“**Comparison of the Ultra Deep Geologic Repository and the Yucca Mt. Site for the Disposal of High-Level Nuclear Waste**.”

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Preamble

“For more than 50 years, the nuclear industry has had a paralyzing problem. It had no way to get rid of its produced waste”

1. Introduction

Today, there are two competing approaches to dispose of High-Level Nuclear Waste (HLW) that is accumulating in the US and around the world. In the US, Yucca Mt. is the current leading contender for HLW disposal. The Yucca Mt. project started in 1978 and has stumbled haltingly along for decades. However, there is another better technology that was initiated in 1999 by patents filed which provided for the use of safely and securely disposing of the HLW in deep closed underground geological basins in basement rock, using a combination of a plurality of horizontal lateral wellbores drilled from a single vertical wellbore, and the HLW is sequestered in capsules placed within these horizontal laterals. This technology is the Ultra Deep Geological Repository – **UDGR**.

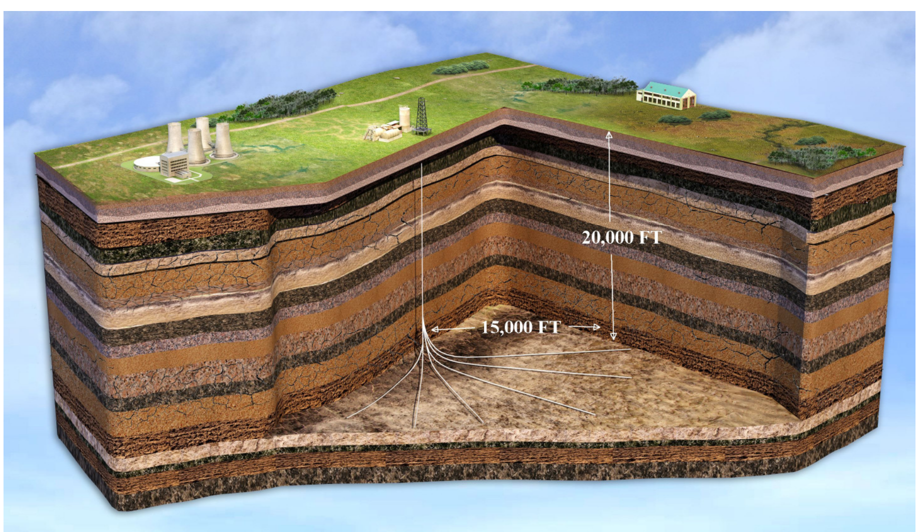

Fig. 1 - Ultra Deep Geologic Repository

Fig. 2 - Multilateral Horizontal Wellbores with Waste Capsules in place.

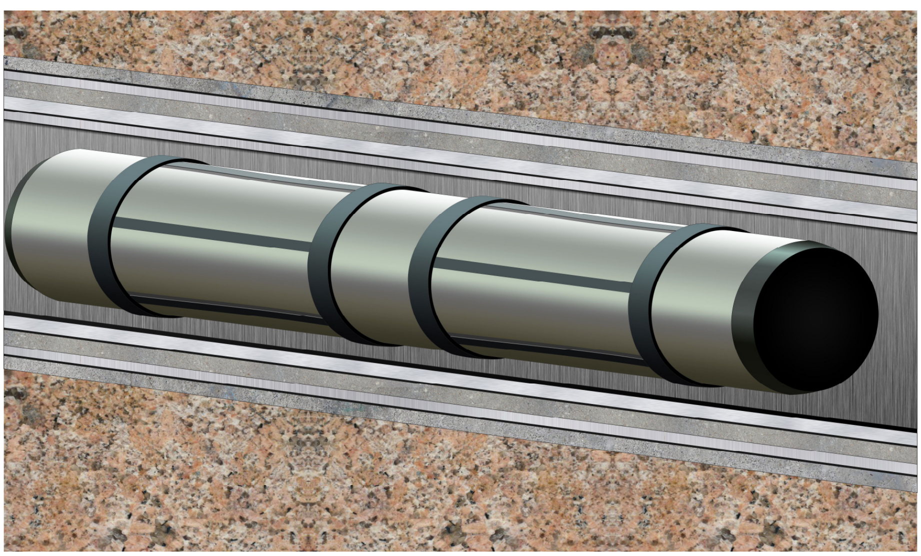

Fig. 3 - Waste Capsule inside Lateral Wellbore encased in Steel and Cement

Fig. 4 - Tunnel Boring Machine used at Yucca Mt.

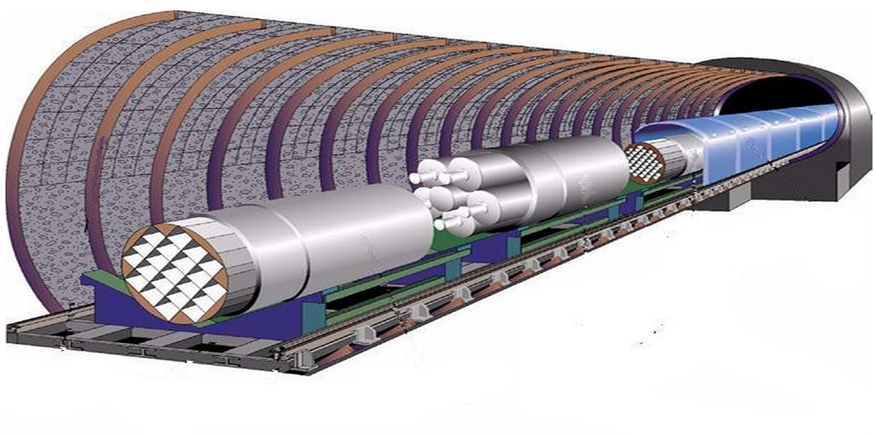

Fig. 5 - Yucca Mt Emplacement Systems for Nuclear Waste

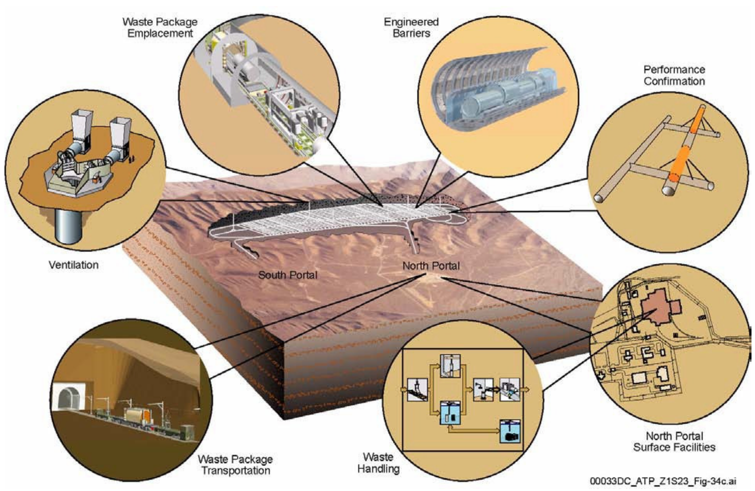

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Fig. 6 - Yucca Mt. Disposal Complex

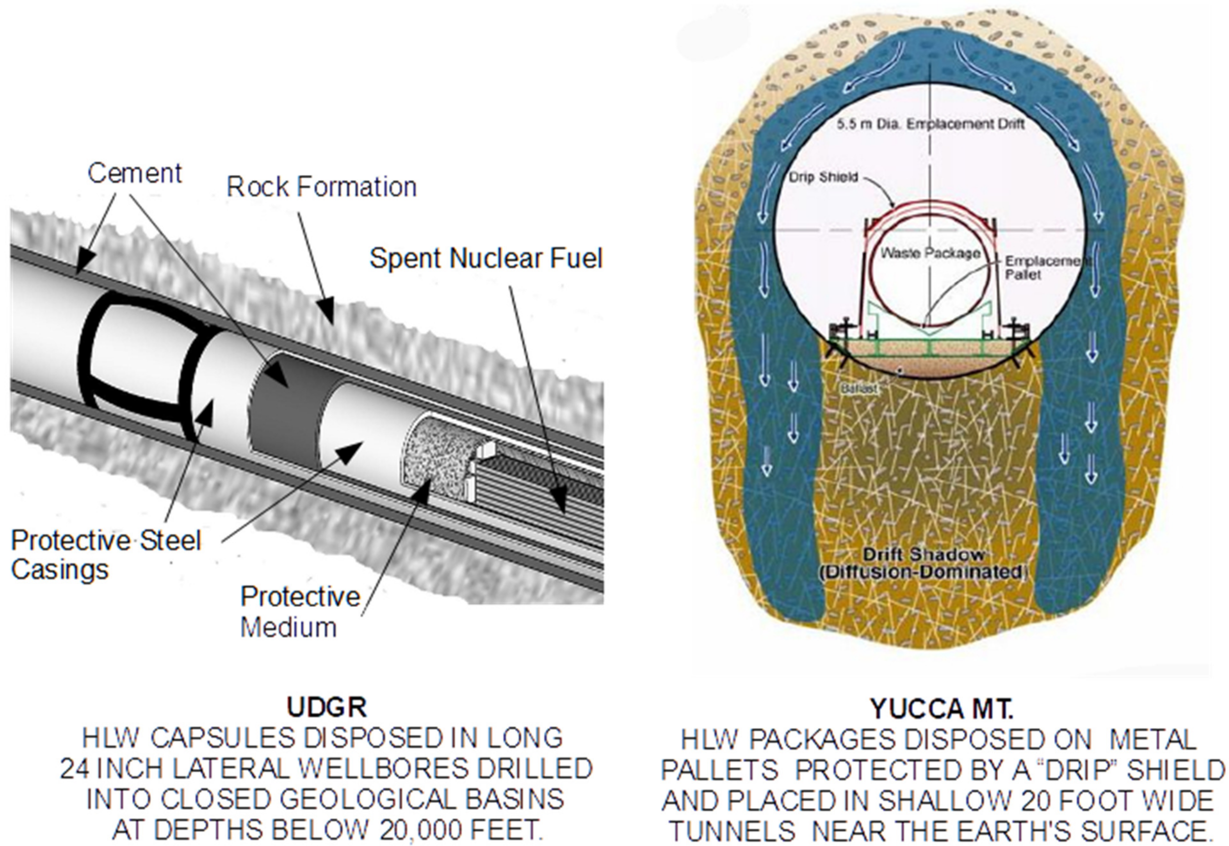

Fig. 7 - UDGR vs Yucca Mt.

The NuclearSAFE Technology (NST) for high-level waste (HLW) disposal is more effective than all proposed and existing disposal technologies and there are many reasons why. There are major improvements provided by this novel UDGR™ approach and these benefits are enumerated below.

2. Timeliness

The UDGR™ system technology is ready to be deployed TODAY (2018) as soon as a suitable isolated geologic basin can be selected and the existing specialized drilling equipment is re-designed, re-purposed, modified and fabricated for use in drilling the wellbores. Materials for the nuclear waste capsules already exist in the nuclear and petroleum industries worldwide.

3. Operational Versatility

The current mature oil and gas well drilling industry has probably the most sophisticated, supply-oriented, logistical command and control operations on the planet. These operations, which are exactly the type implemented by NST, range worldwide, anywhere from the Arctic, the Siberian theaters, deep offshore platforms in the North Sea and the Gulf of Mexico, the African jungles, to the vast deserts of the Continental Africa or western China. The oil and gas industry is one industry which knows how to operate equipment that is sophisticated, complicated and expensive in areas which are usually considered inhospitable, formidable and unreachable.

4. **Comparative Economics**

The UDGR™ technology is significantly cheaper than the current technologies for surface and subsurface HLW storage. Based on a GAO study of USDoE projections which stated;

"The on-site storage option came out with the highest potential cost of the three (options), at $13-34 billion (in 2009 dollars) for the on-site storage of 153,000 metric tons over 100 years, increasing to $20-$97 billion with final geologic disposal".

This computes to about $1,400,000 USD per Metric ton of HLW. The calculations today using the UDGR™ process indicate that safe storage of HLW can be stored at a much more cost-effective rate. Our projections are that the HLW can be encapsulated and stored at a few hundred thousand dollars per metric ton. In addition, the following observations should be noted:

"Roughly 70,000 tons of waste sits in temporary pools and dry storage canisters in 100 reactor sites around the U.S. -- each one requiring an army of guards and millions in electronic surveillance".

"The cost of cleaning up Britain's nuclear waste has increased to almost £48 billion, it was recently revealed and asserted by the British Government; "radical" changes to managing the country's nuclear legacy are required."

"Most nuclear utilities are required by governments to put aside a levy (e.g. 0.1 cents per kilowatt hour in the USA, 0.14 ¢/kWh in France) to provide for management and disposal of their wastes (see Appendix 4: National Funding). So far some US$ 28 billion has been committed to the US waste fund by electricity consumers".

5. **Institutional Acceptance**

The oilwell drilling technology used in the UDGR™ system is well accepted by all technical oversight bodies worldwide, at county, state or national levels, and is very familiar to and accepted by the public at large.

6. **International Acceptance**

The oilwell drilling technology used in the UDGR™ system is well accepted by all technical oversight bodies worldwide and is very familiar to and accepted by the public at large.

7. **Acceptance by Technical Industry**

Major world-wide oilwell service companies have shown confidence in the technology formulated by NST. This indicates their concurrence and support of the technical success of the project.

8. **Retrievability of High-Level Waste**

Using well-developed oilfield techniques, the nuclear capsule modules inserted in the UDGR™ system, are very easily retrieved by qualified personnel using accepted oilfield practices current in the industry worldwide.

9. **Environmental**

The UDGR™ system is at least 15,000 to 20,000 feet deep and as such are well protected for 10,000 years or more, from all known man-made or natural influences for the time required to safely allow the HLW to safely degrade to a safe level of radiation

10. High-Level Waste Volumes Stored

The UDGR™ system can store several million pounds of HLW in each of the several miles of horizontal wellbores.

11. Low-Level Waste (LLW) volumes

This UDGR™ technology can be used to store many millions of pounds of LLW in multiple lateral sites in a UDGR™ system.

12. Licensing of Technology process

The US Governmental Agencies are required to license the disposal sites based on 10 CFR 60 standards. The UDGR™ system can safely meet these published standards.

13. Political Roadblocks

UDGR developers need to work with local and national political groups to educate them about the efficacy and particularly the safety and reliability of these novel UDGR waste disposal processes.

14. Autocriticality

There are seven (7) known pre-conditions and processes that must occur to allow for autocriticality. There is a minimal chance of spontaneous explosion by the HLW in these UDGR™ system situations because it is easily demonstrated that there are no chances of all the necessary and sufficient conditions for autocriticality occurring simultaneously in the UDGR system. In addition, the quantities of fissile material contemplated are very small. Furthermore, naturally occurring nuclear repositories discovered worldwide have existed for millions of years.

15. Resistance to Reuse of HLW

Compared to shallow disposal or surface warehousing for waste disposal, it is impossible to re-enter the UDGR™ wellbores and retrieve the waste material without a massive engineering and drilling effort by qualified drilling personnel with a large highly visible drilling rig on location. The retrieval process will require many months of drilling and milling activity to re-enter the UDGR™ wellbores.

16. Theft-Resistant

To steal the HLW, a thief needs a drilling rig, oilfield "fishing equipment" and specialized personnel and drilling materials. This is a major problem.

17. Diversion Resistance

It is impossible to divert this material since the diverting agent has to drill a completely new wellbore several thousand feet deep to reach the nuclear material. This requires at least ONE year of drilling efforts and several tens of millions of dollars to obtain a drill rig, that is readily visible by all, including satellites.

18. Redundancy

The use of multiple non-aggregated sites for the waste storage repository allows for redundancy in the deployment of the technology. Sites are located at several different locations worldwide. This compares with the single site technology used in competing technologies to solving the problem.

19. Reliability

There are no perceived failure modes for the UDGR™ system when designed, engineered and implemented according to the patented NST technologies.

20. Integrative Solution

The technology provided by the UDGR™ system is effectively superior at a number of levels. Significant risk analysis models provide a level of reliability and predictability that is unavailable in other waste disposal processes.

21. Engineering Barriers

A combination of special steel alloys, specially formulated cements and other protective materials are used as the primary engineering barriers in the wellbores that house the nuclear waste material. Bentonite clays and their derivatives provide radionuclide absorption and other protective systems.

22. Geologic Barriers

The massive geologic barriers include all the 15,000+ feet of overlying rock and various layers of impermeable material like clays and massive shales. This provides a large and insurmountable barrier for the movement of fluids away from the HLW in the wellbores. Ultra deep interstitial saline solutions are very dense and there is no possibility to migrate vertically.

23. Natural Barriers

Barriers include the massive overburden layers, the hydrodynamic isolation of the repository in a geologically isolated basin, the physical isolation inside the steel-cement cylinders.

24. Heat Load

The calculated heat load in the UDGR™ is minimal. Less than 1.0 MT per acre compared to the 83 MT/acre of the Yucca Mt repository as designed by the USDoE.

25. Off-Gassing of Nuclear Material

There has been no reported problem with off-gassing of nuclear material in this type of burial of waste in which vitrified HLW is used.

26. Personnel Health & Safety

Since small quantities (capsule sized modules) of HLW are handled at a time there is no major problem for the safety of the workers and the environment. Operational safety shall be paramount and the capsule systems are adequately protected from gamma ray and neutron radiation.

27. Radiation Safety

Since the NST process disposes of the HLW in isolated deep basins and nothing leaves these basins over geologic time, the radiation safety hazard is extremely low.

28. Radionuclide Migration

No migration of radionuclides is possible away from the UDGR™ because of the plurality of barriers designed into the system and the natural barriers inherent in the repository design. Well designed bentonite clays and their strategic placement provide an effective barriers and buffers to radionuclide migration away from the disposal zones.

29. Spontaneous Ignition

It is not possible for HLW ignition when stored in the UDGR™ system.

30. Ground Water

There is no groundwater in the repository zone where the UDGR™ is sited in the deep rocks. Any liquid is present is blocked from convective transport by the overlying impermeable layers and by the isolated nature of the repository zone and the petrophysical properties of the disposal zones. Yucca Mt. on the other hand, has groundwater zones within a few hundred feet of the proposed disposal zone.

31. System Reboot

There is no generally accepted mode in which the technology shall fail. If the UDGR™ process were not a complete success in certain underground environments as expected, the HLW capsules can then be retrieved and possibly sequestered in some other locale. All analyses dating back to the 1970s and as recently as 2010 by the US Government have focused on solutions that involve deep burial of the HLW as the only valid solution. This UDGR™ technique is the best such answer.

32. Patents

The intellectual property involved is technically and operationally superior to that of the other published patented technologies illustrating geological disposal for the following reasons:

All other published patents depend on single **VERTICAL** well-bores which are then filled with cement above the capsules. This system is inefficient and expensive, since hundreds of wells will have to be drilled to meet the requirements for HLW storage. Vertical wells also create a major problem of loading on the bottom-most capsules because of the high density and weight of all the capsules, thousands of feet in length, above in the vertical wellbore. In the UDGR™ process, there is no such weight problem because the wellbores are **HORIZONTAL** and a single surface well with multiple horizontal laterals can sequester as much HLW as several dozen conventional vertical wells.

No other patent addresses the question of Retrievability of HLW. This is a critical shortcoming in other technologies since under the UDGR™ technology; future generations can retrieve the HLW capsules and allow reprocessing of the nuclear waste to further produce nuclear power from the products in the HLW. Retrievability by other published technologies is dubious.

Economically, the UDGR™ approach is able to meet the requirements of 10CFR 60, Federal regulations at a demonstrably much lower cost compared to other processes like caverns, deep sea burial etc. As shown in table below and also in the appendix, UDGR™ meets all requirements of the Federal Regulations.

The UDGR can be implemented in a matter of months, or at most 2 years, as opposed to the decades required to excavate and implement the shallow mining solutions like Yucca Mt.

33. Intangible Attributes

No other nuclear waste process to date, has the additional intangible attributes of the UDGR™ process namely.

At the State and Federal levels there are several regulators who are intimately familiar with the drilling technology involved in this process.

Transport of the nuclear capsules from their origination point to the disposal site will be done in accordance with existing nuclear regulatory regulations for transport of nuclear material which have been in place for decades and have been extremely safe.

The cost-effectiveness of this process can be demonstrated at all levels of involvement in the project and these savings translate directly to the cost of doing business in the nuclear industry and ultimately to the cost of living for the typical citizen, since the cleanup costs of nuclear waste is calculated to be a significant cost for the future generations.

The public is keenly aware of the need for safe and reliable nuclear waste disposal and the UDGR™ approach meets all the needs by providing a reliable and simple technology which is demonstrably more effective and protecting their safety and welfare at a comparative minimal cost.

The patented UDGR™ process leaves no "visible scars" on the surface except for a protected marker and a security fence locating the wellbore site. It removes all nuclear material from the biosphere where grave consequences can occur if these wastes are spilled.

No impact on the ecology of the area. The burial depth of more than 10,000 feet guarantees an almost undisturbed surface terrain except for minor effects due to the drilling activity. This surface damage can be easily re-mediated and returned to their original pristine state.

There are no major problems of accidents in the industry. Most accidents due to well blowouts occur because of over-pressured gas zones being penetrated while drilling causing "kicks" or influx of fluids. Others like BP (2010) blowout problem, are normally the end results of careless and complacent drilling. These problems will not occur in the UDGR™ development because UDGR™ will not be drilling into active or developing pressurized oil or gas fields.

No safety problems except possibly during the nuclear loading cycle when the waste nuclear material is actually being loaded on location from transportation vehicles to the insertion module at the UDGR™ wellhead.

O&M costs are minimal for a project of this size and complexity; costs are estimated to be less than $15 million annually for the safeguarding and monitoring of a completed project. These costs will involve a surface monitoring and physical exclusion procedures.

The UDGR™ will function as intended since it is a passive system that depends on a massive protective system of overburden rock and its physical, mechanical and chemical isolation from the biosphere. The degradation of the system can be analyzed by looking at the degradation of its component parts. The historical record of mankind, going back 5,000 years, indicates that the steel, cement and the vitrified or ceramicfied components are all basically inert in the environment in which the UDGR™ places them and as such no measurable degradation is expected over the design time horizon of 10,000 years.

The technology is extremely versatile. The well-designed systems will be able to hold the waste for at least 10,000 years as required by law since the developers can demonstrate by scientific dating methods that the selected repository formations have remained undisturbed for at least 20 million years. Secondly the various types of wastes can be handled by modifications of the basic module which is placed in the repository. The "warehouse" for storage itself is a basic design by the UDGR developers which will provide the necessary safe storage for the waste.

In the event of a seismic catastrophe e.g. earthquake or tectonic movement, the waste is still protected by 15,000 plus feet of solid rock, the modules can be cemented in place in multiple steel encased cylinders and are incapable of moving from their initial location. The highly impermeable zone precludes any measurable flow of fluids from the disturbed zones.

Being deposited at the bottom of an isolated basin which is hydrodynamically closed, there is no potential gradient to move the waste out of its containment. Short of active displacement by an invading fluid there is no energy to provide the displacement of this material out of the basin.

There is no process waste produced by this technology except for spent drilling fluids which are routinely handled by the drilling contractors today using EPA disposal guidelines. There is no new nuclear waste involved in this disposal process.

34. Proof of Concept

The viability and proof of the concept and the implementation of the new patented technology is demonstrated because of the success of following process elements which acting complimentarily constitute the UDGR™ system.

Horizontal Drilling – the most advanced drilling concept and application in the last 3 decades is well tested and based on several hundred thousand drilling applications worldwide has become the pre-eminent method drilling for increased oil and gas reserves.

Successful placement of down-hole equipment is a routine daily event in today's petroleum industry. These include:

- Packers, retrievable and permanent
- Bottom Hole Assemblies
- Pumps
- Valves
- Exploration Tools
- Perforating guns and
- Retrievable devices.

Specialized metallurgy and materials developed by Industry and the US and other Government enterprises for use specifically in the nuclear industry. This material shall be used to make the waste containing capsules.

Radiation shielding systems and materials provide the requisite safety as needed until the HLW capsules are safely sequestered at a depth of 20,000 feet in the geologic repository.

REFERENCES

"Scenario Assessment of Autocriticality in the Yucca Mountain Geologic Repository", Kastenberg, W.E et al. University of California, Berkeley, CA. 94720. (1997).

"Final Environmental Impact Statement for Geologic Repository for the Disposal oof SNF and HLW at Yucca Mountain, Nye County, Nevada, USDoE, DOE/EIS-0250, February 2002.

"Yucca Mountain Science and Engineering Report -Technical Information Supporting Site Recommendation Consideration". USDoE, DOE/RW-0539-1, Office of Civilian Waste Management, February 2002.

"E-Mails Reveal Fraud in Nuclear Site (Yucca Mt.) Study", Wald , M., NY Times, April 2, 2005.

"Uncertainty Underground, Yucca Mountain and the Nation's High-Level Nuclear Waste". Mac Farlane A, Ewing R., MIT Press, Cambridge MA. (2006).

"Yucca Mountain: The most studied real estate on the Planet." US Senate Committee Report, Chairman Senator Jim Inhofe, Senate Committee on Environment and Public Works, March 2006.

"US Department of Energy's Motion to Withdraw", Docket No.63-001. Before Atomic Safety and Licensing Board. March 3, 2010.

"Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel", USDoE, October 2014.

"Calls to use Yucca Mountain as a Nuclear Waste Site, now Deemed Safe.", Wald, M., NY Times, October 16, 2014.

"Technical Evaluation of the USDoE Deep Borehole Disposal Research and Development Program"., US Nuclear Waste Technical Review Board, (1/2016).

"Decades-old war over Yucca Mountain nuclear dump resumes under Trump budget plan", Vartabedian R, Los Angeles Times, 3/29/2017.

US Patent Office Patents: US6,654,704 B2 , US 7,047,134 B2, US 8,117,138 B2 , US 8,055,547 B2, US 5,850,614, US 6,238,138 B2 US 8,933,289 B2.

US Patent Office Provisional Patent: 62/673879, 62/670747, 62/671,506, 15/936245, 62/736252, US 2018/0290188 A1
