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A Technology for Integrity Testing of In Situ Leach Mining Wells Using a System of Inflatable Packers

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	m	meter
gal	gallon	min	minute
h	hour	mm	millimeter
in	inch	pct	percent
kg	kilogram	psi	pound per square inch
kPa	kilopascal	V	volt
km	kilometer	W	watt
L	liter	yr	year
lb	pound		

A TECHNOLOGY FOR INTEGRITY TESTING OF IN SITU LEACH MINING WELLS USING A SYSTEM OF INFLATABLE PACKERS

By Jon K. Ahlness,[1] Stephen C. Gould,[2] and Michael G Pojar[1]

ABSTRACT

The Bureau of Mines investigated technologies for testing the integrity of in situ leach mining wells, as required by environmental regulations. To test for leaks, inflatable packers were used to seal the well casing. Laboratory testing determined that the packers could contain a casing pressure up to 50 to 60 psi (345 to 414 kPa) less than the packer inflation pressure. Single- and double-packer configurations were successfully field-tested in 32 wells ranging from 500 to 530 ft (153 to 162 m) in depth. A rigid pipeline and a hoist truck were used to run the packers in and out of the wells for the double-packer tests, which averaged 2-1/4 h each.

In an effort to decrease the time of the rigid-pipe double-packer test, a self-contained trailer-mounted test system was designed and built. It utilizes a winch and steel cable to run the packers in and out of the well and high-pressure nylon tubing for packer inflation. This system was successfully field-tested in eight wells averaging 650 ft (198 m) in depth and resulted in a time savings of 13 pct and an operator-hour reduction of 42 pct.

[1]Mining engineer.

[2]Mechanical engineer.

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INTRODUCTION

The Bureau of Mines began conducting research in 1971 to develop improved in situ leach mining techniques and to minimize environmental risks. Major research areas include well construction techniques, computer simulation, reducing environmental concerns, borehole mining, blasting to increase permeability, and economic analyses. A publication summarizing recent Bureau in situ mining research is available.[3]

As part of this program, the Bureau investigated technologies for determining the integrity of in situ leach mining wells using a system of inflatable packers. This report describes the laboratory and field testing of such packers and the field testing of a complete well integrity testing system.

In situ leach mining is a selective mining technique whereby the ore mineral, which has not been transported from its geologic setting, is preferentially leached (dissolved) from the surrounding host rock by the use of specific leach solutions and the mineral value is recovered. Commercial application of the technique to recover uranium has been used in Texas and Wyoming and is discussed in a previous Bureau of Mines publication.[4]

All current in situ uranium mining operations use injection wells to introduce leach solutions to the ore. State and Federal regulations require that these wells be integrity-tested (pressurized) to prove that they do not have leaks, which could cause excursions (movement of leach solution away from the well field) in aquifers overlying the ore zone. This means that well integrity testing is a regular part of the well field construction phase. Some States also require retesting at certain intervals. The Wyoming Department of Environmental Quality (WDEQ), for instance, requires retesting every 5 yr of use.[5]

It is important to detect well failures for both operating and environmental reasons. Besides ground water contamination, casing leaks might result in excessive costs for leach solution reagents, low mineral recovery, and low-grade pregnant solutions.

The Nuclear Regulatory Commission (NRC) and WDEQ specifications for well integrity testing are not well defined. NRC regulations state that the well casing must be pressurized to its maximum potential injection pressure, isolated from the pressure source, and monitored for 10 to 30 min. If the pressure does not drop more than 5 to 10 pct, the well is deemed acceptable.[6] The WDEQ is in the process of formalizing its regulations, but for the present it is following NRC guidelines.

Before integrity testing regulations were in effect, wells were checked for damage with caliper and resistivity logs, and downhole television cameras. In order to integrity-test a well, the casing must be sealed at the top and bottom. Current methods of bottom sealing utilize a cement seal in wells that are not screened or perforated. A single inflatable packer on a string of pipe is used to bottom-seal wells that are screened or perforated. Top sealing is most commonly achieved with modified well caps that fit onto the casing. These methods are either time consuming or not suitable for isolating casing leaks.

A well integrity testing system utilizing two inflatable packers to seal the

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[3]U.S. Bureau of Mines. In Situ Mining Research. Proceedings: Bureau of Mines Technology Transfer Seminar, Denver, Colo., August 5, 1981. BuMines IC 8852, 1981, 107 pp.

[4]Larson, W. C. Uranium In Situ Leach Mining in the United States. BuMines IC 8777, 1978, 87 pp.

[5]Wyoming Department of Environmental Quality, Land Quality Division. Rules and Regulations. Ch. 21--In Situ Mining, sec. 3(C)(6), Mar. 1981, p. 167.

[6]U.S. Nuclear Regulatory Commission, Uranium Recovery Licensing Branch. Groundwater Monitoring at Uranium In Situ Solution Mines. Rep. WM-8102, Dec. 1981, p. 33.

ends of a casing and a steel cable-winch system to run them in and out of the well would be quicker to use and would make it possible to isolate leaks. The majority of commercially available packers are designed for use in oil wells. They are built for use at great depth in a variety of hostile environments and are positioned, set, and released through drill pipe manipulated by a drilling rig.

Integrity testing of in situ leach mine wells is not as demanding on a packer. Typical depths of 1,000 ft (305 m) or less and a ground water environment mean that shorter, lighter, less expensive packers designed for plastic and fiberglass casing can be used. The Bureau purchased inflatable packers of this type and incorporated them into a self-contained well integrity testing system.

ACKNOWLEDGMENTS

The authors wish to thank Uranerz U.S.A., Inc., and Wyoming Fuel Co. for allowing the Bureau to conduct field tests at their sites near Linch, WY, and Crawford, NE, respectively. Thanks also go to Michael T. Nigbor (a mining engineer with the Bureau of Mines, Denver Research Center) who arranged the procurement of the packers used in these tests, and to Robert Becker, plant manager, Uranerz U.S.A., Inc., Casper, WY, for the many hours he spent running the hoist truck and otherwise assisting during the packer field test.

INFLATABLE PACKER DESCRIPTION

The inflatable packers tested are shown in figure 1. They were manufactured for the Bureau by Paul Properties, Inc.,[7] of Houston, TX. Similar packers from other manufacturers may also be available. The overall length of each is approximately 18 in (457 mm). The inflatable rubber packing element is about 12 in (305 mm) long, is 3.75 in (95 mm) in diam when deflated, and is mounted on a 1.25-in (32-mm) diam steel pipe. The packers are designed for use in 4- and 4.5-in (102- and 114-mm) diam nominal-size casings.

The upper and lower packers are built slightly differently. Besides the 1.25-in (32-mm) diam central steel pipe common to both packers, the upper packer has two 0.25-in (6-mm) diam stainless steel tubes entering the top, one of which goes completely through and exits through the bottom. The flowthrough tube and the central pipe of the upper packer can be used interchangeably as the water pressure line and the lower packer inflate line. The other tube entering the upper packer is used for its inflation.

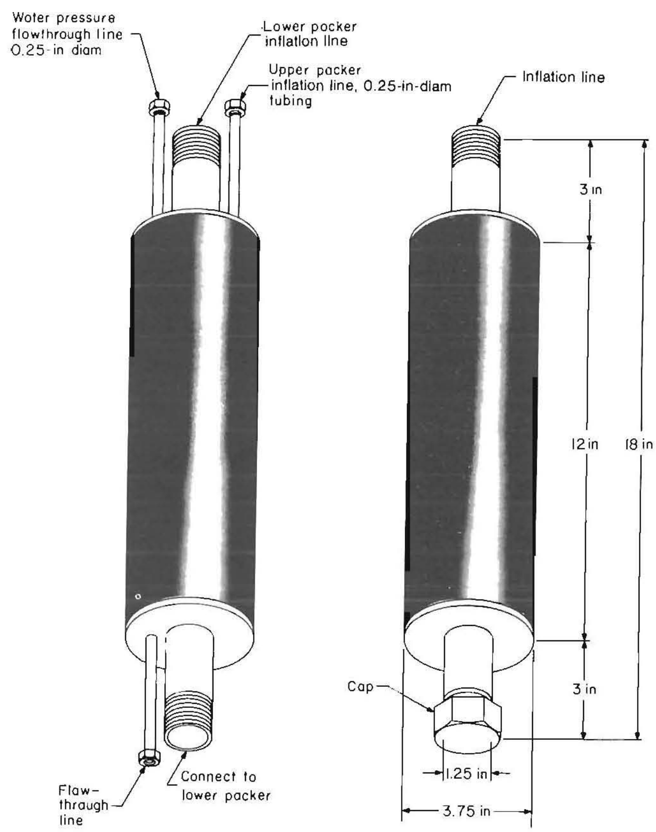

FIGURE 1. - Inflatable packers: left, upper packer; right, lower packer.

[7]Reference to specific products does not imply endorsement by the Bureau of Mines.

With the packers inside the well casing, nitrogen under pressure is applied to the two inflation lines. This causes the rubber packing elements to expand until they contact the inside of the casing, forming a seal. Water pressure can then be built up between the packers. The maximum operating or inflation pressure is 650 psi (4,480 kPa).

PACKER TESTING

The packers were tested in both the laboratory and the field. Laboratory testing was done to determine the maximum holdback pressures (the maximum pressure that can be maintained between the inflated packers without leakage around them) for a range of inflation pressures. Field testing was then done in wells at a site in Wyoming.

LABORATORY TESTS

Procedure

Laboratory tests with the double-packer system were conducted in short pieces (up to 10 ft (3 m)) of unconfined well casing, which was mounted in a nearly vertical position. The purpose of these tests was to determine the ability of the packers to contain pressure in well casings for different packer pressures.

Three sets of tests were run, the first two in 4-in (102-mm) ID polyvinyl chloride (PVC) casing and the third in 4.33-in (110-mm) ID fiberglass casing. The packers were connected together with steel pipe, which prevented them from moving apart during the test and served as the lower packer inflation line. The pipe length was different for each of the three sets of tests. The resulting lengths of open casing between the inflated rubber packer elements for the three sets of tests were 7 in (178 mm), 5.5 ft (1.7 m), and 7 ft (2.1 m), respectively.

The test procedure was the same for all three sets of tests. First the packers were connected together and all fittings were checked for leaks. The packer string was then placed in the piece of well casing. The lower packer was inflated to the desired pressure from a nitrogen tank, the casing above it was filled with water, and the upper packer was inflated to the same pressure as the lower. Figure 2 is a schematic drawing of this test system in a field setting.

The water between the packers was pressurized with a bladder accumulator and a nitrogen tank. An accumulator is an apparatus for storing fluid in a hydraulic system to assure a constant supply at the working pressure, and the bladder inside it prevents nitrogen from entering the casing. The water pressure was increased until water obviously leaked around the packers. This happened when the water pressure became about 20 psi (138 kPa) less than the packer inflation pressure. The valve between the accumulator and the upper packer was then closed, and the water pressure was allowed to stabilize. Stabilization typically took 1 h, at which point a water pressure reading was taken. This was determined to be the

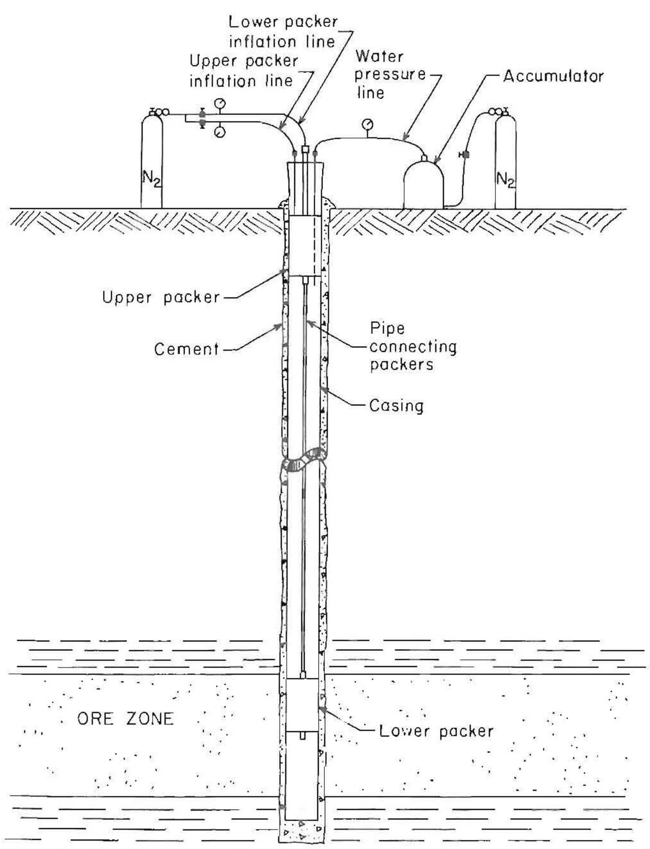

FIGURE 2. - Double-packer test configuration.

maximum holdback pressure. Maximum holdback pressures were determined for packer inflation pressures ranging from 100 to 350 psi (690 to 2,400 kPa), inclusive, for all three sets of tests.

Results

The results from all three sets of laboratory tests are shown in table 1. They are similar for each set of tests, which indicates that packer spacing and small differences in casing diameter have little or no effect on the maximum holdback pressure. The resiliency of the rubber packer element requires an inflation pressure greater than the pressure desired for the well integrity test. From the test data, it can be seen that this pressure differential is about 60 psi (414 kPa), or in other words, the maximum holdback pressure is roughly 60 psi (414 kPa) less than a given packer inflation pressure. Therefore, when well integrity tests are run, the packers should be inflated at least 100 psi (689 kPa) more than the required well test pressure in order to include a safety factor. This is consistent with the recommendations of the manufacturer.

TABLE 1. - Laboratory test results: maximum holdback pressure, pounds per square inch

Packer inflation pressure, psi	4.00-in-ID PVC casing		4.33-in-ID fiberglass casing, 7-ft spacing
	7-in spacing	5.5-ft spacing	
100	55	40	33
125	69	NT	NT
150	91	87	NT
175	119	NT	NT
200	140	140	140
225	170	NT	NT
250	191	190	NT
275	218	NT	NT
300	242	246	240
325	266	NT	NT
350	290	301	NT

NT No test was run.

FIELD TESTS

Test Site

Field testing of the packers was conducted at the Uranerz U.S.A., Inc., Ruth in situ leach site near Linch, WY, about 65 miles (105 km) northeast of Casper (fig. 3). The uranium leaching site, currently in the research and development stage, has 32 leaching wells arranged in 7 interconnected 7-spot patterns (fig. 4). They range from 500 to 530 ft (153 to 162 m) deep and are cased and cemented through the ore zone with 4.33-in (110-mm) ID fiberglass well casing. The wells were not perforated at the time of testing.

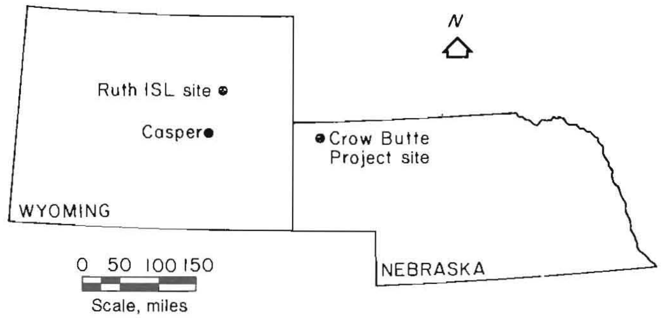

FIGURE 3. - Locations of field test sites.

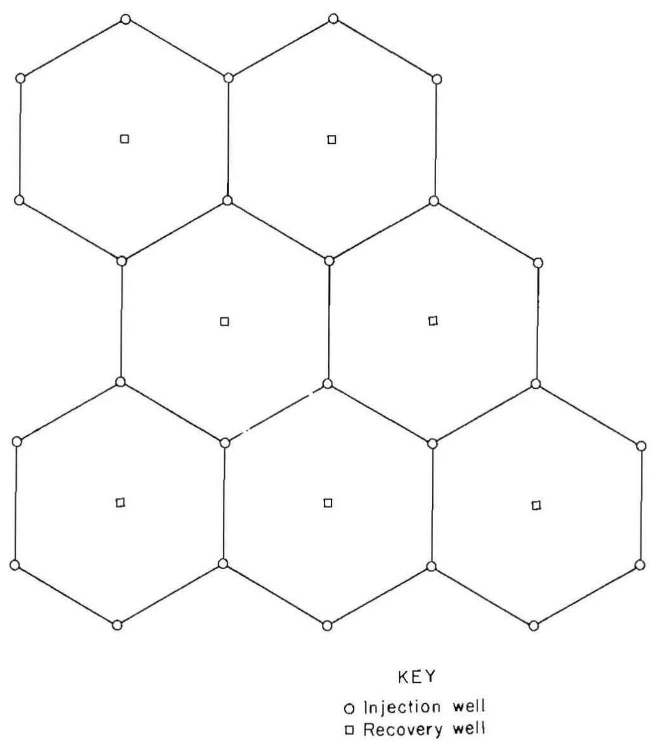

FIGURE 4. - Ruth site well pattern.

The maximum potential injection pressure at the site was 200 psi (1,379 kPa). The pressure drop and time period used for testing were 5 pct and 10 min, respectively. These figures are within NRC and WDEQ guidelines. This meant that the wells could not lose more than 10 psi (69 kPa) during the 10-min test in order to be acceptable.

Procedure

Two types of well integrity tests were run at the site: single and double packer. Single-packer tests use only the upper packer positioned just below the top of the well casing. This test is limited to use in cased and cemented wells that are not screened or perforated. The double-packer test configuration is shown in figure 2 and can be used in any cased and cemented well.

Single-packer tests were run first. The test procedure was to fill a well with water, place the upper packer in the casing below the belled end (this required an extension pipe on the top of the packer), inflate the packer to 300 psi (2,068 kPa), and pressurize the water in the well to 200 psi (1,379 kPa) on a surface gauge. After a 3-min stabilization period, the valve from the accumulator to the well was closed and the well pressure was monitored for 15 min. The gauge used to monitor the water pressure in the well casing was graduated in 2-psi increments and was accurate to ±1/2 pct at full scale. The test apparatus is pictured in figure 5. A single-packer integrity test can be completed in 20 to 30 min.

The only problem that was encountered with the single-packer tests was keeping the packer in the well. The pressurized well water forced the packer up and out of the casing. This was remedied by physically restraining the packer with a modified threaded well cap, as shown in figure 5.

The double-packer integrity testing procedure was to run the lower packer down the well on 0.56-in (14-mm) diam high-pressure stainless steel pipe (13- to 16-ft (4- to 5-m) sections) to the top

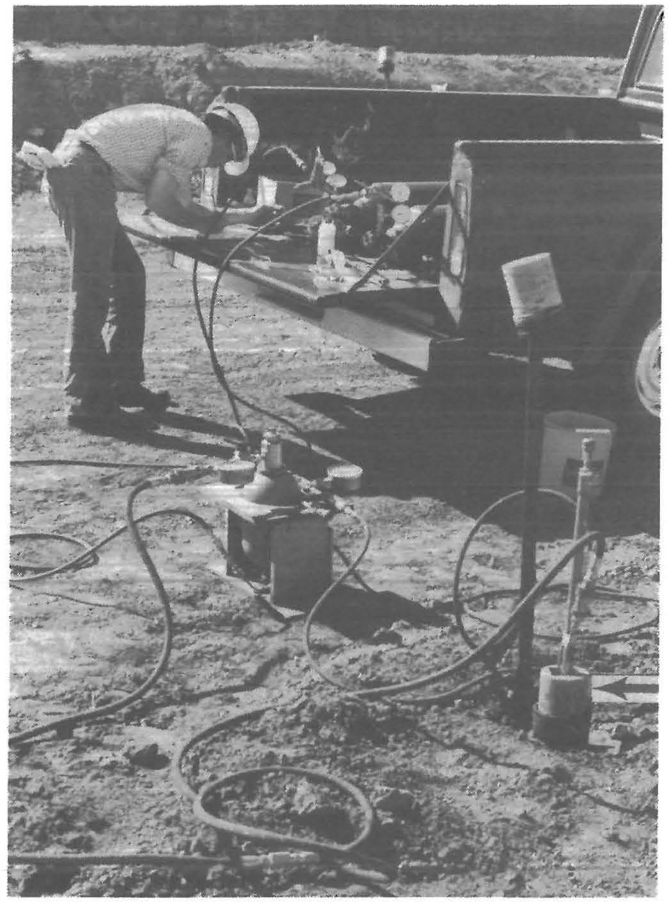

FIGURE 5. - Single-packer field test. Arrow indicates modified well cap.

level of the future well perforations; the upper packer was attached to the pipe string and then lowered into the casing just below the belled end. Packer spacing was almost the entire length of the well. Pipe handling was done with a hoist truck (fig. 6) and was fairly time consuming. (Trip-in time to 500 ft (150 m) typically took about 45 min and trip-out time about 30 min.)

The lower packer was then inflated to 550 psi (3,792 kPa), the casing was filled with water (if it was not already full), and the upper packer was inflated to 300 psi (2,068 kPa). (The lower packer was inflated an extra 250 psi (1,724 kPa) to take into account the 500-ft (150-m) water pressure head.) The water in the casing between the packers was pressurized to 200 psi (1,379 kPa) on a surface gauge and allowed to stabilize for 3 min before the valve from the

FIGURE 6. - Hoist truck lowering packer into well.

accumulator was closed. Casing pressure was then monitored for 15 min.

If a large drop in pressure occurred (indicating a leak in the casing), several pipe sections between the packers were removed to decrease the spacing and raise the lower packer. The test procedure was then repeated. If a large pressure drop occurred again, more pipe was removed and another test was run. This process was repeated until the pressure remained at or near the initial level. The location of the casing leak (or uppermost leak if there was more than one) was then approximately known from the depth of the lower packer.

When the water between the packers was pressurized, the upper packer would rise about 2 or 3 in (51 or 76 mm) because of pipe and joint tensioning; however, even though the packer moved, no leakage occurred around it. The only problem in the double-packer tests occurred when the joints in the pipe between the packers leaked. This caused the casing pressure to increase during a test and required extra time to find and correct the problem.

The double-packer tests were run with a three-person operating crew: one to operate the hoist truck controls, one to connect and disconnect the pipe at the pipe rack, and one to handle the pipe wrenches to make and break pipe joints. This was probably the most efficient manner in which the rigid-pipe system could be handled. When no problems were encountered, double-packer test time averaged 2-1/4 h in these wells, which had an average depth of 503 ft (154 m). This time does not include any casing water fill time. Since the wells were not screened or perforated, they were all filled in advance. A two-person crew could operate this system, but efficiency would decrease, resulting in a longer time necessary to complete a test (probably an additional 20 to 30 min). If only one person were to attempt to run a test, a tremendous inefficiency would result and probably limit integrity testing to a single well per shift.

Results

Single-packer tests were run on 27 of the 32 leaching wells at the site. The other five wells were known from water level monitoring to have leaks. Well numbers and casing pressure information for the single-packer tests are shown in table 2. The WDEQ and NRC guidelines for well integrity (maximum 10-psi (69-kPa) drop in 10 min) were met in 21 wells but not in 6: wells 13, 16, 18, 20, 21, and 22.

Those six wells along with four of the five wells with known leaks were then tested using the double-packer system. The casings in 8 of these 10 wells were

TABLE 2. - Single-packer test results: casing pressure, pounds per square inch

(Casing pressure at 0 min = 200 psi)

Well[1]	5 min	10 min	15 min	Well[1]	5 min	10 min	15 min
4.............	198	195	193	19.............	199	198	197
5.............	199	198	197	20.............	182	176	173
6.............	198	196	196	[2]21.............	144	141	140
7.............	198	196	195	22.............	190	182	175
8.............	199	199	199				
9.............	198	197	196	23.............	198	198	198
10.............	200	199	197	24.............	199	198	197
11.............	197	195	192	25.............	198	196	194
12.............	197	195	194	26.............	198	196	194
				27.............	195	191	190
13.............	184	172	163	28.............	199	197	195
14.............	197	196	194	29.............	199	193	183
16.............	158	110	69	30.............	197	194	192
17.............	199	196	194	31.............	197	195	194
18.............	171	142	110				

[1]Wells 1, 2, 3, 15, and 32 had known leaks; single-packer tests were not run.
[2]Casing pressure at 0 min = 170 psi.

proven competent, as shown in table 3. The leaks were associated with poor cement seals at the bottoms of these wells, and there was no problem with the casings themselves. Wells 16 and 18 lost pressure, and well 3 had a leak at a depth of about 15 ft (4.6 m) known from water level monitoring.

Well 18 was the first well tested with the double-packers that lost substantial pressure. In order to locate the leak, a series of double-packer tests was run in the well, each time raising the lower packer, as described in more detail in the preceding section, "Procedure." A leak was found near the top of the well between 2 and 8 ft (0.6 and 2 m). Time and pressure data were not recorded for each of the leak isolation tests in the well. Each test was run just long enough to determine whether the casing pressure remained stable. If the pressure was dropping, the test was discontinued and the lower packer was raised and another test initiated. As the spacing between the packers decreased, the casing pressure dropped faster if there was a casing leak in the test interval.

Since the leak isolation process required so much time, it was decided to test the 2- to 8-ft (0.6- to 2-m) depth portions of the remaining wells before conducting the full-length double-packer test. This proved successful when well 16 was found to leak in this same zone.

TABLE 3. - Double-packer test results: casing pressure, pounds per square inch

(Casing pressure at 0 min = 200 psi)

Well[1]	Bottom packer depth, ft	5 min	10 min	15 min
1.....	494.5	198	197	195
2.....	513.7	197	195	194
13....	507.6	199	199	198
15....	494.5	199	198	197
[2]16....	8.0	NT	NT	NT
18....	503.0	151	110	69
20....	503.0	200	200	200
21....	472.8	199	198	198
22....	513.4	199	199	198
32....	500.3	199	198	197

NT No test was run.
[1]Well 3 had a known leak at about 15 ft; no double-packer test was run.
[2]A pressure of 200 psi could not be reached, indicating a leak.

The ground around wells 3, 16, and 18 was excavated to determine the cause of the leaks. Physical examination revealed that loose joints and two missing O-rings were the problem. After these joints were repaired, single-packer tests proved that all these wells were competent (table 4).

Through all of the laboratory and field tests the packers performed well and suffered no visible damage.

TABLE 4. - Single-packer test results after casing repair: casing pressure, pounds per square inch

(Casing pressure at 0 min = 200 psi)

Well	5 min	10 min	15 min
3..............	198	193	189
16..............	198	196	194
18..............	200	198	198

INTEGRITY TESTING SYSTEM DESCRIPTION

After the packers and integrity testing procedures were proven in the field, the Bureau designed and built a trailer-mounted well integrity testing system (WITS) (figs. 7-8), which uses a winch and steel cable to run the packers in and out of the well. The advantages of the WITS are--

1. No drill rig or hoist truck is needed to run the packers in and out of the well.

2. A test can be completed in a shorter amount of time.

3 The system can be operated by one person.

4. Casing leaks can be located in the well.

5. The system is easily portable.

These advantages will result in a lower cost per well tested.

The system consists of the following components:

1. Electric winch (200-lb (91-kg) maximum capacity) with 0.25-in (6.4-mm) diam galvanized steel cable.

2. Gasoline-powered electrical generator (115 V, 2,500 W).

3. Hand-operated reel (19-in (483-mm) diam drum) with 0.25-in (6.4-mm) diam high-pressure nylon tubing.

4. Boom.

5. Accumulator (5 gal (18.9 L)).

6. Nitrogen tanks.

7. Inflatable packers.

8. Water reservoir.

9. Plumbing system (regulator, valves, gauges, etc.).

The winch raises and lowers the cable to position the packers at the desired depths in the well. It is powered by the electrical generator. The hand-operated reel holds the high-pressure nylon tubing used to inflate the packers; both a single line used in the standard double-packer tests and a triple line for leak isolation tests. The boom is used to position the cable over the well casing. The accumulator is used in combination with the nitrogen tanks to pressurize the water in the casing between the packers. It has an internal rubber bladder to prevent nitrogen gas from entering the well. Nitrogen pressure is used to inflate the packers, which expand in the casing and create a seal. The packers (fig. 1) can be used in any 4- or 4.5-in (100- or 115-mm) nominal-size well casing. The water reservoir is used for filling the accumulator and can be used to "top off" a well if only a small amount of water is needed. The plumbing system is used to control the flow of nitrogen and water. The pressure gauge on the water line is

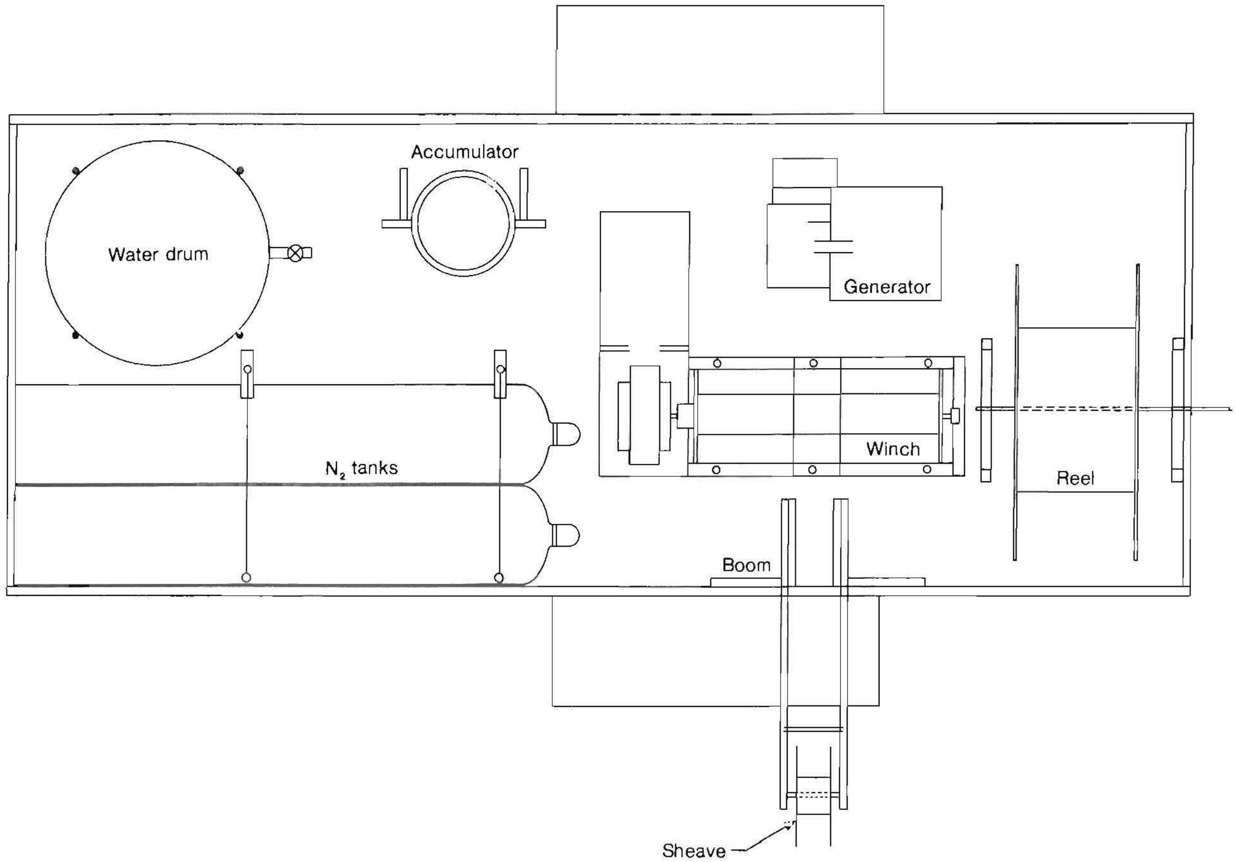

FIGURE 7. - Diagram of well integrity testing system (WITS).

FIGURE 8. - Trailer-mounted well integrity testing system.

TABLE 5. - System component costs (1982)

Component	Cost
Flatbed trailer	$911
Electric winch	2,160
Galvanized steel cable (0.25-in diam, 700 ft)	210
Generator (115 V, 2,500 W)	375
Nylon high-pressure tubing (0.25-in OD, 2,500 ft)	172
Bladder accumulator (5 gal)	867
Inflatable packers (2)	2,000
Pressure regulators (2)	170
Pressure gauges (3)	360
Miscellaneous (steel, fittings, canvas cover, etc.)	380
Total	7,605

graduated in 2-psi increments and is accurate to ±1/2 pct at full scale.

The system component costs are shown in table 5. The total cost of the WITS was $7,605.00 in late 1982. This cost does not include labor costs for constructing the boom and hand-operated reel, and for mounting the components on the trailer.

FIELD TESTING OF SYSTEM

TEST SITE

Wyoming Fuel Co.'s Crow Butte Project site is located in northwestern Nebraska about 5 miles (8 km) southeast of Crawford (fig. 3). Eight wells were completed at the site in 1982 for hydrologic test work and to collect environmental baseline data. Six wells were in the ore zone and averaged 650 ft (198 m) in depth. Three of these wells will be monitors, two will be injectors, and one will be a producer in the proposed pilot plant operation for which permits were applied in February 1983. The water table in these wells was about 115 ft (35 m) below the surface. The other two wells were in shallow aquifers for ground water monitoring. The wells were all cased with 4.5-in (114-mm) Yelomine (PVC plastic) well casing and were screened in the ore zone.

The maximum potential injection pressure, as stated in the pilot plant permit application, is 100 psi (689 kPa). The well integrity test criteria at the site were a casing pressure of 100 psi (689 kPa), which had to be held within 10 pct (10 psi, 69 kPa) for a period of 10 min after the pressure source to the well had been closed off.

PROCEDURE

All the wells were screened, so double-packer tests were run. Upper and lower packer inflation pressures were 300 and 500 psi (2,068 and 3,447 kPa), respectively.

Since no leaks were found in any of the wells, double-packer leak isolation tests were tried only in one well to test the procedure. A fixed distance of 15 ft (4.6 m) was maintained between the packers. This unit was lowered down the well in 15-ft (4.6-m) intervals, with an integrity test run at each stop.

The triple line of nylon tubing was attached to the three connections on the top of the upper packer. This allowed the upper packer to be lowered down the well.

PROBLEMS

Two major problems surfaced during the field testing of the WITS. The first and most troublesome was that the lower packer caught in the casing as it was being lowered into the well. This occurred at depths around 600 ft (180 m) and was evident when the nylon inflation tube stopped moving down the well. In most cases, by raising and lowering the packer at these catch spots, the packer could be worked past them and down to near the desired depth. If the downward momentum of the packer could be maintained, the catching problem did not occur as often. There was no catching problem when raising the packer up the well.

This problem may be caused by a lack of weight in the bottom packer in conjunction with increasing well deviation (friction of the packer against the casing) at depth. The lower packer weighs 11 lb (5 kg) in air, but only 4 lb (1.8 kg) in water.

The second problem was leaks in the lower packer inflation line between the two packers. This is obvious when the lower packer is inflated and the casing is filled with water. If a leak is present, a continuous stream of bubbles will break the surface. These are not to be confused, however, with entrapped air bubbles from the casing filling process, which are usually smaller and diminish after a short time.

Leaks of the lower packer inflation line have to be eliminated before a valid integrity test can be conducted; otherwise, the casing pressure will increase during the test. It was easiest to check the line connections before they were lowered into the well. The procedure was to lower the lower packer into the well until a connection in the inflation line was reached. The packer was then inflated and the connection checked for leaks with soap bubbles. The connection that caused the most problems was the one at the bottom of the upper packer. It was connected and disconnected with every test, and the wear on the brass fitting made it more susceptible to leakage. It was necessary to replace this fitting occasionally.

TIME REQUIREMENTS

The double-packer test procedure can be broken down into five operations, each with its own time requirement, as shown in table 6. These times were developed with a two-person crew conducting the tests. It should be possible to operate the WITS with only one person. The setup time is the time required to move the equipment from one well to another and position it correctly. Double-packer positioning time was greatly affected by the problem of the lower packer's catching, described earlier, and is an average for the wells tested. The water fill time was based on a 115-ft (35-m) water table depth and a 4.5-in (114-mm) ID well casing.

Table 6 also shows average test times for three different well depths (85, 190, and 650 ft (26, 58, and 198 m)), corresponding to those tested at the Crow Butte field site. The time required to test a well in the 634- to 652-ft (193- to 199-m) depth range was about 2-1/2 h. The 503-ft (153-m) well depth corresponds to the average depth of the wells double-packer tested with the rigid-pipe system at the Uranerz Ruth site. Those tests averaged 2-1/4 h. A direct time comparison shows that the WITS can test a well

TABLE 6. - Test times, using the WITS

Operation	Average time or rate	Time, min			
		85-ft well	190-ft well	650-ft well	503-ft well[1]
1. Setup	20 min	20	20	20	20
2. Double-packer positioning (lowering)	11 ft/min	8	18	59	46
3. Casing water fill	7 ft/min	12	17	17	(2)
4. Integrity test	25 min	25	25	25	25
5. Double-packer removal (raising)	20 ft/min	5	10	33	26
Total	NAp	70	90	154	117

NAp Not applicable.

[1]Times extrapolated from column 2.

[2]Casing water fill time was not included in the 2-1/4-h average time for the rigid-pipe double-packer test at the Uranerz Ruth site.

TABLE 7. - Crow Butte Project field data summary

Well	Max packer depth, ft	Lower packer depth, ft	Well pressure, psi			
			0 min	5 min	10 min	15 min
1........	643	639	100.0	98.5	96.5	95.5
2........	635	619	100.5	99.0	97.0	96.0
3........	642	634	100.5	94.5	90.0	NR
[1]3........	642	634	100.0	96.0	94.0	91.5
4........	646	635	100.0	97.0	94.0	91.0
5........	634	618	99.5	96.0	93.5	91.0
6........	189	184	100.0	99.0	98.5	98.0
7........	83	79	100.0	100.0	100.0	99.75
8........	652	558	100.0	93.5	89.0	NR
[1]8........	652	558	100.0	96.0	92.5	90.0

NR No reading taken. [1]Retest.

in 18 fewer minutes than the rigid-pipe system in a 503-ft (153-m) well. This is a time savings of 13 pct. A direct labor comparison shows that the WITS reduces operator-hours by 42 pct, remembering that the times for the rigid-pipe system were developed with a three-person crew. Since the WITS times were based on an average of all tests, and the rigid-pipe system times were based only on tests where no problems occurred, these time saving estimates should be condidered conservative.

RESULTS

The well integrity test results for the eight wells tested at the Crow Butte Project site are shown in table 7. The requirements for testing were to maintain 100 psi (689 kPa) within 10 pct (10 psi, 69 kPa) for a period of 10 min. All of the wells met these requirements. Wells 3 and 8 lost 10.5 and 11.0 psi (72 and 76 kPa), respectively, during their first tests, but after repressurization to 100 psi (689 kPa), they remained within the allowed 10 pct.

In the deep wells (634 to 652 ft (193 to 199 m)), some difficulty occurred in lowering the lower packer to the desired depth, as previously described. In all of these wells except 8, the lower packer was set in the last section of casing (the casing was in 20-ft (6-m) lengths). In well 8, the lower packer was finally set at 558 ft (170 m), which was 94 ft (29 m) short of the maximum packer depth.

Even though no leaks were found in any of the wells, the double-packer leak isolation test procedure was tried in well 7. Two tests were run, one from 0 to 15 ft (0 to 4.6 m), and the other from 15 to 30 ft (4.6 to 9 m). No pressure was lost during either test.

CONCLUSIONS

Preliminary laboratory and field testing of the inflatable packers proved their effectiveness in sealing 4-in (102-mm) diam nominal-size PVC and fiberglass well casings; the packers were used in single- and double-packer well integrity tests, with well pressures up to 200 psi (1,379 kPa). It was found that packer inflation pressure should exceed the well casing test pressure by a minimum of 100 psi (689 kPa). The packers were field-tested in 32 in situ leach mining wells and performed within expectations. Single-packer tests required a physical constraint to keep the packer from moving up and out of the well when the casing was pressurized. The double-packer tests were run with a rigid pipeline connecting the packers.

The amount of time required to run the packers in and out of the well with this system led the Bureau to design and construct a self-contained trailer-mounted well integrity testing system (WITS). The WITS was successfully field-tested in eight in situ leach mining wells at depths up to 640 ft (195 m). Double-packer well integrity tests were run at 100 psi (689 kPa) in 4.5-in (114-mm) diam PVC well casing. The only major unresolved problem encountered during testing was the lower packer's catching as it was lowered down the well. This typically occurred at depths around 600 ft (183 m) and required extra time to position the packer at the desired depth. The problem was probably caused by the light weight of the packer in conjunction with the friction of the packer against the casing, caused by increasing well deviation at depth. With the WITS, wells can be integrity-tested faster and with fewer people than with a rigid-pipe system.

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