Oct. 29, 1963 J. J. REYNOLDS ETAL 3,108,439

UNDERGROUND DISPOSAL OF RADIOACTIVE LIQUIDS OR SLURRIES

Filed May 23, 1960 3 Sheets-Sheet 1

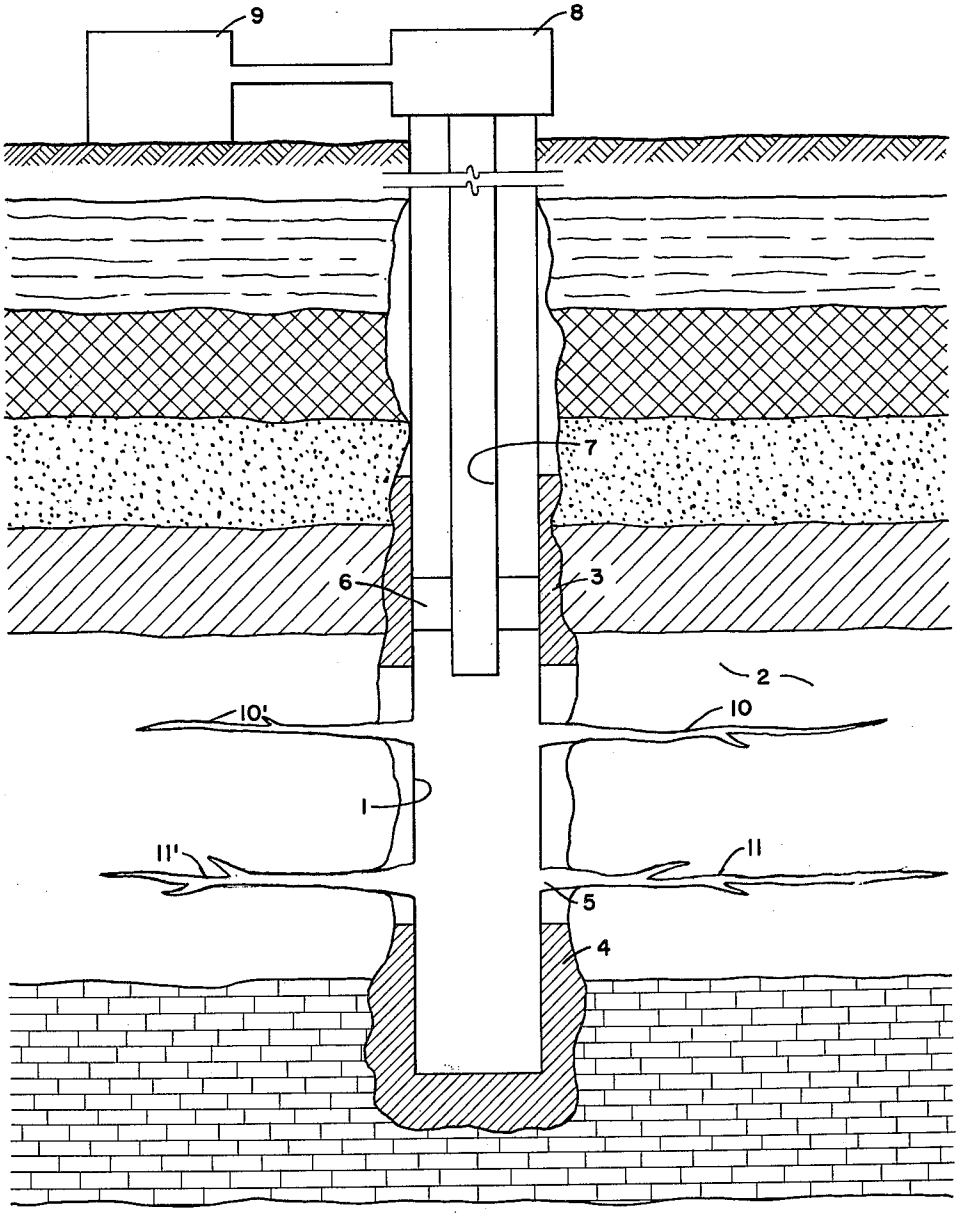


FIG. 1

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UNDERGROUND DISPOSAL OF RADIOACTIVE LIQUIDS OR SLURRIES

Filed May 23, 1960 3 Sheets-Sheet 2

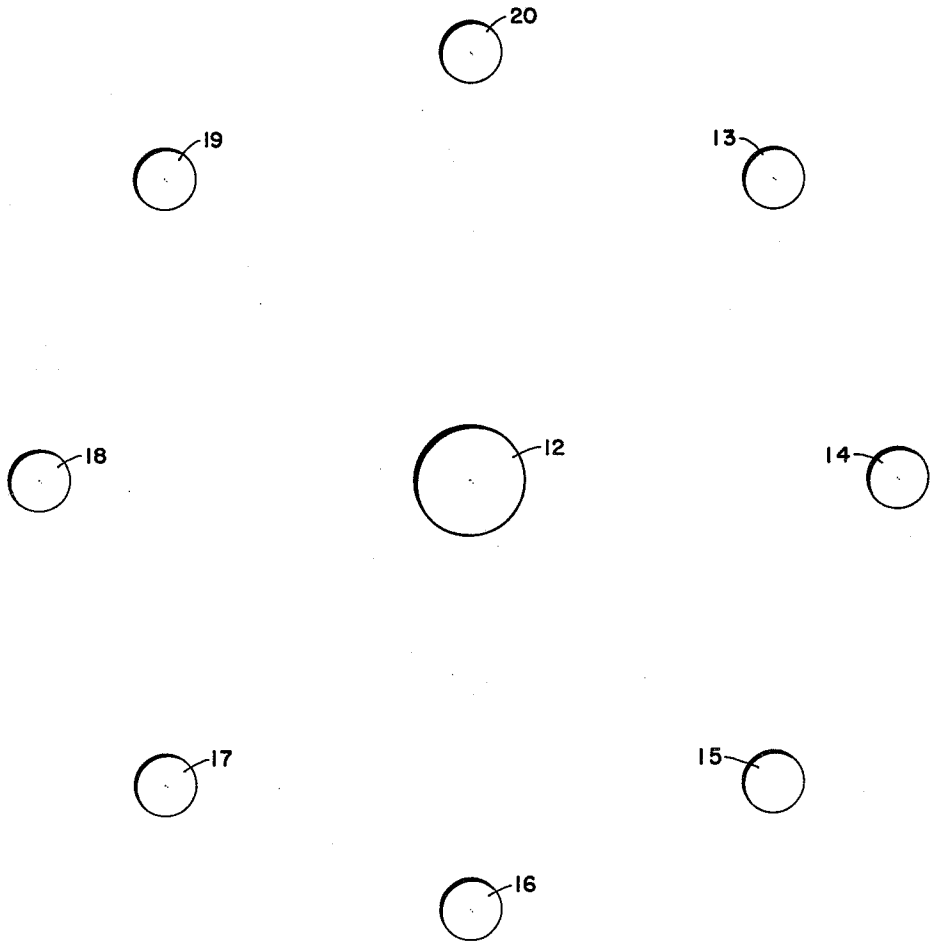


FIG. 2

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UNDERGROUND DISPOSAL OF RADIOACTIVE LIQUIDS OR SLURRIES

Filed May 23, 1960 3 Sheets-Sheet 3

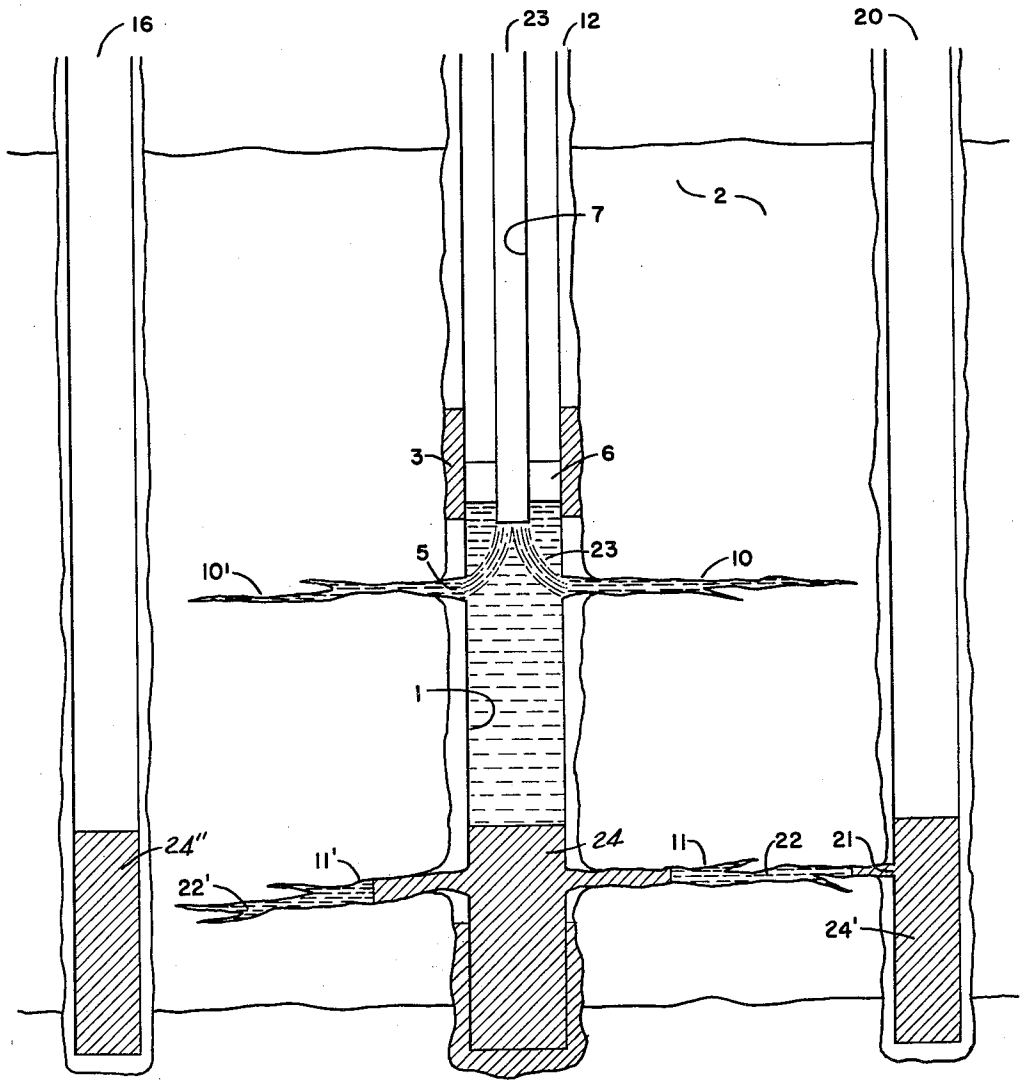


FIG. 3

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United States Patent Office

3,108,439

Patented Oct. 29, 1963

3,108,439

UNDERGROUND DISPOSAL OF RADIOACTIVE LIQUIDS OR SLURRIES

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Filed May 23, 1960, Ser. No. 30,988
17 Claims. (Cl. 61—.5)

The present invention appertains to the disposal of radioactive liquids or slurries such as that resulting from reactors employing fissionable material as a source of energy. More particularly, the invention relates to the subterranean storage of these radioactive wastes and still more particularly concerns the disposal of high level wastes in artificial subterranean reservoirs such that they will be contained without movement. This application is a continuation-in-part of our application Serial No. 762,991, filed September 24, 1958, entitled "Underground Disposal of Radioactive Liquids or Slurries" and now abandoned.

The use of atomic power by the military and the testing of experimental fission reactors already are beginning to cause the accumulation of wastes in substantial volumes. An early solution providing for sale and adequate disposal of waste has been sorely needed, although prior to this invention such has failed to be found by the many researchers endeavoring to do so.

The primary difficulty with radioactive wastes, particularly fission product waste, is that they cannot be disposed of by ordinary dilution methods. In order to bring solutions to accepted A.E.C. activity tolerances, the dilution is so great that the method is unfeasible. Retainment until sufficient radioactive decay has taken place to allow dilution seems to be the only solution. In the normal distribution of elements from the fission process, this means a contaminant of approximately 500 to 600 years' life. As the volume of these wastes increases, it is apparent that the problem of properly containing these wastes will become enormous if not already so. For example, one reactor is estimated to consume 13,500 kg. of fuel per year which will yield 3,370 kg. fission product and, after reclaiming the unused fissionable elements, will give about 16,000,000 gallons of waste per year. This is only the waste from one moderately large reactor.

The radioactive level of the fission products presents a problem in that they require attention to shielding. The amount of shielding required depends, naturally, on the amount and energy distribution of the radioactive elements. The fission products vary somewhat with the characteristics of a given reactor; however they mainly consist of a large number of short-lived energetic elements and a few long-life members. Thus, the shielding problem becomes less with time. As a range, the fission products in a fuel rod from the Material Testing Reactor at Arco, Idaho, at 30 days' cooling requires 5½ feet of concrete; in 6 years the shielding required would be less than 1 foot. From that time on, however, the shielding thickness changes very little due to the exponential character of radioactive decay and the presence of some long half-life energetic isotopes. Regardless of the exact amount of shielding required due to preaging, it is obvious that shielding is a problem and a prerequisite. An operation with maximum shielding is not only advantageous but required.

The release of radiation energy due to radioactive decay gives rise to another problem, namely, heat evolution. If the heat is not dissipated, it is possible to attain extremely high temperatures in time. The amount of heat evolved, of course, will depend on the amount of radioactivity. The resultant temperature will depend on the heat transferred out of the system. Most tank systems

and accumulated storages are shielded and are therefore poor heat transfer systems. In order to take care of the evolved heat, cooling systems must be employed. Proposed methods wherein the radioactive wastes have been added to aquifers have not been entirely successful.

Heat and radioactivity are sufficiently intimately related that normal measures taken to overcome one greatly magnifies problems of the other. For instance, when waste is insulated against escape of particles of emission, then the heat is likewise insulated and is incapable of being dissipated without special effort. At any rate, the inter-relation of the two complicates the solution of these two individual problems.

The disposal of radioactive wastes from the fission products of nuclear power reactors has been accomplished with some success in concrete tanks lined with stainless steel, surface earthen reservoirs often termed cribs. Others have contemplated the injection of radioactive wastes into salt domes, limestone, and depleted natural occurring reservoirs.

All of these above-tested methods have met with serious shortcomings, such as subsurface movement or migration of the radioactively hot waste to public water supplies with resultant contamination which threatens the health of the surrounding populace. Each have a relatively small capacity and are generally limited in practice to low level wastes despite their enormous cost.

The injection of wastes into subsurface porous strata of one type or another encounters the perplexing problem of chemical reaction with the formation and plugging a result therefrom. Foraminous reservoirs also fail to cope with the problem of heat build-up, resulting in fusion of the strata which can have far reaching effects; for this reason, injection into caverns is even more untenable. Then, too, reservoirs permit movement through subsurface flow to other strata, reservoirs, and the like. Unintentional contamination of surrounding reservoirs could result in substantial losses of petroleum and other mineral reserves which are not present in over abundant quantities presently to say nothing of their monetary value which certainly is a factor to be considered.

Chemical reaction involving ion exchange clays has been suggested as a means of disposing of these wastes. This, however, causes the solidification of the clay hampering the injection of wastes in any substantial quantities, and further such a method will not prevent movement or direct escape of all the contaminants.

Summarily, any real solution to the problem of disposal of radioactive wastes must necessarily cope satisfactorily with extremely large volumes of substances having ionic compositions of relatively high concentration and probably containing solids, high intensity radiation, high levels of heat energy, and long retention times.

It is a principal object of the present invention to provide a method of disposal of fission products that will avoid the shortcomings of prior art in a safe an economical manner.

Another object of our invention is to provide an expeditious and facilitory manner of disposing of radioactive wastes.

These and other objects are accomplished by injection into properly placed artificial fractures in subterranean nominally nonporous rock. Some of such rocks are termed shales but are a type which do not contain reservoirs of fluid material, materials which could provide a means of escape. By definition, such rocks are impermeable and do not permit escape through foraminulous structure, since such does not exist as it does in reservoirs of the type wherein it is fluid filled or the fluid is depleted or entirely removed.

A few such typical shales or deposits are as follows: Pierre Shale, Cody Shale of West Wyoming, Mancos

Shale of Colorado and Utah, Barnett Shale of West Texas, Wolf Camp Shale of Pennsylvanian Age, and Tertiary Age Shales of the Gulf Coast.

Such rocks have heretofore received little attention, because in effect they have been rocks of no utility. This makes the present process even more desirable, since it makes use of heretofore entirely valueless formations. These formations are at least by comparison rather plentiful and alleviates much transportation by making available "disposal reservoirs" in almost all areas. This can readily be appreciated by those familiar with the radioactive waste disposal problem.

Although the satisfactory rock formations are nominally not porous, they should be fracturable or friable along a single plane.

Reference may be made to the drawings which disclose certain embodiments of the invention by way of illustration and which will aid the understanding of the invention.

FIGURE 1 shows a diagrammatic vertical section of a well, showing the penetrated impermeable formation which is fractured and into which radioactive waste is to be introduced and stored in said formation.

FIGURE 2 shows an overhead view of the injection well 12 and an illustrative arrangement of check wells 13 through 20.

FIGURE 3 shows a diagrammatic vertical section of an injection well and two of the check wells.

FIGURE 1 shows a means for the storage of radioactive waste through a single well. As shown in this figure, the casing 1 penetrates the nominally nonporous formation 2 in which the radioactive waste is to be stored. This formation is properly isolated by seals 3 and 4 to prevent dissipation into the surrounding formation. The lower portion of the casing 1, located in stratum 2, is perforated as at 5. Within casing 1 is a packer 6 and tube 7. Attached at the upper portion of casing 1 and tube 7 is suitable fracturing apparatus 8 and suitable waste reservoir 9. Fracture 10 or its counterpart 11 are the artificial reservoirs into which the radioactive waste is injected through tube 7 from reservoir 9 by means of apparatus 8.

FIGURE 3 shows an injection well 12 and check wells 16 and 20 with a fracture which has broken through to 20 at 21 and is sealed, the sealing compound having been injected into wells, 12, 16 and 20 as shown by 24. The trapped waste 22 is shown between wells 12 and 20 in fracture 11. FIGURE 3 also shows another fracture 10, not fully propagated, with radioactive waste stream 23 being injected thereto.

The technique of drilling and fracturing is not unlike that used in oil and water well drilling for recovery of the oil or water.

Briefly, this process is carried out by first drilling a well so that it traverses a suitable formation with the depth selected to give adequate shielding from the most energetic fraction to be handled. The well is then equipped with a casing which is sealed both above and below the fracturable formation, for example, with cement to insure its isolation. In the simplest case, the formation is fractured in a substantially horizontal direction. This may be performed according to any of the several recognized techniques, namely, gun perforating, preslotting the pipe, acid cutting, and the like, followed by injection of any suitable fracturing fluid. If desired, the formation can be fractured by using radioactive waste liquid or slurry as the fracturing fluid. The waste can be employed alone or in combination with any of the conventional fracturing fluids or fracturing fluid additives, for example, fluid loss additives.

An important factor in carrying out the invention is to open a single fracture in a substantially horizontal direction. It will, of course, be well understood by those skilled in the art that fractures of the nature contemplated by the present invention will not always run out from the wellbore in an exact, or even substantially, horizontal direction; but in any event such fractures will be at an angle with respect to the axis of the wellbore. When a conventional fracturing fluid is used, ordinarily this fluid is removed from the system and radioactive waste substituted therefor in the fracture. If desired, the fracture can be propagated by injecting radioactive waste fluid at a pressure greater than the formation breakdown pressure. When deemed appropriate, fracturing is ceased, and the fracture is sealed to prevent escape of the radioactive waste.

While a simple case involves only a single fracture, it is possible and, in general, will be found desirable to isolate this fracture and initiate others from the same well. In such a case, then, it is possible to deposit waste in a plurality of fractures radially disposed from a single well. Heat is continuously given off by the radioactive waste and must be eventually removed from the formation. In view of this, it is necessary to hold the number of said radiating fractures at some minimum and thereby limit the total quantity of radioactive waste to an amount which will allow dissipation of heat from the formation. The amount of radioactive waste which can be stored is dependent on the level of the radioactivity of the particular waste, the size of the formation in which the waste is disposed, and the location of the fractures within the formation. The amount of heat evolved can readily be determined by calculations from the level of radioactivity of the waste. The foregoing measures are taken to insure adequate heat dissipation and thereby prevent excessive temperatures and pressures within the formation.

As an example of the heat evolution that must be dealt with, the following information is presented. A waste after 2, 6, and 10 years, evolved 10, 5, and 5 B.t.u. per hour per cubic foot, respectively, which shows that heat is not a short-lived difficulty. A waste having the characteristics below evolved 1–3 B.t.u. per hour per gallon or 7–21 B.t.u. per hour per cubic foot:

Gross beta activity	1.6×10^{6}—2.2×10^{10} c./m./ml.
Alpha activity	6.0×10^{3}—6.0×10^{5} c./m./ml.
Radioactivity	1–4×10^{2} c./gal. (neutralized).
Effective life	About 600 years.
Power equivalent	1 gm. U^{235}=24,000 kw.-hr. (100% efficiency).
Fission product wastes	1 gm. U^{235} forms 1 gm. fission products.
Waste from processing	0.5 to 5.0 gal. waste sol./gm. U^{235} consumed.

Waste analysis:

Ions—	Conc., moles/liter
Al	0.5–2.5
NO_3	2.0–3.0
H	0.5–3.0 (pH<1)
Na	0.1–0.2
F	2.0–3.0
Zr	0.3–0.6
SO_4	0.3–0.6

Specific gravity: 1.0–1.4.

Generally, the nonpermeable, nonforaminulous formations to be utilized for disposal of radioactive waste will be found at depths of 5,000 feet or less; although disposal into rock formations at greater depths is feasible and is contemplated as being within the scope of this invention. Depths of less than 50 feet should never be employed for high level wastes, as such will not provide sufficient shielding. As a practical precautionary measure, however, the shallowness will be determined by the water table. This is, in general, hundreds of feet, for example, 800 feet. There will be locations found where depths of say 100 or 200 will be satisfactory, nonetheless. Fracturing has been successful at depths in excess of 12,000 feet. At depths greater than 20,000 feet, however, the

subterranean stratum is found to be what is termed plastic. Where stratum is plastic, horizontal fractures are difficult to initiate and perhaps to be propagated. In the case of the formations preferred in this invention, substantially horizontal fractures are comparatively easy to initiate and propagate as well. At any rate, drilling to the shallower formation is preferred for economic reasons, so long as shielding is adequate; however the deeper substantially nonforaminulous formations are not to be ruled out entirely. Formations of the type to be used in this invention are often found to extend for miles in a substantially horizontal direction. They very often are quite thick, for example, 1,000 feet or greater. The tremendous storage capacity can be readily appreciated when one considers that such a formation may be fractured in a plurality of zones. A formation of say 1,000 feet in thickness fractured in zones 5 feet apart, each zone being a sectional area of one square mile, would have a storage capacity in gallons that would be an answer to the tremendous volumes of waste to be disposed of.

A preferred nonforaminulous formation for this invention is one that is bounded by a clay having ion exchange properties. This is not essential but is desirable because, should waste inadvertently be allowed to escape the formation by nonobservance of proper cautions pointed out herein, such escaped waste will at least be retarded from further dissipation to more hazardous locations. Such is not necessary when the invention and cautions are adhered to. A more detailed description of how the present invention may operate is herein set forth.

A well is drilled so as to traverse an impermeable, nonforaminulous formation. The formation is isolated as by cementing. The nonporous formation is perforated by, for example, gun perforation. It may be found desirable to isolate the perforated zone with packers in some cases. The fracturing fluid which may be the radioactive waste is pumped into the well under pressure, thereby building up a hydrostatic pressure. When the hydrostatic pressure exceeds the formation breakdown pressure, the formation will part or fracture. The pressure ceases to rise as fluid is injected and assumes a roughly constant value. The fluid pressure measurements at the surface indicate that the formation breakdown pressure has been reached. Inasmuch as the pressure required to overcome the rock bounding strength is small at great depths in comparison to the pressure required to lift the effective overburden, the pressure drop may be small when the formation breakdown pressure is reached. The formation breakdown pressure, therefore, may be more accurately defined as the pressure at which the increase of the rate of fluid injection into the formation will not materially increase the fluid pressure. When deemed proper, depending upon particular existing conditions, waste injection is stopped; and the fracture is sealed, as for example, by cementing. The same procedure then may be repeated at a different level of the same formation.

Roughly the pressure required is equivalent in pounds per square inch to one-half the depth of the formation in feet. This pressure varies, however, from place to place, depending upon the depth and the nature of the formations, folding of the formations, and the like.

Fracturing and propagation of fractures with concomitant disposal of radioactive waste should never be pursued to the outer extremity of the disposal formation. This would constitute a breakthrough and release the radioactive materials to surrounding strata which could eventually result in the radioactive materials reaching the earth's surface or other equally hazardous locations below the surface.

One way to prevent breaking through the extremities of the disposal formation is to locate surrounding pilot and check wells in the same formation. The pilot and check wells are fixed with detection devices for radioactive materials and an automatic signaling device. These may be of various types and will readily occur to those skilled in the art, the essential thing being that the operators are alerted to a breakthrough at the check wells so that injection into the fracture is stopped. The fracture may then be sealed at both the injection and check wells to contain the radioactive waste therein. The procedure may then be repeated at a different zone in the same formation using the same injection well and check wells.

Usually the fractures are formed substantially in the shape of a circle or an ellipse. When the formation is large and the desired fracture relatively limited in size, it is possible to prevent breakthrough at the extremities thereof by the use of a single check well; however, usually it is desirable, as pointed out above, to provide surrounding check wells, that is, a minimum of at least three check wells. The maximum number of check wells is impossible to predict. This will depend entirely on the particular location. For instance, where a river passes in the vicinity of the disposal well, it will be found desirable to employ a considerably greater number of check wells on this side, since a breakthrough to the river could be disastrous. It is to be remembered that there is a corresponding increase in the over-all cost involved with increasing number of check wells, but it also should be remembered that safety will be the determining factor. These two factors will be reconciled without difficulty, however. The individual cost of such check wells may be reduced by utilizing a smaller diameter than that employed for the injection well.

It will be readily apparent to those skilled in the art that the injection wellbore is best located at a considerable distance from a fault or fold. At least fracturing is best only initiated in the direction of a fault or fold when they are some distance from the wellbore.

Another caution to be practiced is the avoidance of any vertical fracturing. Should vertical fracturing occur, despite efforts to the contrary, it will generally be found desirable to seal and abandon that particular fracture; however the direction of fracture can be controlled almost without exception where the stratum is nonplastic.

The storage capacity afforded by the method of this invention can be illustrated as follows:

A well drilled into nominally nonporous rock, and fractured using the procedures outlined above to obtain a fracture one-quarter inch extending over an acre sectional area, was found to contain approximately 6,700 gallons of injected fluid. When the fracture was extended to a sectional area of one square mile, it would contain approximately 4,300,000 gallons. The fracture sealed will hold this waste indefinitely because of its inability to escape.

The terms impermeable, nominally nonporous, and nonforaminulous as used hereinabove throughout the description of the present invention are synonymous.

The term fracturing as used herein and in the claims is to be interpreted as one single fracture or a plurality of such fractures separated by layers of the nonporous rock formation. It is therefore within the scope of the appended claims to make, fill, and seal one feature before beginning another fracture or to perform each of said steps simultaneously on a plurality of fractures. It is likewise to be understood that the use of surrounding check wells and other methods of detecting and signaling the extent of the fracture is to be considered as inclusive within the scope of the invention.

It is to be understood that herein in this invention any numerical limitation to the shallowness of wells is not to be observed to the complete exclusion of consideration of the water table level. For simplicity, a numerical limit is placed, but this is to be interpreted as having the qualification above placed thereon, although such is not explicitly stated.

The invention having been particularly described, it will be understood, of course, that the invention is not

limited thereto, since many modifications will be apparent to those skilled in the art; and it is therefore contemplated to cover by the appended claims any such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A method of subterranean disposal of radioactive waste which comprises providing a wellbore having a casing therein which penetrates an impermeable rock formation, sealing between said casing and said impermeable rock formation to provide a sealed zone, fracturing through said zone to provide at least one fracture which extends into the formation at an angle with respect to the axis of said wellbore and at a depth sufficient to provide shielding at the surface from the most energetic fraction of radioactive waste to be injected thereinto, said fracture being confined within said impermeable rock formation, injecting radioactive waste into a fracture so formed in said impermeable rock formation, and injecting a sealing material into the impermeable formation to seal the radioactive waste in said impermeable rock formation.

2. The method according to claim 1, wherein a plurality of check wells are provided spaced from and surrounding the injection well in the impermeable rock formation within the vicinity of the well bore to determined the extent and direction of fracture.

3. The method according to claim 1 wherein at least one check well is provided in the impermeable rock formation within the vicinity of the wellbore to determine the extent and direction of fracture.

4. The method according to claim 3 wherein the impermeable rock formation is fractured in a substantially horizontal direction.

5. The method according to claim 4, wherein a plurality of check wells are provided spaced from and surrounding the injection well in the impermeable rock formation within the vicinity of the well bore to determine the extent and direction of fracture.

6. The method according to claim 1 wherein the waste is injected through the wellbore at a pressure greater than formation breakdown pressure, all fracture propagation produced thereby being confined within said impermeable rock formation.

7. The method according to claim 6 wherein at least one check well is provided in the impermeable rock formation within the vicinity of the wellbore to determine the extent and direction of fracture.

8. The method according to claim 6 wherein the impermeable rock formation is fractured in a substantially horizontal direction.

9. A method of subterranean disposal of radioactive waste which comprises providing a wellbore having a casing therein which penetrates an impermeable rock formation, sealing between said casing and said impermeable rock formation to provide a sealed zone, directing a fracturing fluid comprising radioactive waste through the wellbore and outwardly therefrom through said zone in such manner as to provide in the impermeable rock formation at least one fracture which extends at an angle with respect to the axis of said wellbore, said fracture being at a depth sufficient to provide shielding at the surface from the most energetic fraction of radioactive waste, said fracture being confined within said impermeable rock formation, and injecting a sealing material into the impermeable formation to seal the radioactive waste in said impermeable rock formation.

10. The method according to claim 9 wherein at least one spaced check well is provided in the impermeable rock formation within the vicinity of the wellbore to determine the extent and direction of fracture.

11. The method according to claim 9, wherein a plurality of check wells are provided spaced from and surrounding the injection well in the impermeable rock formation within the vicinity of the well bore to determine the extent and direction of fracture,

12. A method of subterranean disposal of radioactive waste which comprises providing a wellbore having a casing therein which penetrates an impermeable rock formation, sealing between said casing and said impermeable rock formation to provide a sealed zone, fracturing through said zone with a fracturing fluid to provide at least one fracture which extends into the formation at an angle with respect to the axis of said wellbore, said fracture being confined within said impermeable rock formation and at a depth sufficient to provide shielding at the surface from the most energetic fraction of radioactive waste to be injected thereinto, injecting radioactive waste into the aforementioned fracture, and injecting a sealing material into the impermeable rock formation to seal the radioactive waste therein.

13. The method according to claim 12 wherein the impermeable rock formation is fractured in a substantially horizontal direction.

14. A method of subterranean disposal of radioactive waste which comprises providing a wellbore having a casing therein which penetrates an impermeable rock formation, sealing between said casing and said impermeable rock formation to provide a sealed zone, directing a fracturing fluid through the wellbore and outwardly therefrom through said zone in such manner as to provide in the impermeable rock formation at least one fracture which extends at an angle with respect to the axis of the wellbore, said fracture being confined within said impermeable rock formation and at a depth sufficient to provide shielding at the surface from the most energetic fraction of radioactive waste to be injected thereinto, removing said fracturing fluid and injecting radioactive waste into the aforementioned fracture, and injecting a sealing material into the impermeable rock formation to seal the radioactive waste therein.

15. A method of subterranean disposal of radioactive waste which comprises providing a wellbore having a casing therein which penetrates an impermeable rock formation, sealing between said casing and said impermeable rock formation to provide a sealed zone, directing a fracturing fluid through the wellbore and outwardly therefrom through said zone in such manner as to provide in the impermeable rock formation at least one fracture which extends at an angle with respect to the wellbore, said fracture being confined within said impermeable rock formation and at a depth sufficient to provide shielding at the surface from the most energetic fraction of radioactive waste to be injected thereinto, injecting radioactive waste into the aforementioned fracture without removing the fracturing fluid therefrom, said radioactive waste being injected at a pressure greater than formation breakdown pressure, all fracture propagation produced thereby being confined within said impermeable rock formation, and injecting a sealing material into the impermeable rock formation to seal the radioactive waste therein.

16. A method according to claim 15 wherein at least one check well is provided in the impermeable rock formation within the vicinity of the wellbore to determine the extent and direction of the fracture.

17. The method according to claim 16 wherein the impermeable rock formation is fractured in a substantially horizontal direction.

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