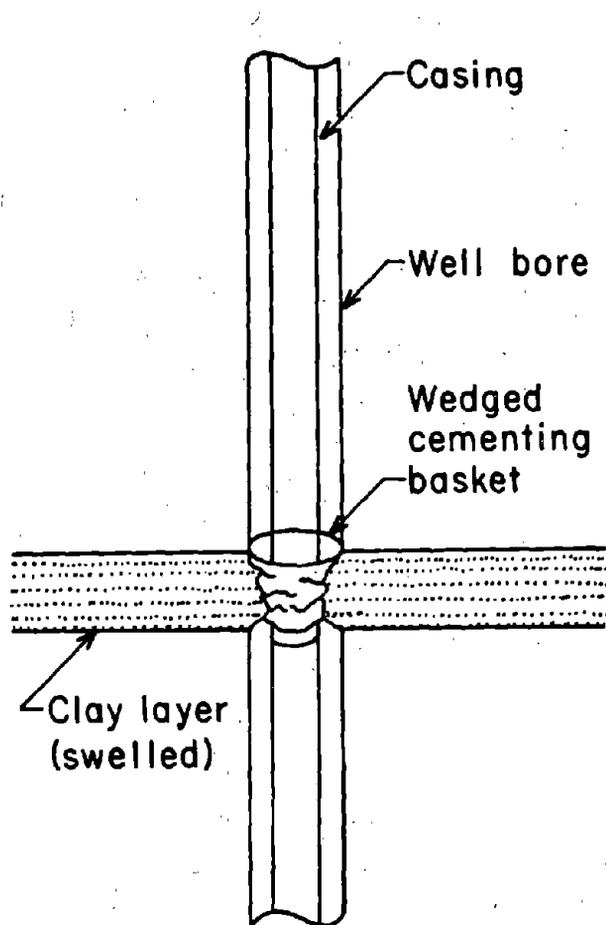


FIGURE 7. - Wedging of the cementing basket caused by clay swelling.

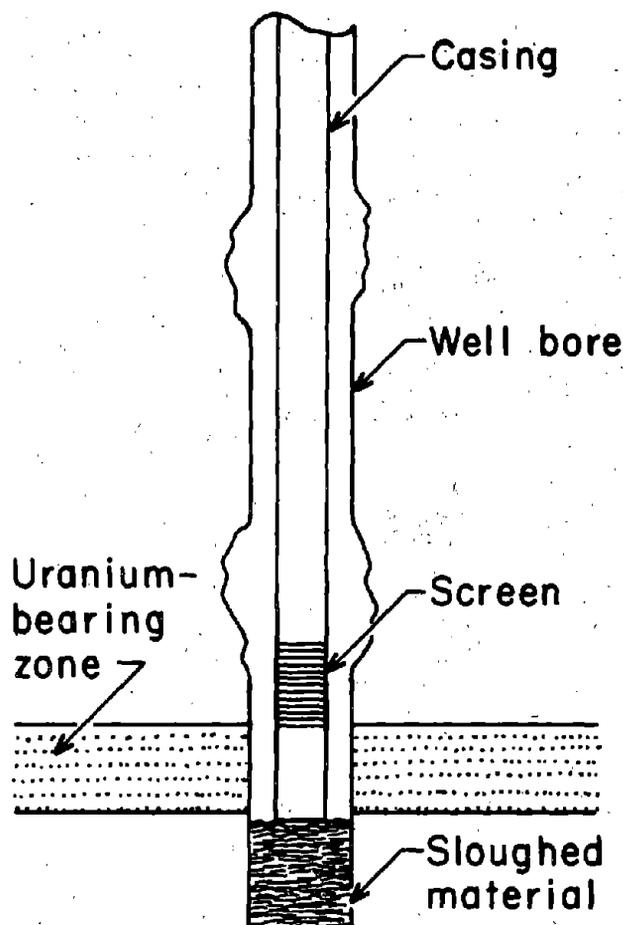


FIGURE 8. - Screen misplacement caused by sloughing of well bore wall.

If a large amount of sloughing occurs, so much material can drop into the bottom of the hole that the tailpipe and hence the screen cannot be lowered to the desired depth as shown in figure 8. If sloughing occurs at the basket depth, the cement can flow around the basket.

CEMENTING

Proper cementing between the casing and the formation is vital. If this space is not sealed, ground water and leaching solution can move from one aquifer to another along the outside of the casing as shown in figure 9. This results in a loss or dilution of leaching solution and possible escape of pollutants. Portland type I cement is often used, with about 6 or 7 gallons of water per 94-pound sack of cement. Some companies have used up to 14 gallons of water per sack. However, cement tends not to stay in suspension with more than 10 gallons of water per sack. Also, shrinkage increases as water content increases. To reduce shrinkage and help insure a good seal, 1 to 4 pounds of bentonite per sack of cement can be added.

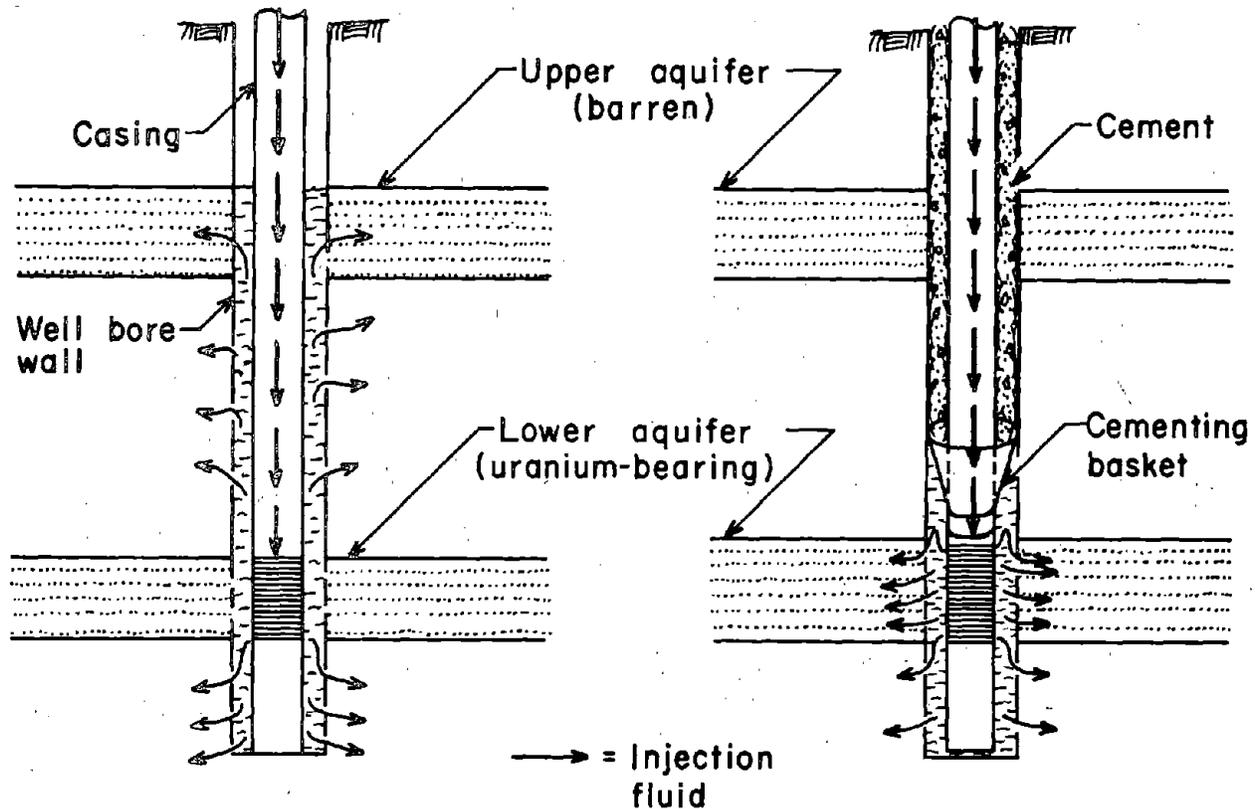
A Uncemented or poorly cementedB Cemented properly

FIGURE 9. - Control of fluid injection direction through cementation.

The method of placing the wet cement slurry is important. If it were merely poured along side the casing, adequate sealing would be unlikely. The cement would bridge the gap above spots where the casing was close to the formation.

The Texas Water Quality Board requires the casing method of cementing (7, p. 242). In the variation of this method used for in situ leaching wells, a cementing basket (fig. 10) is attached to the casing above the screen before the casing is lowered into the well. The basket comes on a short section of casing that contains plaster of paris and a plywood plug. The cementing basket is attached so that it will be at a shale or other competent layer above the ore. Holes of about 1-inch diameter called weep holes are drilled either in the casing attached to the basket or near the bottom of the next higher casing (fig. 11).

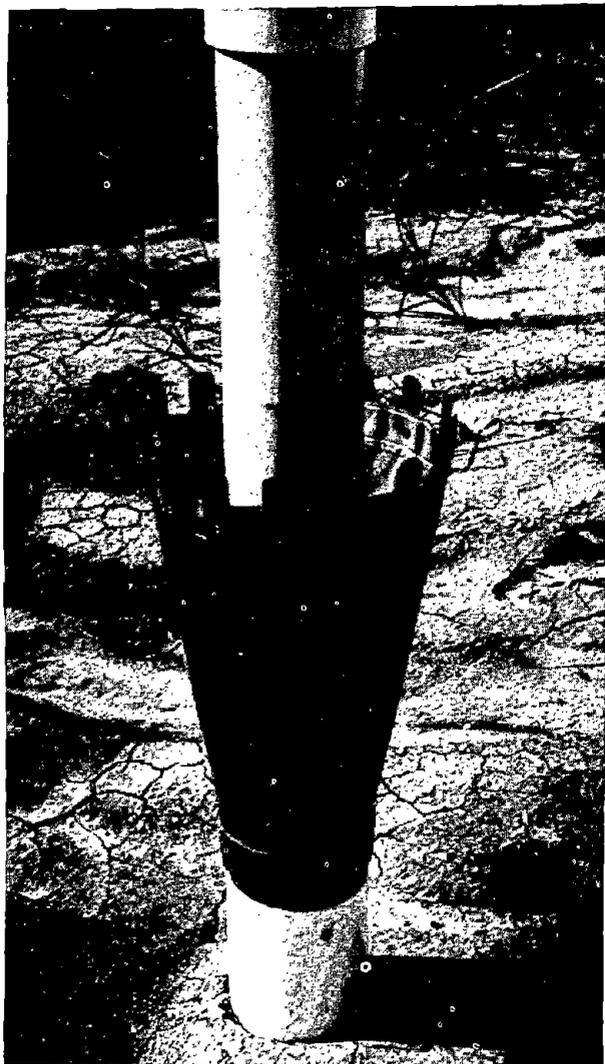


FIGURE 10. - Cementing basket.

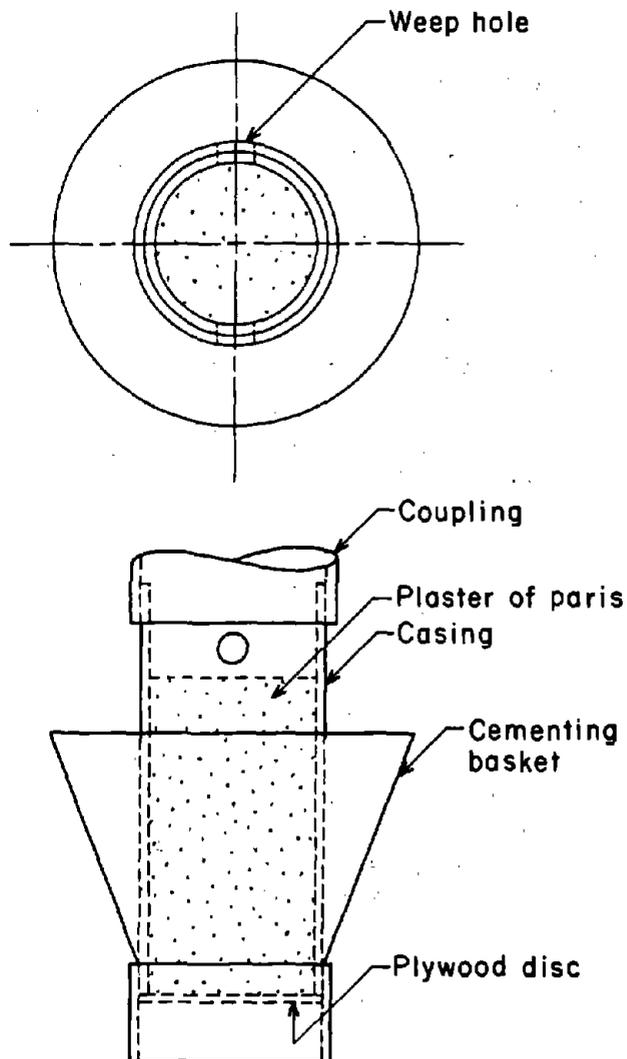


FIGURE 11. - Cementing basket and plaster of paris plug prefabricated unit.

After the casing has been lowered into position, the wet cement slurry is pumped down the inside of the casing and flows out the weep holes above the cementing basket. The cementing basket prevents the cement from flowing down over the screen, and it forces the cement to flow up the annulus between the casing and the borehole wall as shown in figure 12. After a volume of cement sufficient to fill the annulus has been injected, water is pumped into the casing to force or "chase" most of the cement out of the casing, through the weep holes and up into the annulus. Volumes are chosen so that some cement is

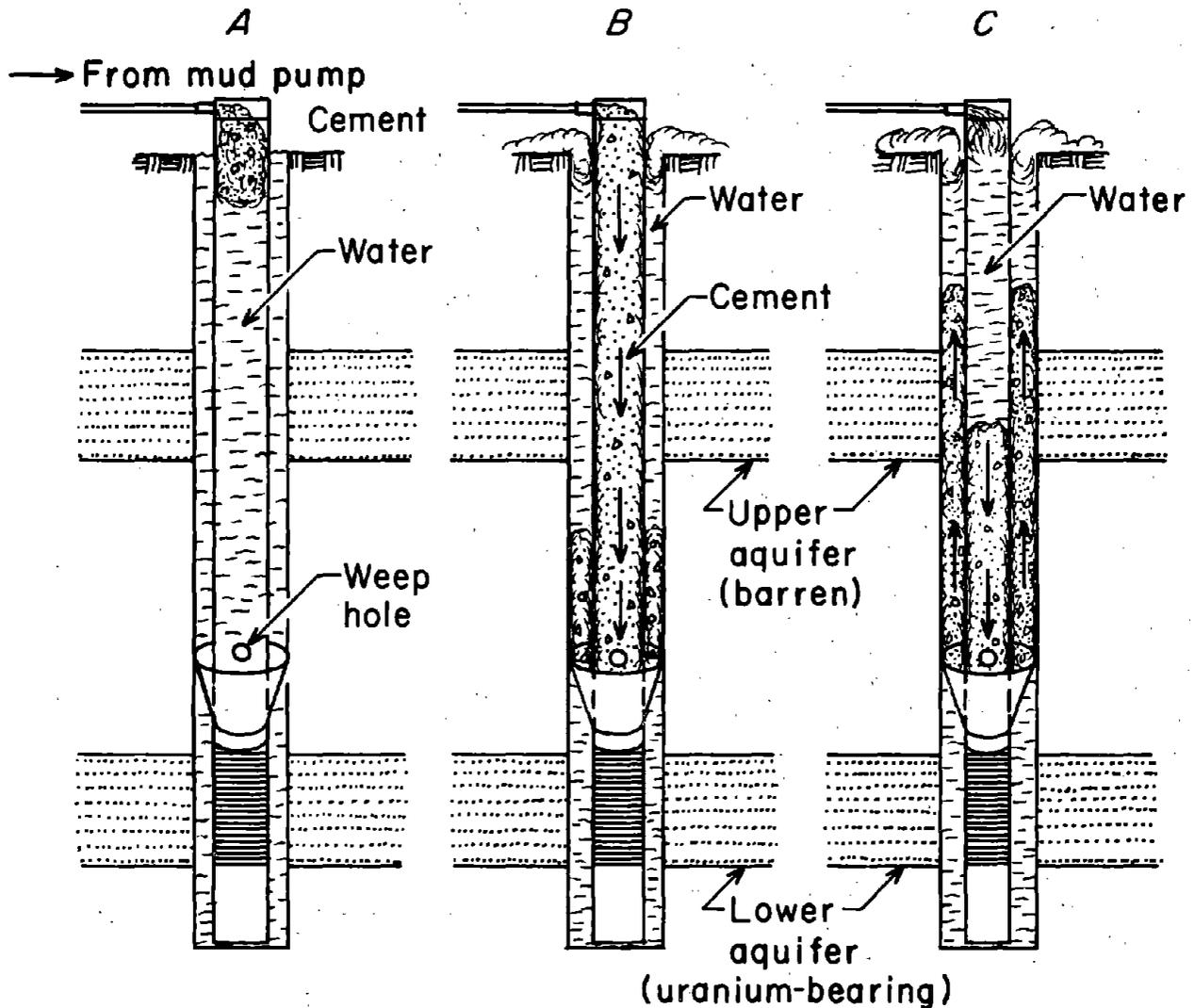


FIGURE 12. - Cementing operation.

left in the casing as shown in figure 13. After the cement has set, the excessive cement and the plug in the cementing basket section are drilled out. The well is then ready for development.

Incomplete sealing may result if much sloughing occurs above the cementing basket. Ordinarily, a small amount of sloughing at one point will not seriously impair the sealing, since the cement will isolate this spot. However, if substantial sloughing occurs, the seal may be poor over enough distance that some aquifer mixing may be possible. For this reason, it is desirable to minimize the time between lowering the casing and cementing. Letting the casing stand overnight in the hole without being cemented should be avoided whenever possible.

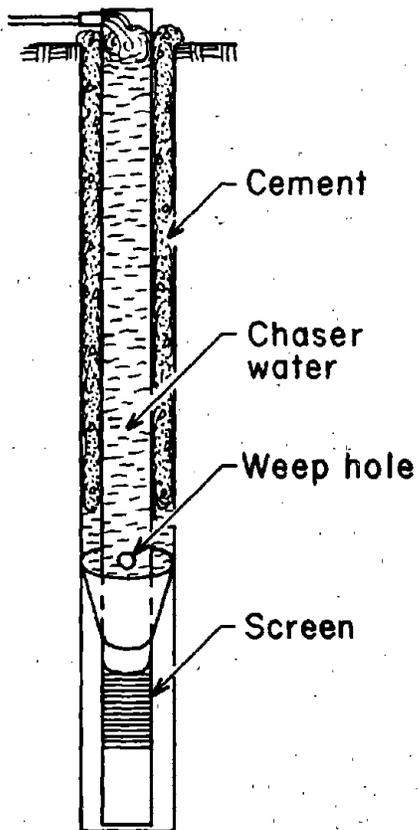
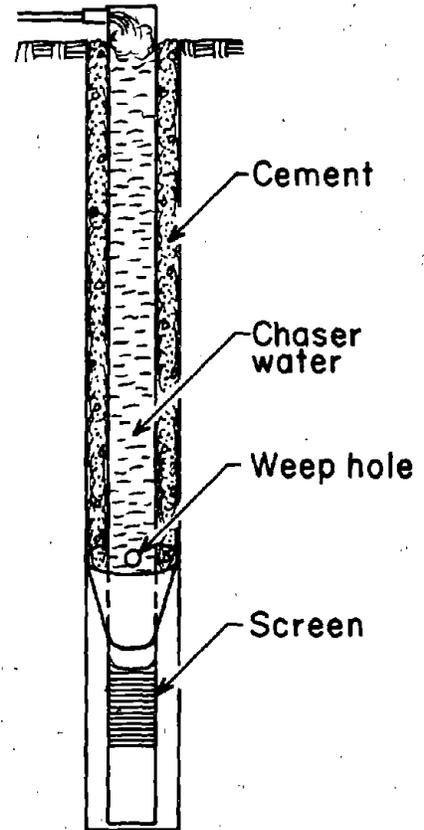
A Too much chaser waterB Proper amount of chaser water

FIGURE 13. - Chasing the cement.

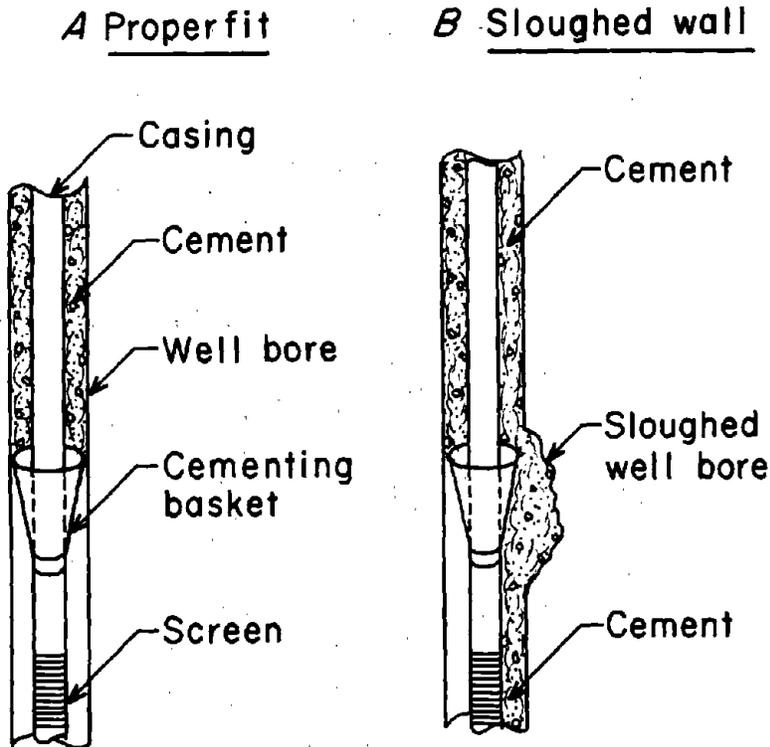


FIGURE 14. - Cementing basket placement.

If the cementing basket is not making good contact with a competent shale or other layer, the cement may be able to pass the basket and cover the screen. This can happen if there is sloughing at the basket, as in figure 14, or if the fingers of the basket are bent in during the setting of the casing and do not spring out again. There are cementing baskets with fingers that will not spring back after being pressed against the casing; these should be avoided.

An alternative to the casing method of cementing is to force the cement through a small pipe outside of the casing (7, p. 240), if there is sufficient space between the casing and the borehole wall. How-

ever, most companies appear to favor the casing method.

DEVELOPING

Well developing is defined as "those steps in completing a water well that aim to remove the finer material from the aquifer, thereby cleaning out, opening up, or enlarging passages in the formation so that water can enter the well more freely" (7, p. 295). Proper well development is essential for both injection and recovery wells, but it may be impossible if the wrong drilling fluid is used, if the drilling fluid is used incorrectly, or if the screen slot size is incorrect.

Wells can be developed either by gravel packing or by natural development. Natural as used here only denotes the absence of gravel packing; it does not mean avoiding forcing water into and out of the formation. Gravel packing consists of placing graded material around the well bore in an annular space drilled or reamed for this purpose. Gravel packing has two disadvantages: It is more expensive than natural development and it makes removal of the fine material more difficult because it must move through the gravel pack. Gravel packing is seldom used in in situ uranium leaching wells; it may be beneficial in extremely fine sand deposits, but it is usually unnecessary.

The first step in development is a gentle washing of the screens with a simple jetting tool attached to the lower end of the drill string. This

low-pressure operation should not be confused with high-pressure jet development. A thorough washing of a 10-foot-long, 4-inch-diameter screen will take 1 to 2 hours.

The next step is pumping to remove the drilling fluid and fine particles from the borehole wall. Only after pumping brings up clear water should more vigorous development such as jetting, airlifting, or surging be attempted. Vigorous development before pumping may force drilling fluid into the formation and make proper development impossible.

Developing with a high-pressure (200 to 300 psi) jet (7, p. 307) or airlifting after pumping can provide more vigorous water movement and break up sand grain bridges (7, p. 299) that may have formed on the screen. Jetting is effective, but must be used carefully to avoid breaking the screen if screens with inner ribs are used. A rotating jetting device can catch on a rib and break it. Either a jetting device with no projections should be used, or the jetting device should not be rotated while jetting. Breakage would be less likely with a screen wrapped on a perforated pipe, but this type of screen does not allow the jetting action to be so effective. The force of the water jet itself does not break the screen. A Bureau of Mines laboratory test showed that even the ribbed-type screen did not break with a water-jet pressure of 675 psi.

Airlifting consists of injecting air fast enough into the bottom of the well through a small pipe so water is lifted out of the well. The resulting turbulence in the well bottom breaks up the sand bridges.

Mechanical surging (7, p. 299) consists of operating a plunger up and down in the casing. The resulting in-and-out flow is very effective at breaking sand bridges; however, surging is seldom needed. If it is used, it should be used with care. In large amounts of clay, the clay can stick to the screen and clog it. The screen can be broken if surging is done too vigorously, especially if it is partially clogged.

The use of chemicals can aid in development; for example, a small amount of flocculating agent appears to help remove guar gum based drilling fluids from the borehole wall and to help drop clay in the mud pit. IEC obtained good results adding 2 oz of Cyfloc-326, a flocculating agent available from IMCO Services Div., Halliburton Co., to the circulating fluid during development of 7-3/8-inch-diameter, 250-foot-deep wells that had been drilled with Revert. Flushing with a combination of hydrofluoric and hydrochloric acid has been used successfully in oil wells (6), and it has been suggested for improving injection wells for in situ leaching. The combination may be more effective than the presently used hydrochloric acid flushing.

SUMMARY

From the preceding sections, it has been shown that there are many factors that should be considered if good injection wells are to be made. Factors that tend to be overlooked but that can have a great effect on the well include:

1. The type of screen and slot size.
2. The quality of the cementing basket.
3. The type of drilling fluid.
4. The method and thoroughness of development.

Neglecting any of these factors can lead to wells with too much fluid resistance to serve their intended purpose.

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