Cold War Geology: Lessons From Nuclear Fracture Simulation*

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Abstract

Between 1967 and 1973, the US detonated nuclear devices in NM and CO in an attempt to fracture-stimulate tight gas sands as part of its Plowshare Program. Three tests, all in U Cretaceous sandstones, were conducted - Gasbuggy (12/10/67, 29 kt), Rulison (9/10/69, 43 kt), and Rio Blanco (5/17/73, three simultaneous 33 kt). (For comparison, Hiroshima was 15 kt). The tests resulted in high-permeability rubble-filled cavities surrounded by fractured reservoir rock. The tests took place during a peak of weapons testing (60–90/yr) and at the beginning of a period of arms-control negotiations. Significantly, the last test occurred after the National Environmental Policy Act of 1969 went into effect. Had the tests been successful, the required environmental impact statement proposed 5665 nuclear-stimulated wells with 3–5 devices/well for development of the Green River, Piceance, and Uinta Basins between 1978 and 2017. Plowshare ended in 1975; economics and public fear of all things nuclear contributed to its demise. Public-education efforts to explain new technologies, however, remain much the same even today. How did (do) geoscientists then (and now) address: 1) anti-nuclear (climate-change) issues; 2) full disclosure of radionuclide (groundwater) contamination; 3) mistrust of government (big oil) scientists; and 4) damages from test-triggered earthquakes (frac-induced pollution)? What lessons from the anti-nuclear-frac'ing movement of the 1960s and 70s can we learn from today?

Selected References

Howard, G.C., and C.R. Fast, 1970, Hydraulic Fracturing: Society of Petroleum Engineers, 203 p.

Liversidge, A., 1969, Not Enough Gas in the Pipelines: Fortune, p. 120-122, 189-190.

Cold War Geology: Lessons from Nuclear Fracture Stimulation

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American Association of Petroleum Geologists
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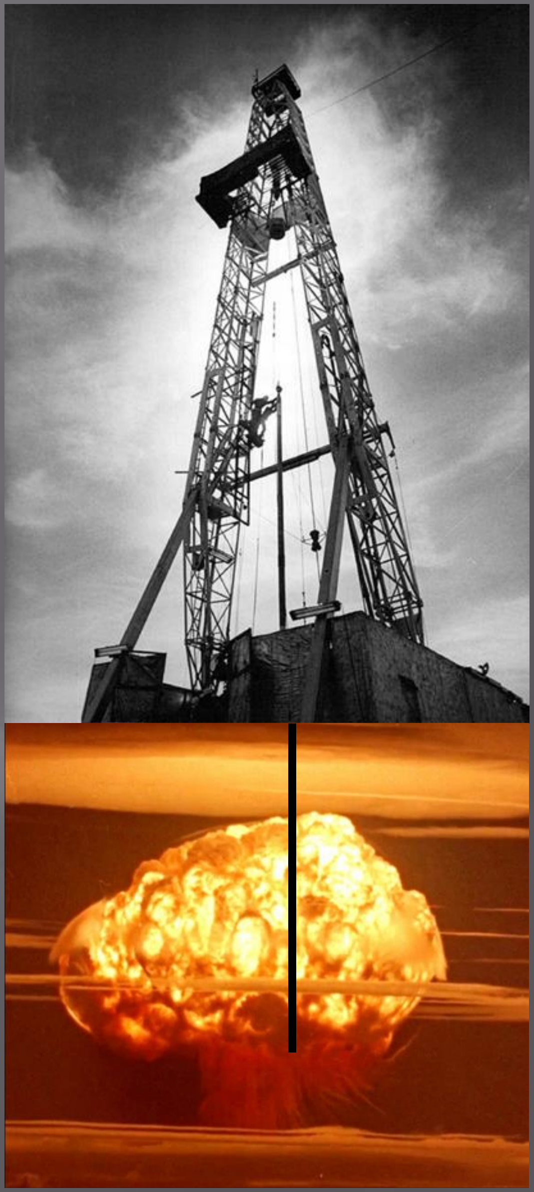
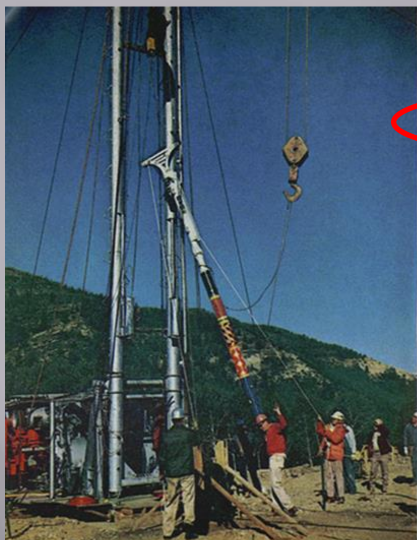
Why try nuclear frac'ing at all?

1. Perceived gas/energy shortage.
2. Enormous resource in Cretaceous tight gas sandstones in Rocky Mountain region.
3. Jobs. By early/mid 1960s, writing was on the wall for those involved in nuclear weapons research and production.



Professional and public media: Fortune magazine, Nov. 1969

"Nuclear explosions may blast a path to adequate gas reserves."



Nuclear explosions may blast a path to adequate gas reserves. In Austral Oil Co.'s Project Rulison in September this forty-kiloton charge was lowered 8,400 feet into gas-bearing sandstone near Rifle, Colorado.

Not Enough Gas in the Pipelines

Natural gas now supplies one-third of the nation's energy requirements. But a prospective shortage of supplies may deflate expectations of an expansive future. And federal price regulation is not helping.

by Anthony Liversidge

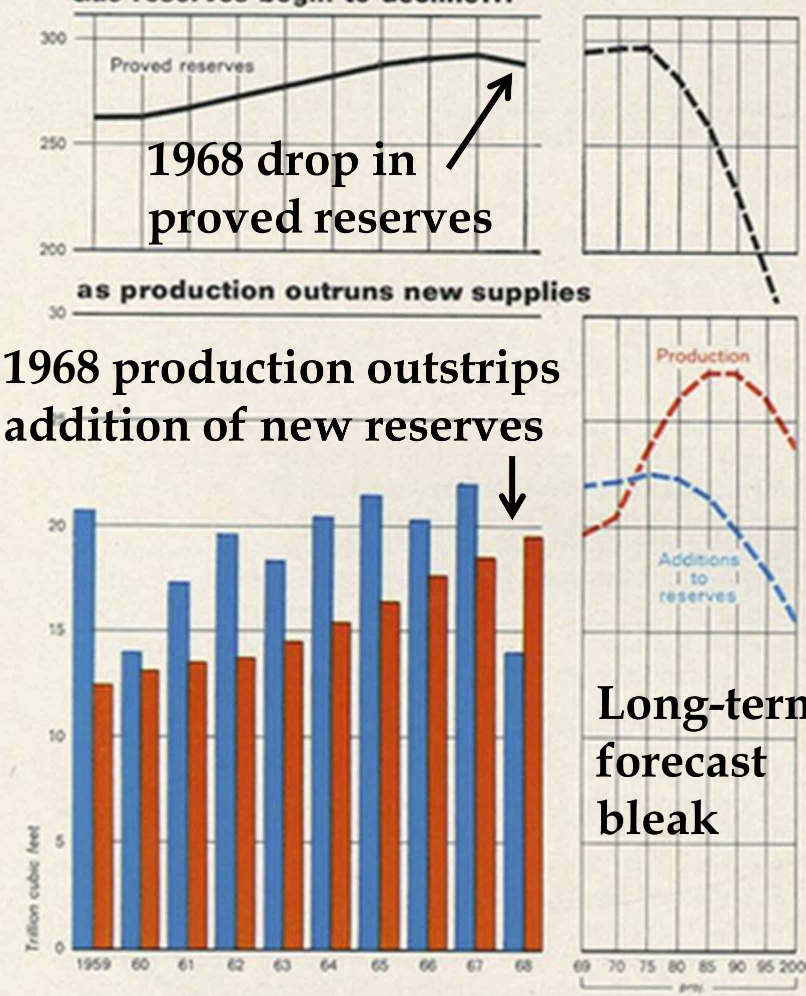
The blue flame of natural gas burned ever more brightly in the U.S. in each year of the Sixties. Barely thirty years ago, natural gas was flared at the wellhead as an unwanted byproduct of the search for oil. Today it supplies an astonishing one-third of the total energy used by the U.S. economy—as much as is supplied by oil, and nine times as much as by hydroelectricity. Spurred by the relative cheapness and cleanness of gas, the market has outstripped all but the rosiest projections. Ten years ago, 32 million customers burned 12 trillion cubic feet of gas. This year over 40 million customers will consume more than 20 trillion cubic feet. In the same period the value of the industry's gross plant has almost doubled, from $20 billion to $38 billion.

The advantages of gas over competing fuels would seem to point toward a future even more brilliantly illuminated by the "immaculate fuel." Nuclear energy, an alternative source of power, is coming along much more slowly than was expected a few years ago (see "A Peak Load of Trouble for the Utilities," page 116). The future for oil and coal is clouded by the fact that they contain high amounts of sulphur, a major cause of dirty air; natural gas contains virtually none.

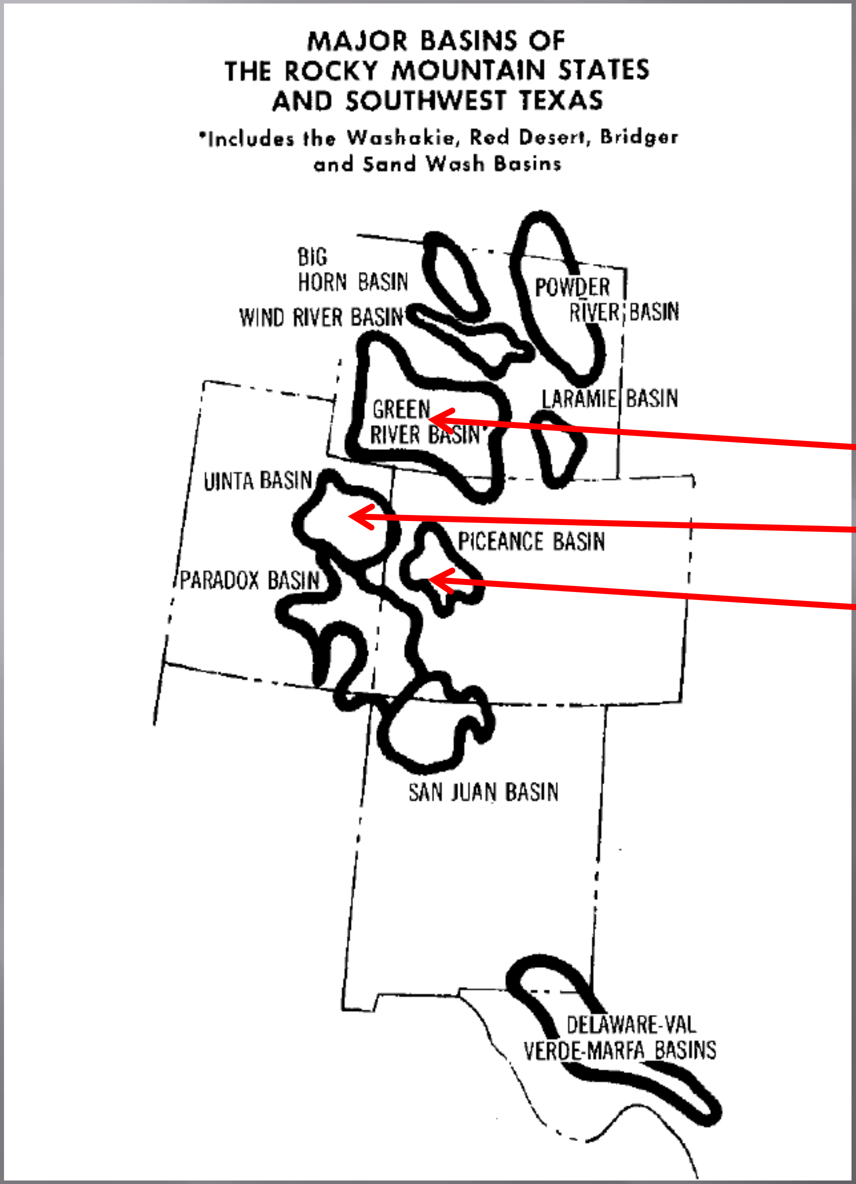
New uses of gas are ballooning with promise. The anti-pollution car of the future may be powered not by steam or electricity, but mainly by natural gas. A $360 kit will readily convert an average car to run on compressed gas, and such a kit is now on the market. Since such conversion could rescue the internal-combustion engine, the implications are dramatic, as Governor Reagan obviously appreciated when shown one of the forty converted cars that Pacific Lighting Corp. has put on the California roads. (He is said to have cried "By golly!") Great potential could also lie in the electrochemical fuel cell, which produces electricity from gases. Three such cells, designed by Pratt & Whitney Aircraft, provide power for the Apollo spacecraft. In fact, an economy entirely driven by gas is not far beyond present technical capabilities.

All these glowing prospects, however, are dimmed by one more immediate concern. At the beginning of what could be its biggest stage of growth, the gas industry is about to run short of its raw material. This crisis in supply was first signaled some twelve years ago, when the rate of drilling oil and gas wells began to level off, while production and consumption continued upward. Last year for the first time, proved reserves of gas in the U.S., the on-the-shelf inventory of the industry, declined, while production outran new discoveries. Now major distributors in the East are having difficulty lining up new supplies for the growth in demand projected beyond 1970.

One composite estimate by eleven major pipeline companies that gather gas from the fields recently put the shortfall for the winter of 1970-71 at about 2 billion cubic feet daily of unsatisfied new demand. Some scattered local shortages, indeed, may already be appearing. Northern Natural Gas Co., a big pipeline company in Omaha, is trying to withdraw a pipeline permit application it made recently because, it says, it did not have sufficient reserves to feed the projected line. While current reserves can be



Last year, total proved gas reserves in the U.S. fell for the first time (upper chart). Climbing production (red bars, lower chart) outstripped new additions to reserves (blue bars) in 1968. This may be temporary, but the projection of long-term trends shows that production will eventually have to decline unless new sources are opened up. The forecasts were made by Dr. Martin A. Elliott of Texas Eastern Transmission Corp. and Dr. Henry R. Linden of the Institute of Gas Technology.



Reserves of Natural Gas from Fracturing Techniques

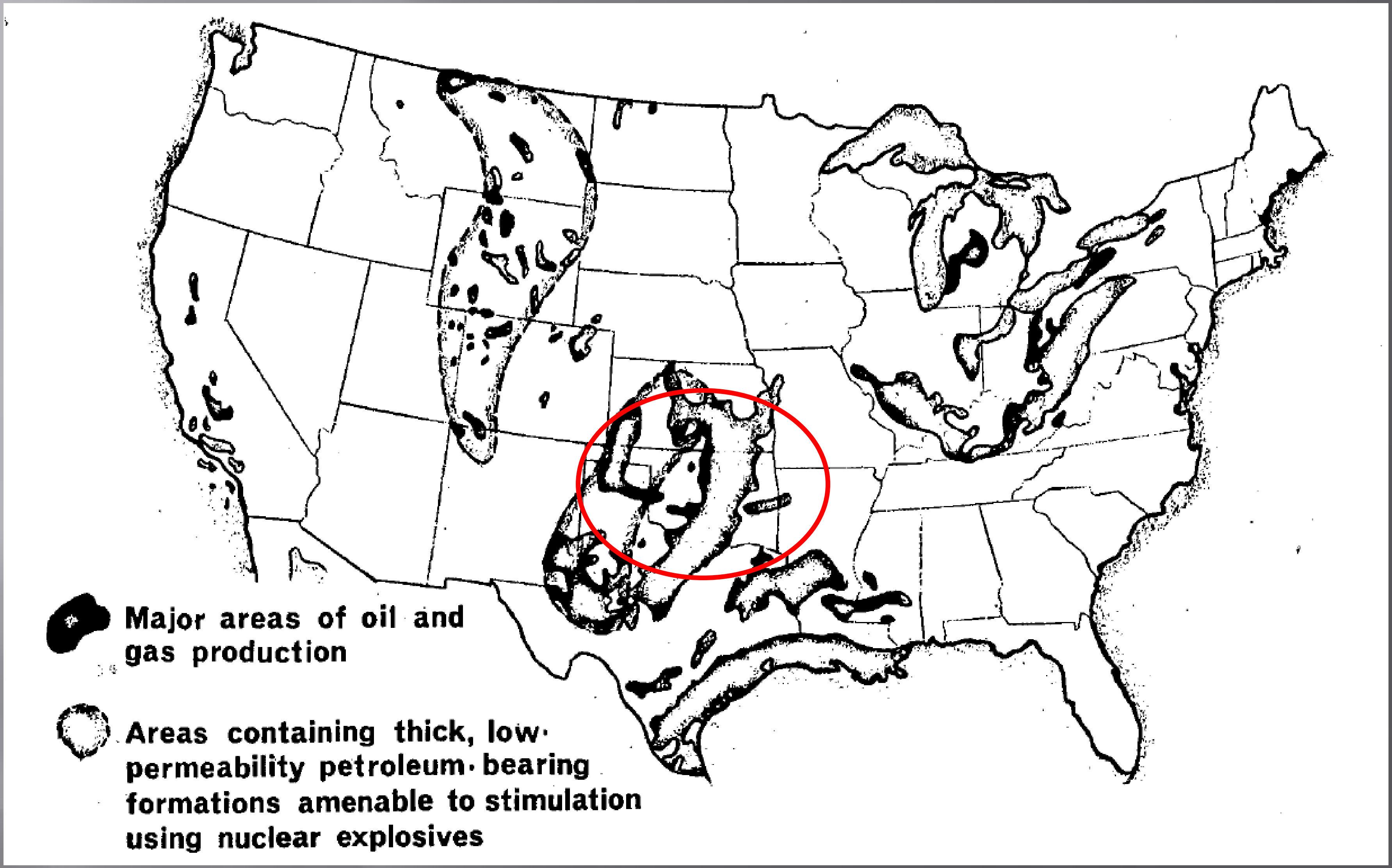
(source: Natural Gas Supply Technology Task Force, National Gas Survey, US Federal Power Commission, 1973)

96-120 tcf

60-75 tcf

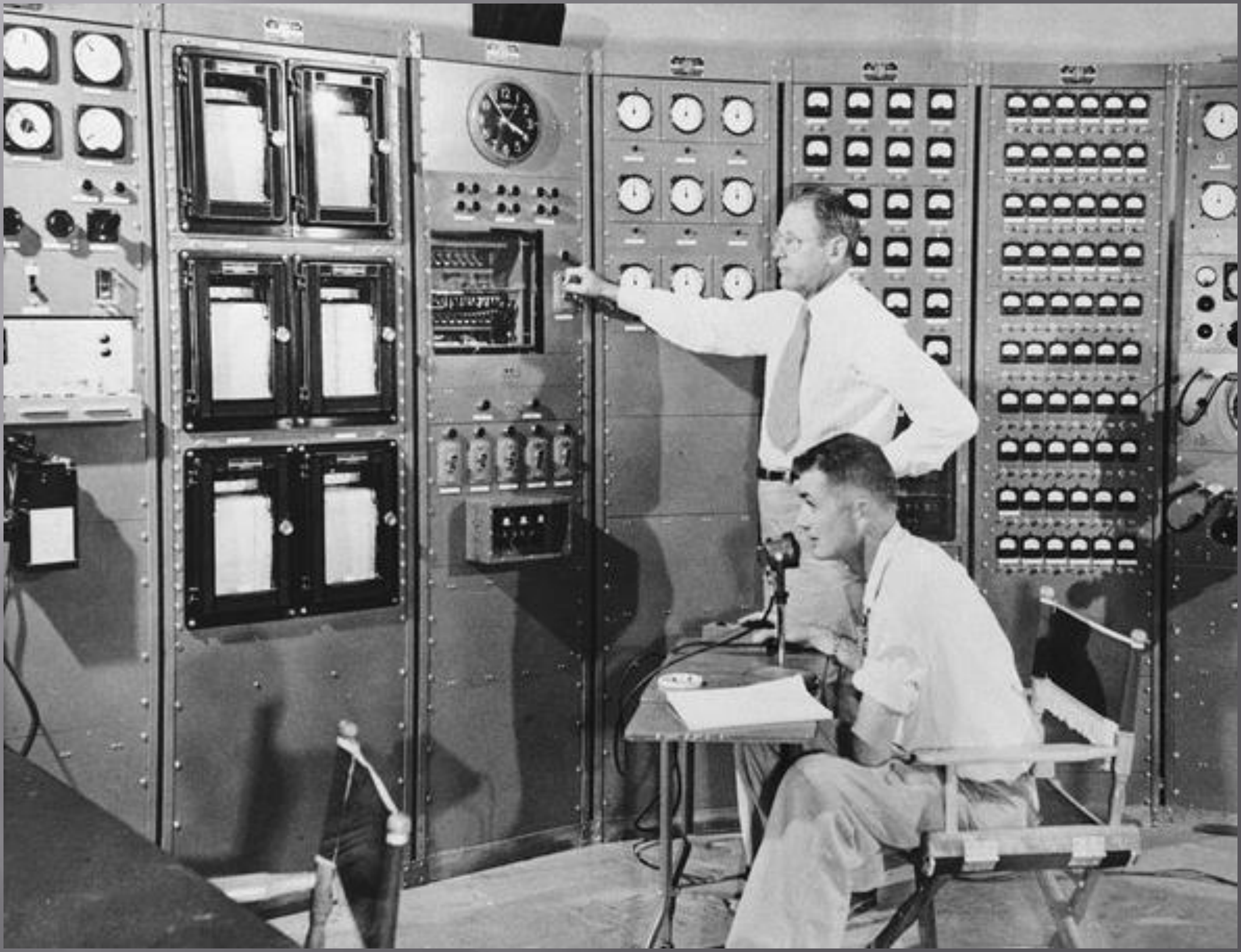
84-105 tcf

Remember these 3 basins:
Will return to at end of talk.



From “Hydraulic Fracturing” by G.C. Howard and C.R. Fast
Society of Petroleum Engineers of AIME, 1970

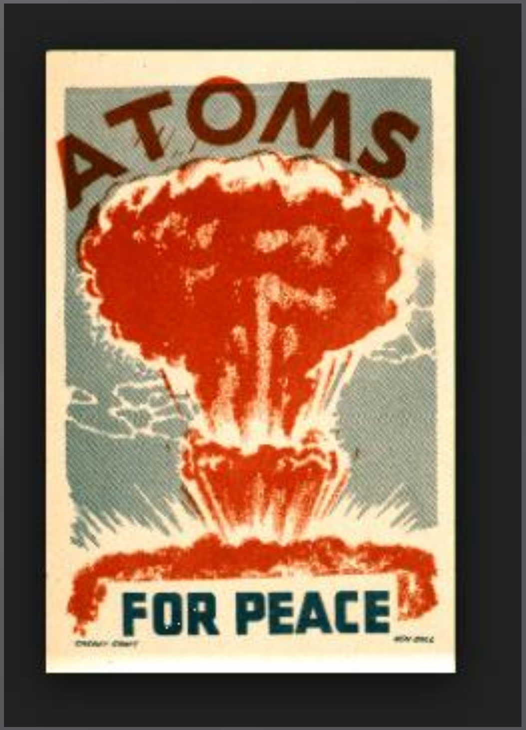
Jobs. The Plowshare program and nuclear frac'ing in the context of the Cold War.

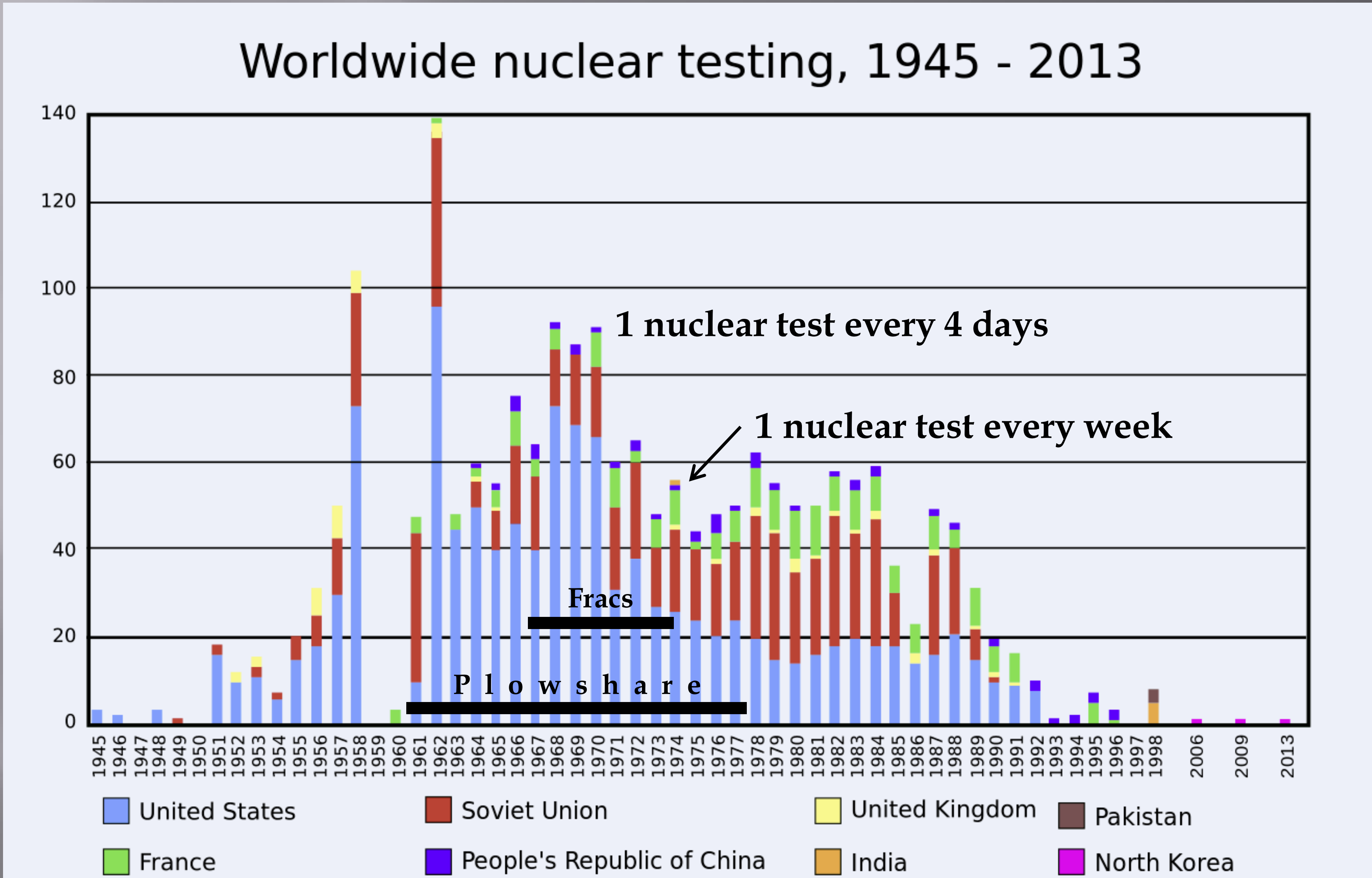


PROJECT PLOWSHARE (27 nuclear tests, 1961-1973)

"And he shall judge among the nations, and shall rebuke many people: and they shall beat their swords into plowshares, and their spears into pruning hooks: nations shall not lift up sword against nation, neither shall they learn war any more." (Isaiah, 2:4)

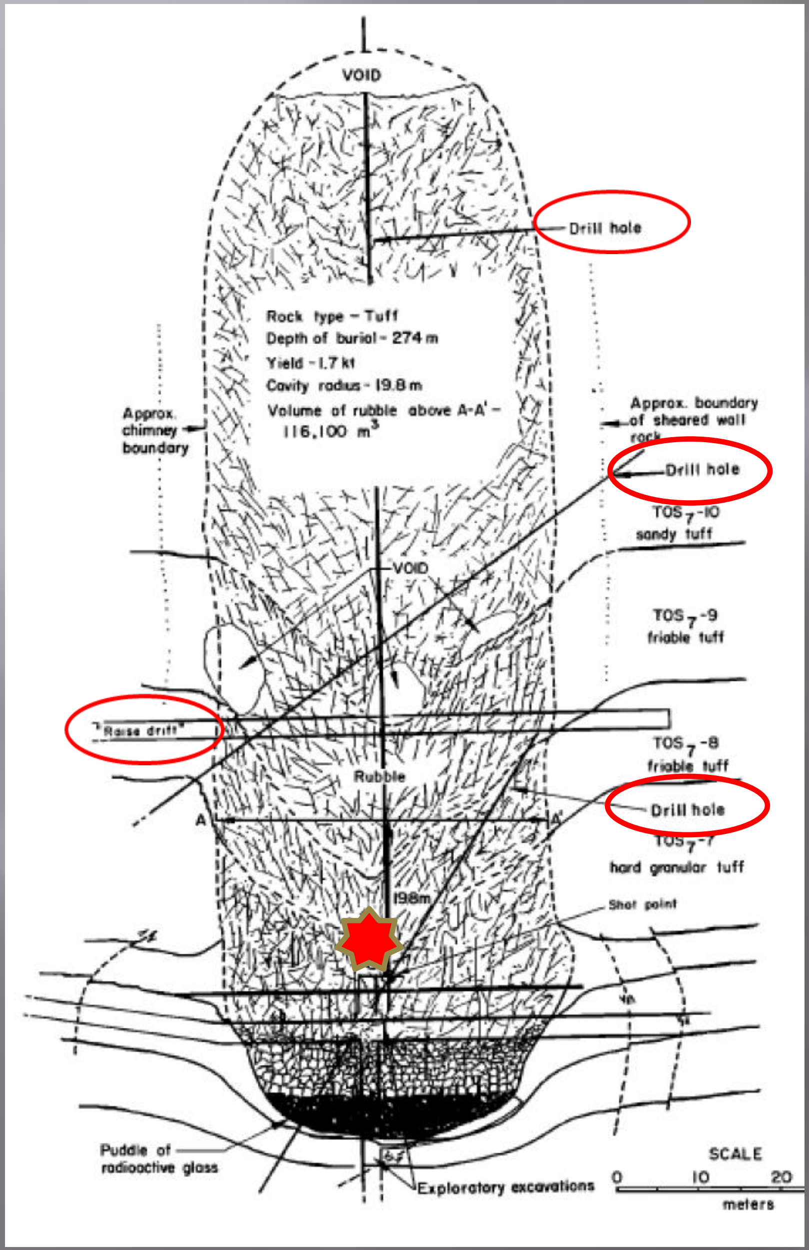
- Rubblize ore deposits for *in situ* leaching
- Strip overburden from mineral deposits
- Store water in rubble chimneys
- Store gas in rubble chimneys
- Accelerate groundwater recharge, connect aquifers
- *In situ* retorting of oil shales
- Develop tar sands in Alberta
- Fracture hot dry rock for geothermal energy
- Fracture tight gas sands
- Excavations
  - Harbors, canal through Nicaragua
  - Highways, railroads, waterways through mountains
  - Re-routing river systems



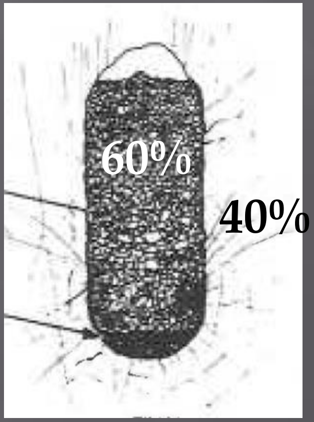


The context of Plowshare and the nuclear-frac'ing tests

Rainier Test – Sept. 19, 1957

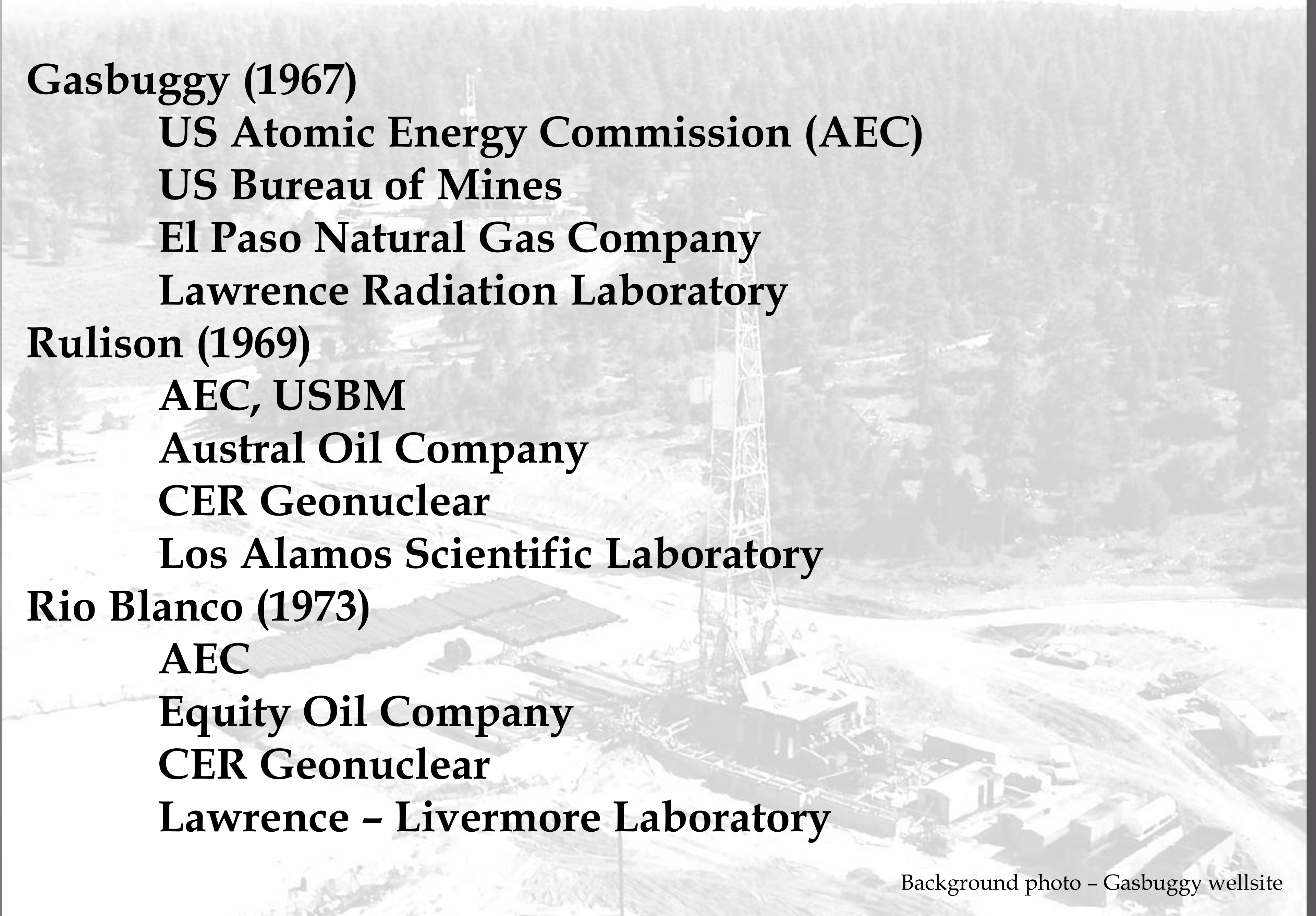


- 1.7 kt, 900 ft deep in bedded tuff at NTS
- A weapons test, first data on what underground nuclear explosion would do to surrounding rock.
- Few msecs - 1,000,000º K, 7,000,000 bars
- Cavity lined w/ ~4 in. of melted rock.
- 30 sec - 2 min - fluid flows down sides and drips from roof to form radioactive puddle at bottom.
- Then collapse, progressing vertically.
- Envelope of fractured rock (w/ increased permeability) extending away from collapse breccia.



Reservoir: Collapse breccia (chimney) and fractured envelope.

US Nuclear Frac'ing Tests: Gov't – Industry Partnership



Gasbuggy (1967)

- US Atomic Energy Commission (AEC)
- US Bureau of Mines
- El Paso Natural Gas Company
- Lawrence Radiation Laboratory

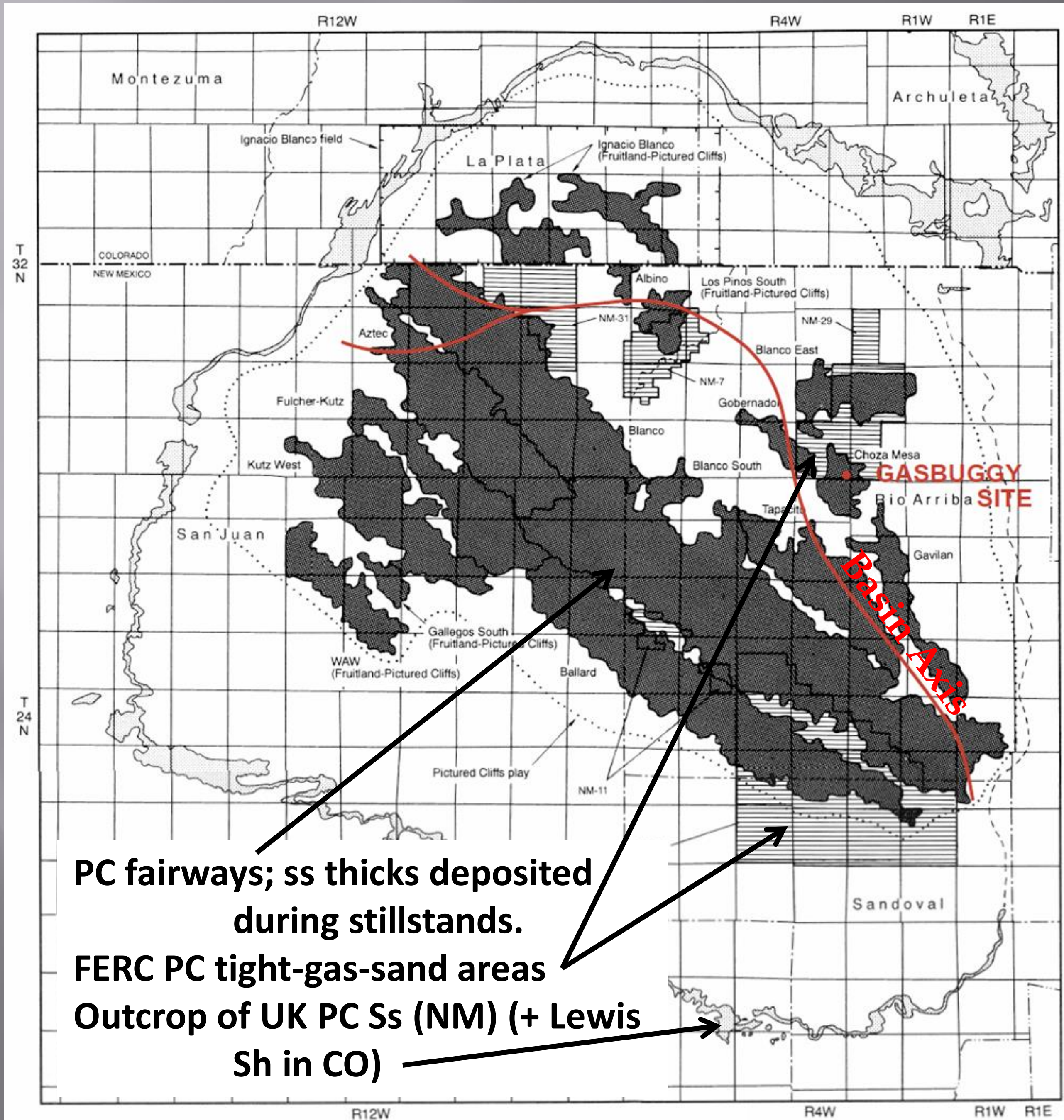
Rulison (1969)

- AEC, USBM
- Austral Oil Company
- CER Geonuclear
- Los Alamos Scientific Laboratory

Rio Blanco (1973)

- AEC
- Equity Oil Company
- CER Geonuclear
- Lawrence – Livermore Laboratory

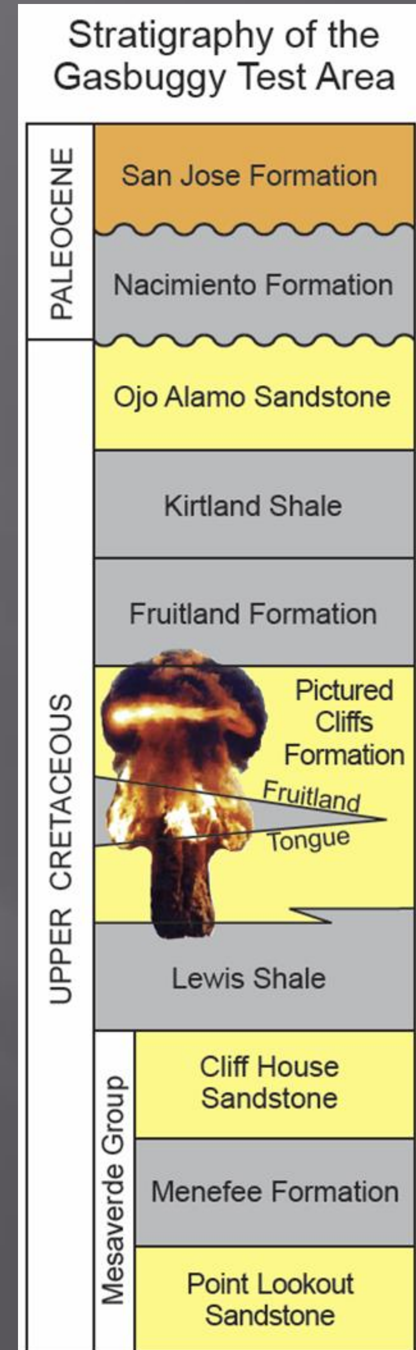
Background photo – Gasbuggy wellsite



PC fairways; ss thicks deposited during stillstands.

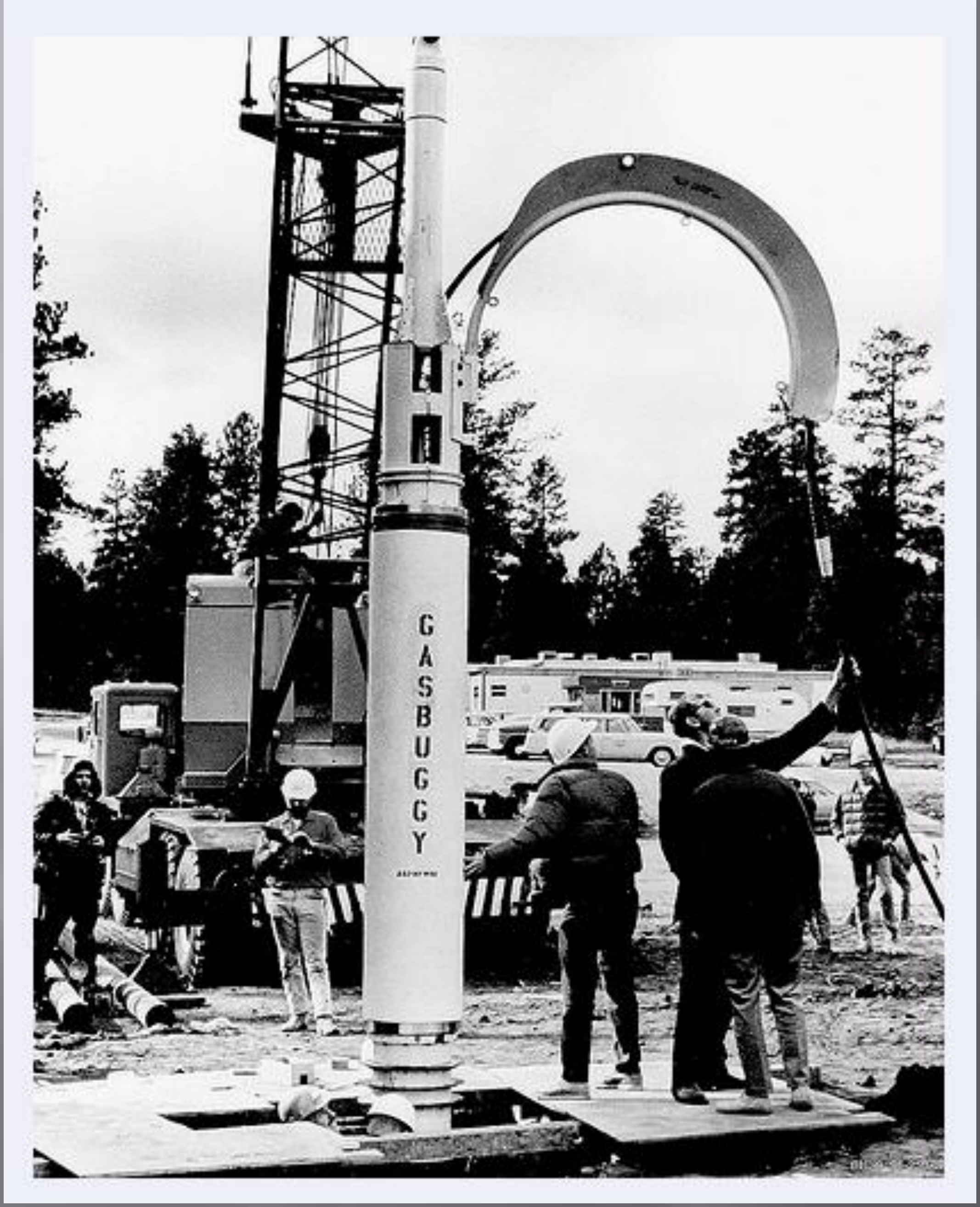
FERC PC tight-gas-sand areas

Outcrop of UK PC Ss (NM) (+ Lewis Sh in CO)



Pictured Cliffs Sandstone (Upper Cretaceous)

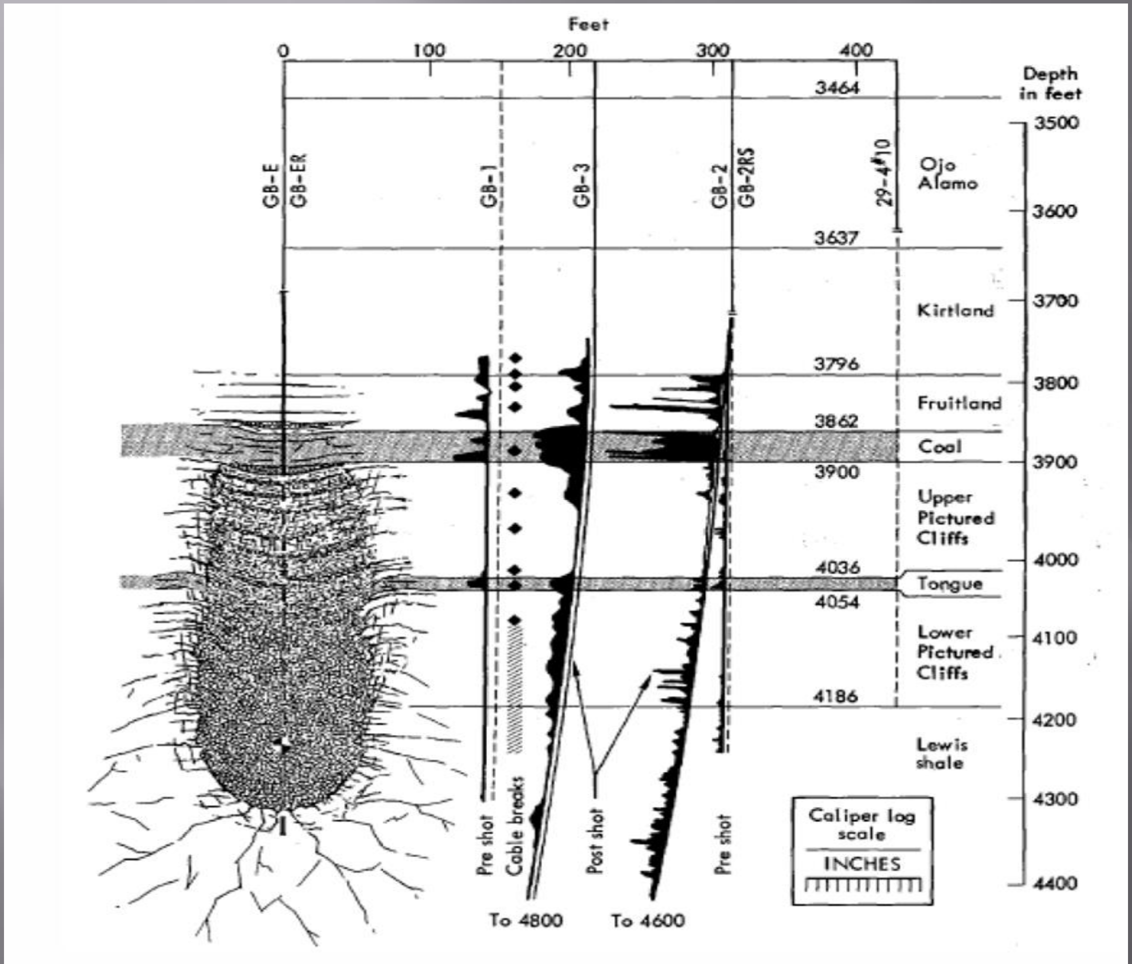
Avg. perm: 0.1 – 0.01 md
Calc. in-place reserves: 33 MMcf/ac, only 10% recovered by conventional wells
Calc. EUR by nuclear frac'ing: 67% at 160-ac spacing



Lowering Gasbuggy 29 kt fusion device into emplacement hole GB-E.

13 ft long, 18 in. in diameter. Detonated at depth of 4240 ft near top of Lewis Shale on December 10, 1967.

Gasbuggy Chimney



Shot point in Lewis Sh.; fractures and cavity grew upwards into base of Fruitland Fm.

Results

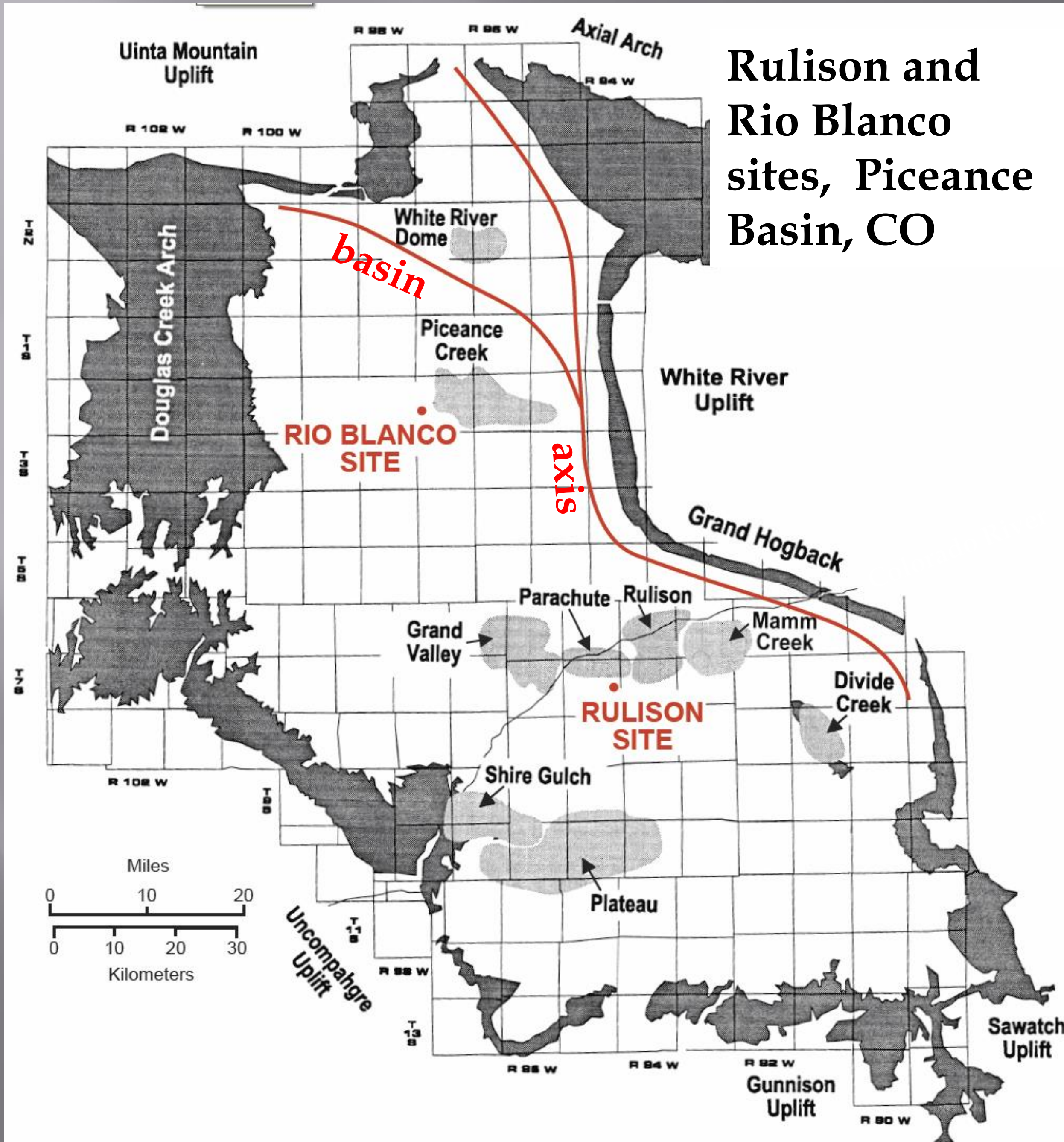
- 4.5 – 5.2 M earthquake

- Chimney 333′ high, 160′ diameter
- Frac network 2.75X chimney radius
- IP ~1mmcf/d, 2X to 7X that of nearby unstim conv wells
- EUR ~1bcf/20 yrs, 8X that of local conv wells

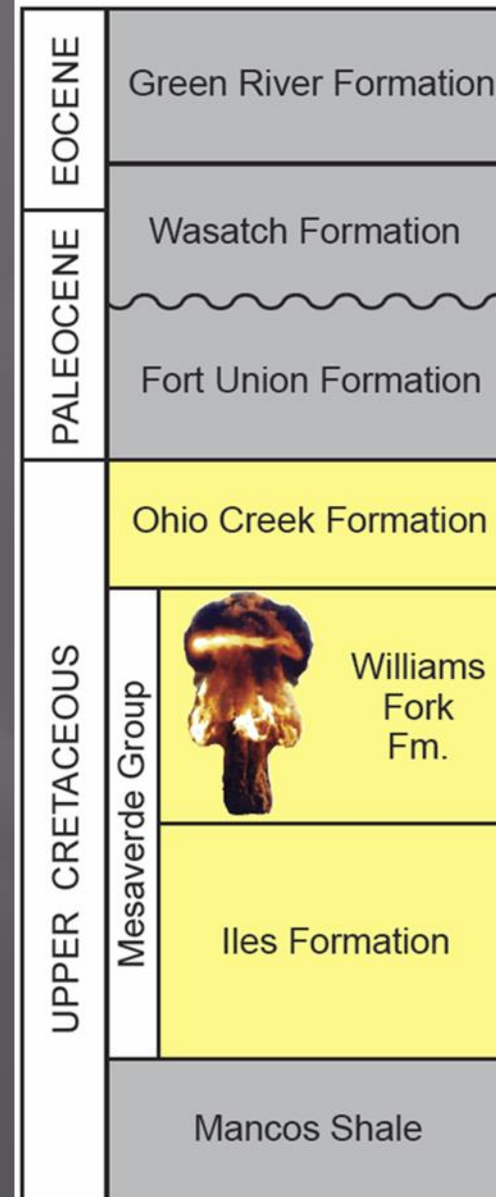
BUT ……..

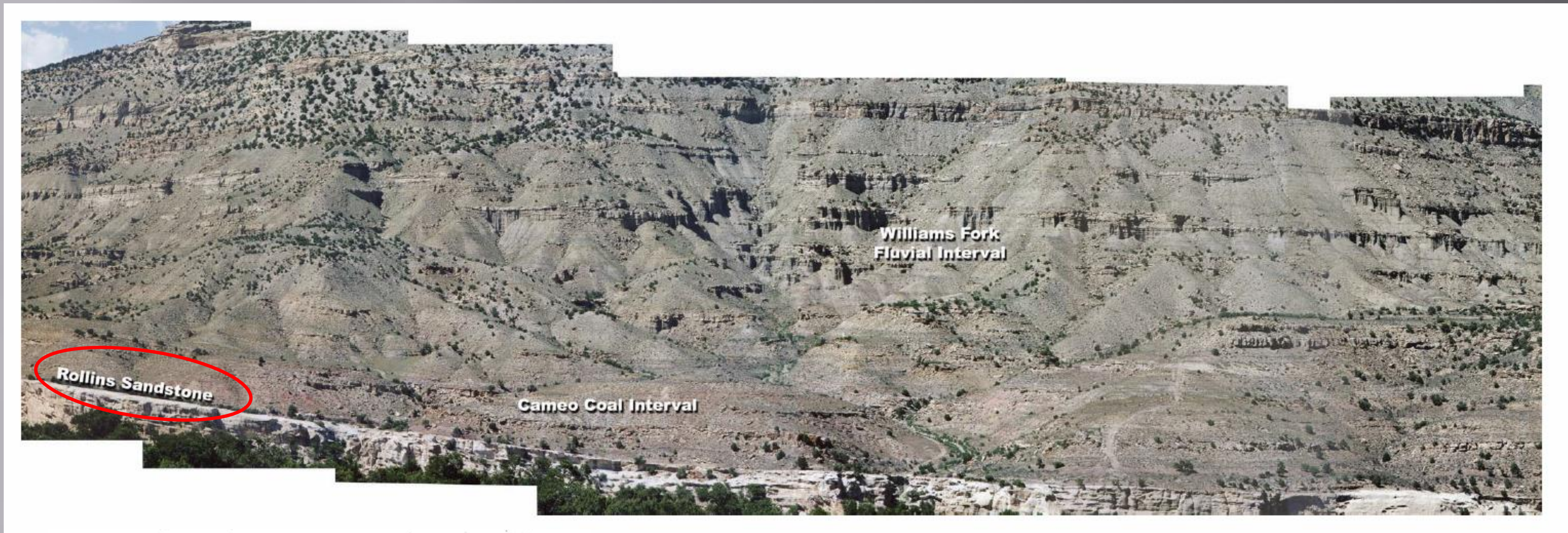
- High CO_2
- Some radionuclides in gas
- Fracs not connected to chimney

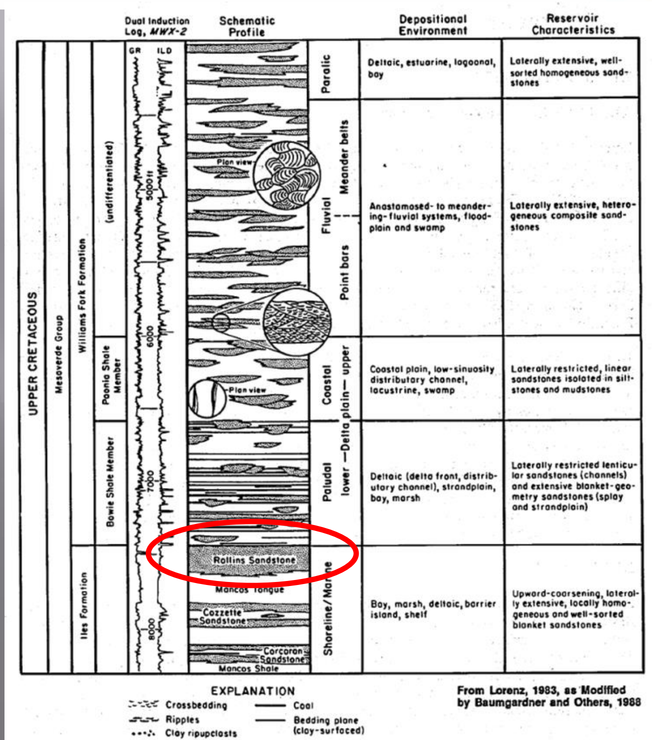
Rulison and Rio Blanco sites, Piceance Basin, CO



Stratigraphy of the Rulison Test Area

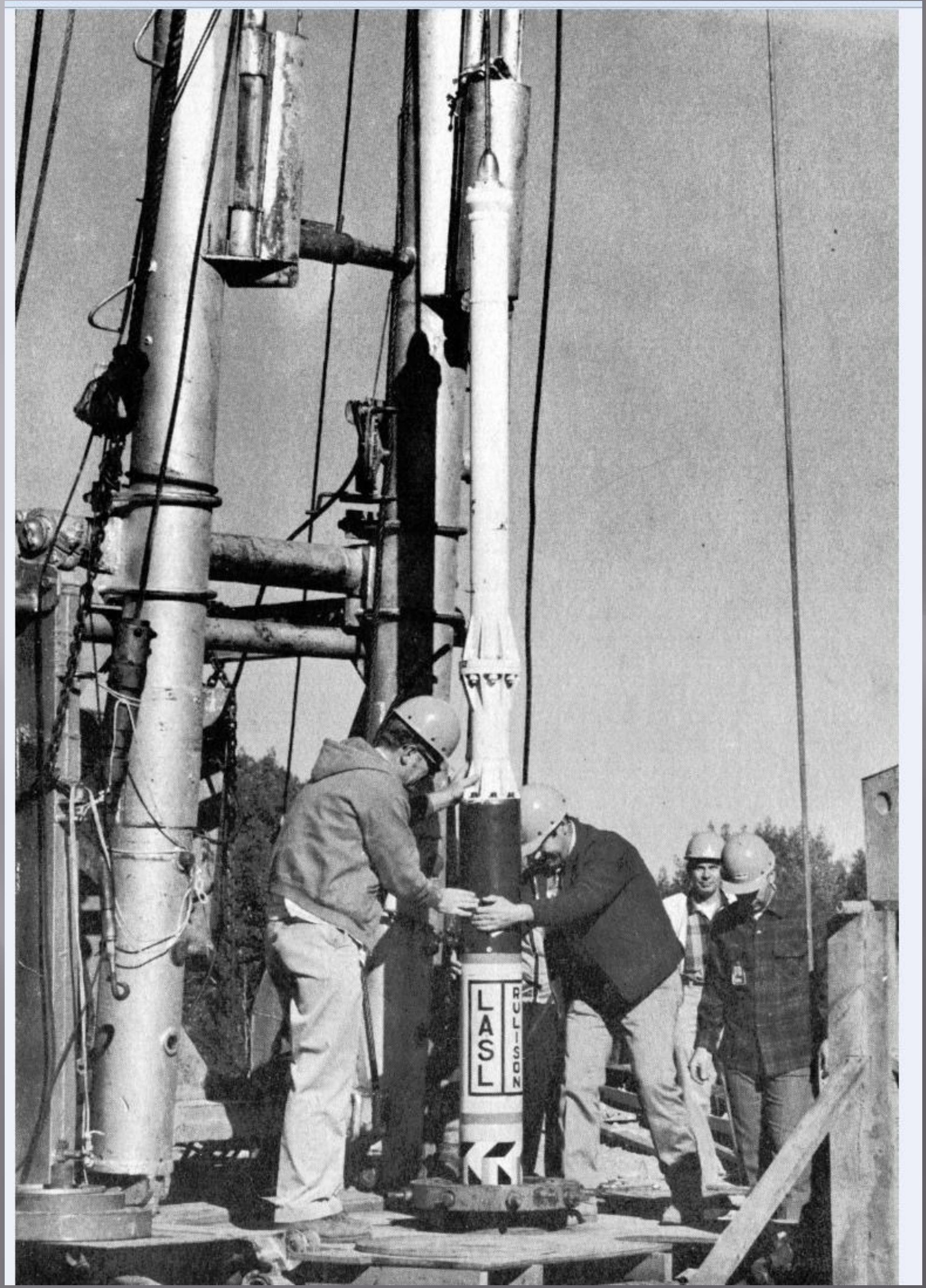






Photomosaic of Williams Fork Formation, Mesaverde Group, showing discontinuous nature of fluvial sandstones in fine-grained overbank deposits.

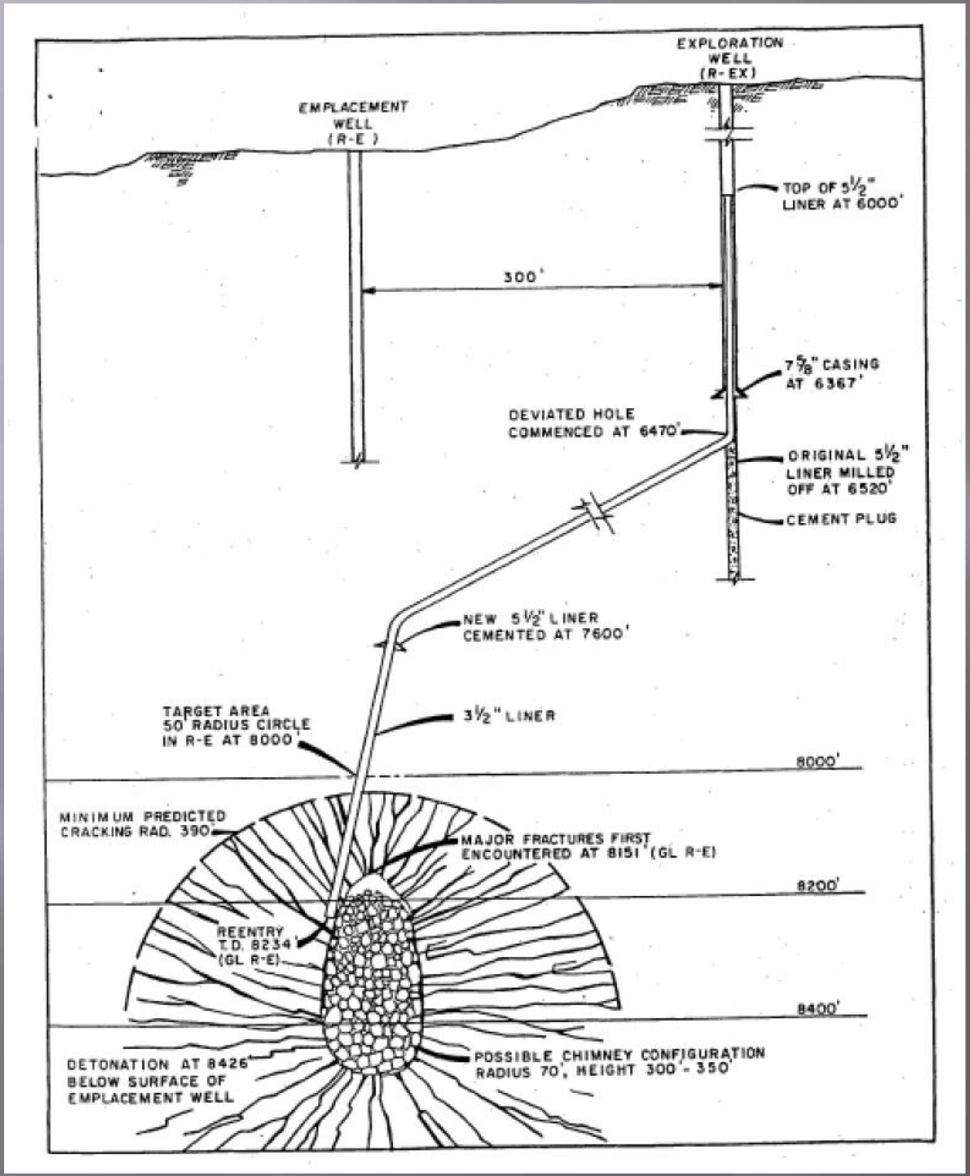
Note – Reservoir character very different from Pictured Cliffs Ss.



Lowering Rulison 43 kt fission device into emplacement hole R-E.

15 ft long, 9 in. in diameter, 1200 lbs. Detonated at depth of 8426 ft in Mesaverde Group on September 10, 1969.

Sketch of Rulison Chimney



Results

- 5.4 M earthquake, 16 <1 after-shocks for 43 minutes after shot
- Geophones detected collapse 5 to 150 secs; some noise for 9 hrs.

- Chimney 350′ high, 152′ in diameter
- Frac network 3X to 5X chimney radius (designed 6.5X)
- 108-day IP ~0.5 bcf; ~2X to 4X nearby conv wells
- EUR ~1.8 bcf/20 yrs, 2X to 3X that of local conv wells.

But ………

- High CO_2 and water vapor
- Some (but lower than GB) radionuclides in gas
- Public concern

January 1, 1970 (Back to Context)
National Environmental Policy Act of 1969

Required all federal government agencies to prepare environmental assessments and issue environmental impact statements.

Established the President's Council on Environmental Quality that eventually became the Environmental Protection Agency (EPA).

Effect on Plowshare: NEPA could not force release of nuclear technical data, but could force public disclosure of on-site and off-site consequences of detonations.

Schedule for Construction of Nuclear Stimulated Gas Wells (Rio Blanco Environmental Impact Statement, US Atomic Energy Commission, 1973)

TABLE 1

SCHEDULE FOR CONSTRUCTION OF NUCLEAR STIMULATED GAS WELLS

Construction Region	Area, Sq.Mi.	1973	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Add'l Time to Complete Field Dev., Years	Approx. Year of Field Completion	Total Wells
Green River (N)	600			WW			5 WWII	5	10	20	30	35	35	35	35	35	35	→ ~28 →	2016	1200
Green River (S)	540					EXP			5	5	10	20	30	35	35	35	35	→ ~26 →	2014	1080
Piceance (N)	550	RB			5 RBII	---	10	20	30	35	35	35	35	35	35	35	35	→ ~22 →	2010	1100
Piceance (S)	650					5 RuII	---	10	20	30	35	35	35	35	35	35	35	→ ~29 →	2017	1300
Uinta (1)	300						EXP			5	5	10	20	30	35	35	35	→ ~13 →	2001	600
Uinta (2)	200								EXP			5	5	10	20	30	35	→ ~ 8 →	1996	385
TOTAL PRODUCTION WELLS					5	5	15	35	65	95	115	140	160	170	195	205	210	210 210		5665

* Assuming 2 wells per section

WW = Wagon Wheel

RB = Rio Blanco

Ru = Rulison

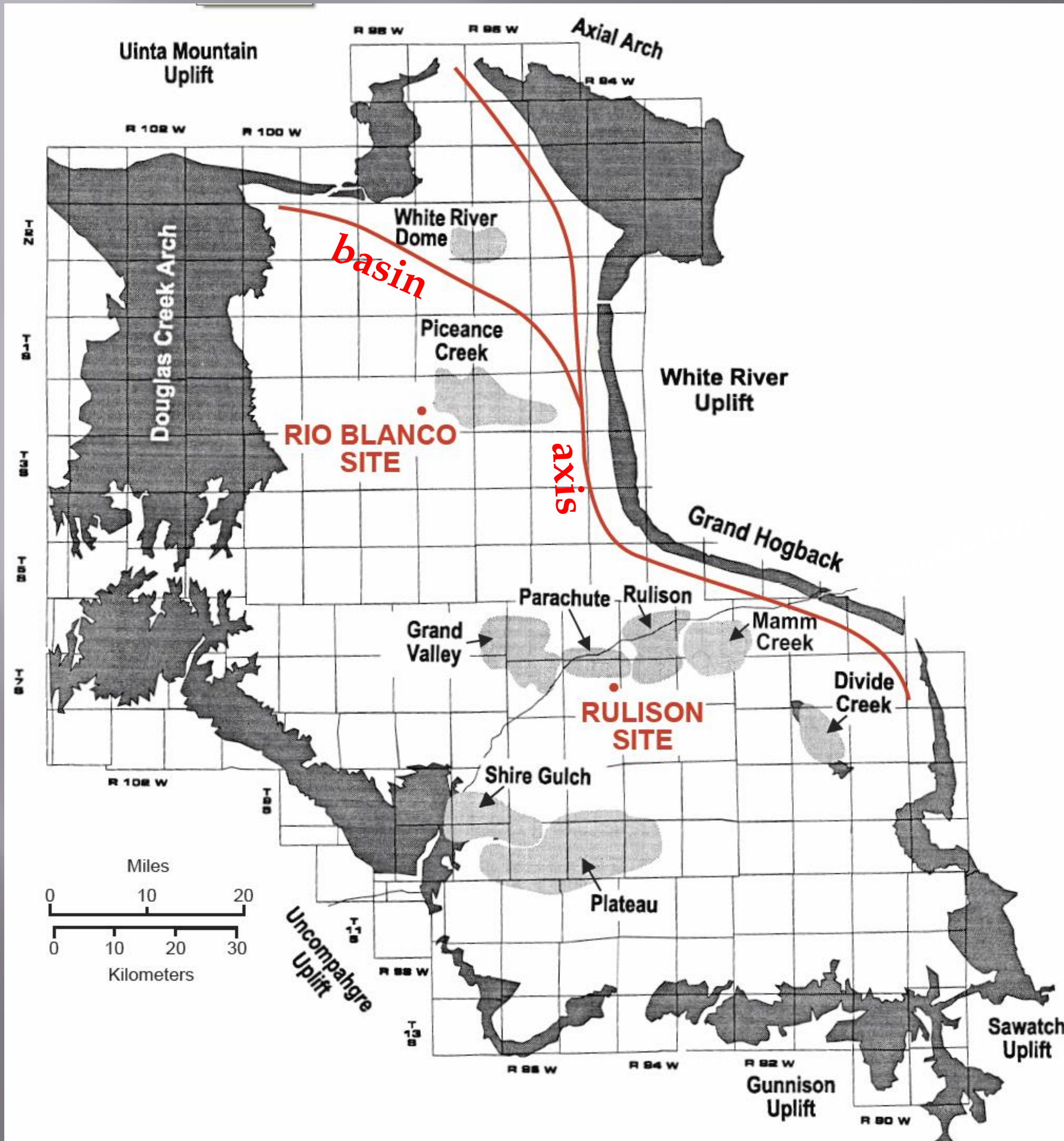
EXP = Experimental Well

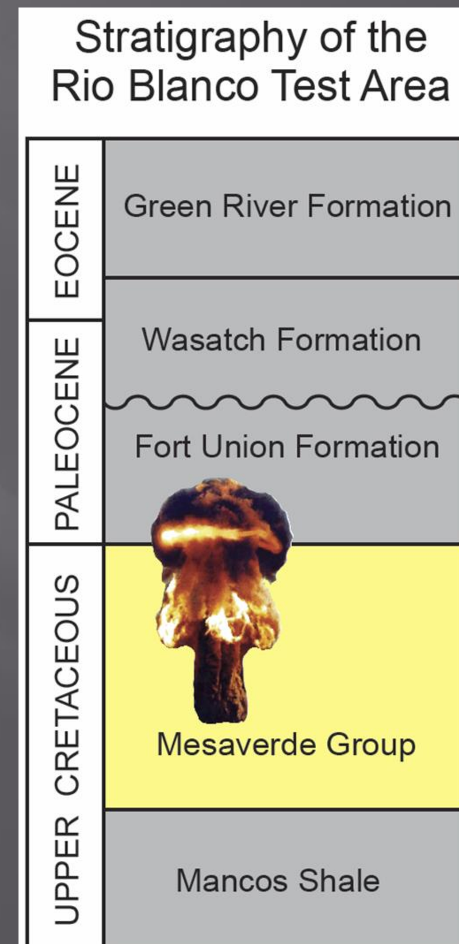
NOTE: Year of table entry is shot year
Emplacement well drilling occurs in previous year
Gas production begins in following year

- 7 -

5665 wells in Green River, Piceance, and Uinta Basins, finished in 2017. At 3 to 5 devices/well, 17,000 to 28,000 nuclear devices would be required.

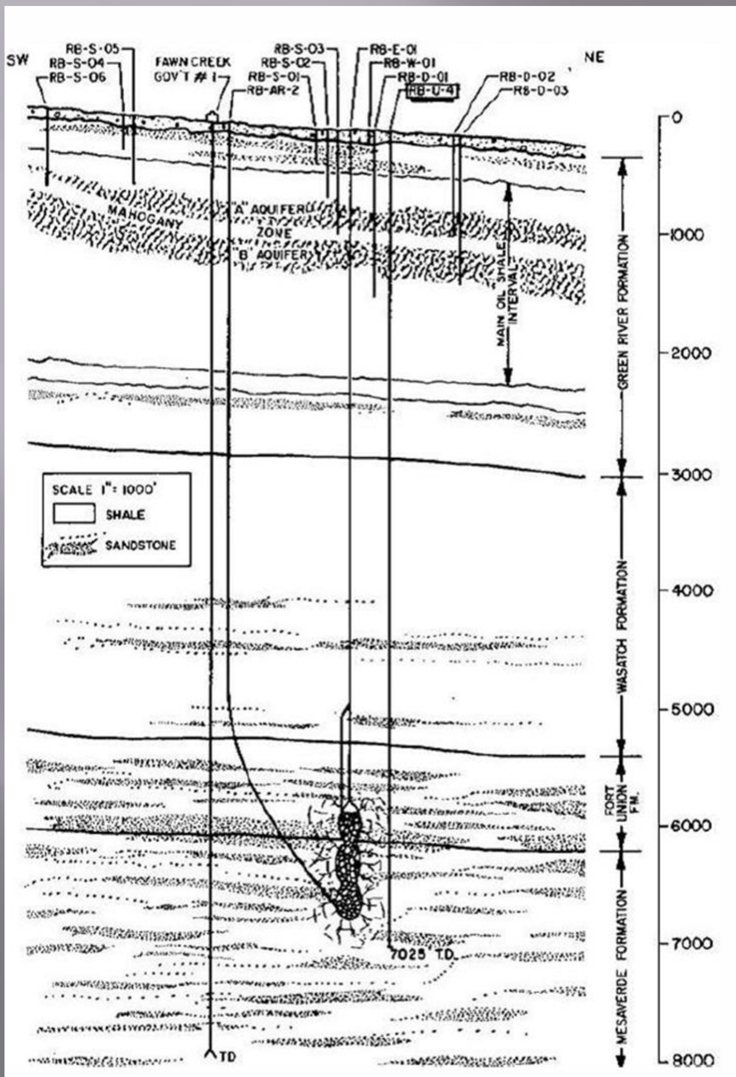
Rulison and Rio Blanco sites, Piceance Basin, CO





Rio Blanco rig and device; One of three 33-kt nuclear devices being lowered into emplacement hole RB-E-01.

3 simultaneous 33-kt shots May 17, 1973



Results

• 5.4 M earthquake, rock-falls, 95 aftershocks (max 2.5 M) to 8 days after shot.

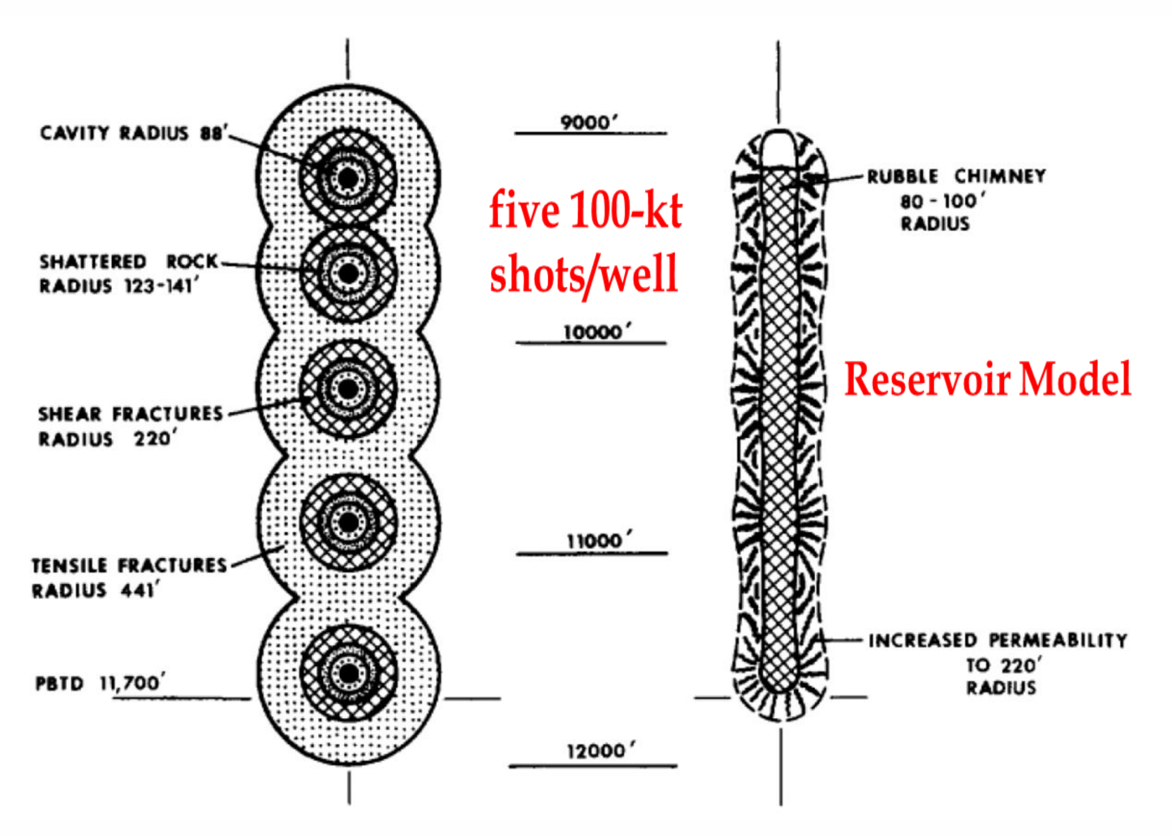
• IP 5.5 mmcf/day for 7 days, but rapid pressure drop

But …………

• High $CO_{2,}$ some ^{85}Kr and tritium
• Chimneys not connected
• Upper chimney production much less than predicted
• Amount of induced micro-fracturing very small
• Large public outcry

SUMMARY –Mesa Verde poorly characterized; in hindsight, was unsuitable for nuclear frac'ing

Proposed, post-Rio Blanco tests: Wagon Wheel and Wasp.



Wagon Wheel – five sequential* 100-kt shots into UK and PEo strata in Pinedale Field, Green River Basin to produce 2700-ft-high chimney and envelope of induced fractures.

Wasp – 50-kt shot, 11,000 to 12,000 ft deep on Pinedale Anticline, same strata as Wagon Wheel. Abandoned.

* Limited by July 1974 Threshold Test Ban Treaty

The Demise of Plowshare:

- **27 nuclear (and many conventional) tests 12/61 to 5/73**
- **First excavation test – Sedan – fallout in Iowa**
- **First Plowshare test – Gnome – geyser of radioactive steam and smoke**
- **Later excavation tests – 1963 LTBT, public safety, conventional explosives cheaper**
- **Little public opposition to 1967 Gasbuggy test**
- **Growing environmental movement, significant opposition to 1969 Rulison test *and* to flaring of gas**
- **Jan. 1, 1970 – NEPA and required EISs**
- **Significant opposition to 1973 Rio Blanco test.**
- **Wagon Wheel cancelled due to local opposition, changing national mood regarding nuclear explosions**
- **Sept. 1975 – Plowshare terminated. $82M spent**

THEN AND NOW

- HOW REAL?

- HOW IMPORTANT AS DRIVERS OF ACCEPTANCE OF NEW TECHOLOGY?

- Anti-Nuclear Sentiment ↔ Climate-Change Concern

- Radioactive Gas ↔ Groundwater Contamination

- Viet Nam War / Watergate, Distrust of Government ↔ BP Macondo, Keystone, Distrust of Big Oil

The Fear Factor:

<u>Look</u> magazine – December 15, 1970

LOOK ■ DECEMBER 15, 1970 Volume 34, No. 25

THE NUCLEAR THREAT INSIDE AMERICA

HERE IT IS: THE ATOMIC ENERGY COMMISSION ALLOWS STRONTIUM-90 IN YOUR MILK, TRITIUM IN YOUR WATER, PLUTONIUM IN YOUR AIR AND MAKES WALLS GLOW.

For 24 years the Atomic Energy Commission has grown up fat, powerful, unquestioned. Its vast, loyal band of scientists, functionaries, businessmen and politicians talk about "nuclear enhancement," "nuclear events," and "nuclear landscaping," license and run atomic-power generators and weapons factories that dump "radwaste," which will bubble for thousands of years—lasting longer than governments, records, perhaps man himself. AEC has spent $49 billion. It's got friends.

Now AEC is under attack. More than 112 nuclear power plants are promised by 1980. Private citizens have blocked six in 1970. University of Nevada researchers checking the buildup of iodine-131 in cattle thyroids across the West conclude: "The principal known source of I-131 is exhaust gases from nuclear reactors and associated fuel-processing plants."

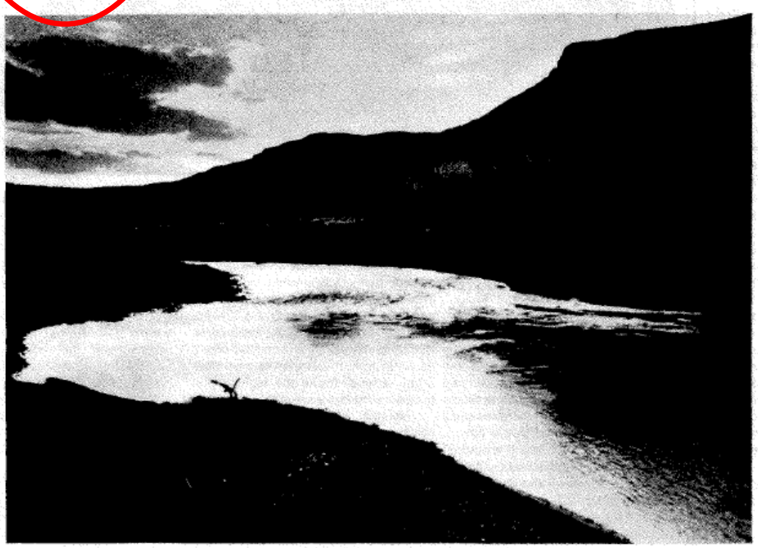
Scientists argue that our underground blasts for research—more than 23 so far this year versus two in Russia—are expensive, repetitive and careless. Radioactive plutonium now covers 250 square miles of the Nevada Test Site. AEC admits the desert is contaminated. "It's going to be contaminated a long, long time," says a spokesman. "That's why we're testing here. That's the kind of thing we have to do."

Many AEC officials are working hard to overcome their reputation. Others are skating fastest where the ice is thinnest. Critics bristle at a nuclear policy run by insiders impatient with environmental questions and want a voice in safety and radiation standards used by the AEC. They argue against AEC's dual role of promoter and regulator of atomic energy. "That," says a critic, "is like letting the fox guard the hen house."

AEC sees its mission as a crusade. Howard B. Brown, Jr., assistant general manager, says: "We have circumnavigated the globe many times over, spreading the gospel about the peaceful atom." Opponents are heretics.

Two of them, Drs. John Gofman and Arthur Tamplin of AEC's Lawrence Radiation Laboratory (Livermore, Calif.), argue that AEC's "safe radiation dose" is unsafe. If everyone got AEC's safe dose, they claim, there would be 16,000 to 24,000 more cancer and leukemia deaths a year in the U.S. They demand an immediate reduction to a tenth of the AEC level.

AEC fumes. "Gofman, Tamplin and their allies are . . . trying their case in the press and other public forums," said James T. Ramey, an AEC commis-



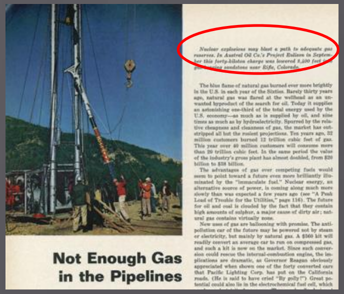
The AEC spent three years wooing Western Coloradans for Project Rulison—an experimental blast for gas—above the Colorado River (left). PR men promised a boom economy, low taxes, and a tiny 40-kiloton underground nuclear blast. But the AEC's economic "shot in the arm" hasn't been felt. The other shot, however, "was like a train rushing up the canyon," says Lee Hayward of Grand Valley, "then the jolt, a terrific shake. Then the shock wave come through. Cliffs started pouring rocks. It was quite a show, really."

BY JACK SHEPHERD LOOK SENIOR EDITOR PHOTOGRAPHS BY JOEL BALDWIN

continued

"Here it is: the Atomic Energy Commission allows strontium-90 in your milk, tritium in your water, plutonium in your air and makes walls glow."

(But remember this?)



"Nuclear explosions may blast a past to adequate gas reserves."

Fortune, Nov. 1969

Anti-Nuclear Sentiment – Climate-Change Concern

- Both real in the Public's eye.
- Fear (vs. Facts) drove/driving Public Opinion.

Some questions for which I have no answers:

Would public have accepted nuclear frac'ing if Cold War mentality didn't exist?

Would public accept hydraulic frac'ing if climate change wasn't a concern?

Yes, but still have G/W contamination issue (next slide)

No, but gas (bridge to future) >>> oil >>> coal

Radioactive Gas ⟷ Groundwater Contamination

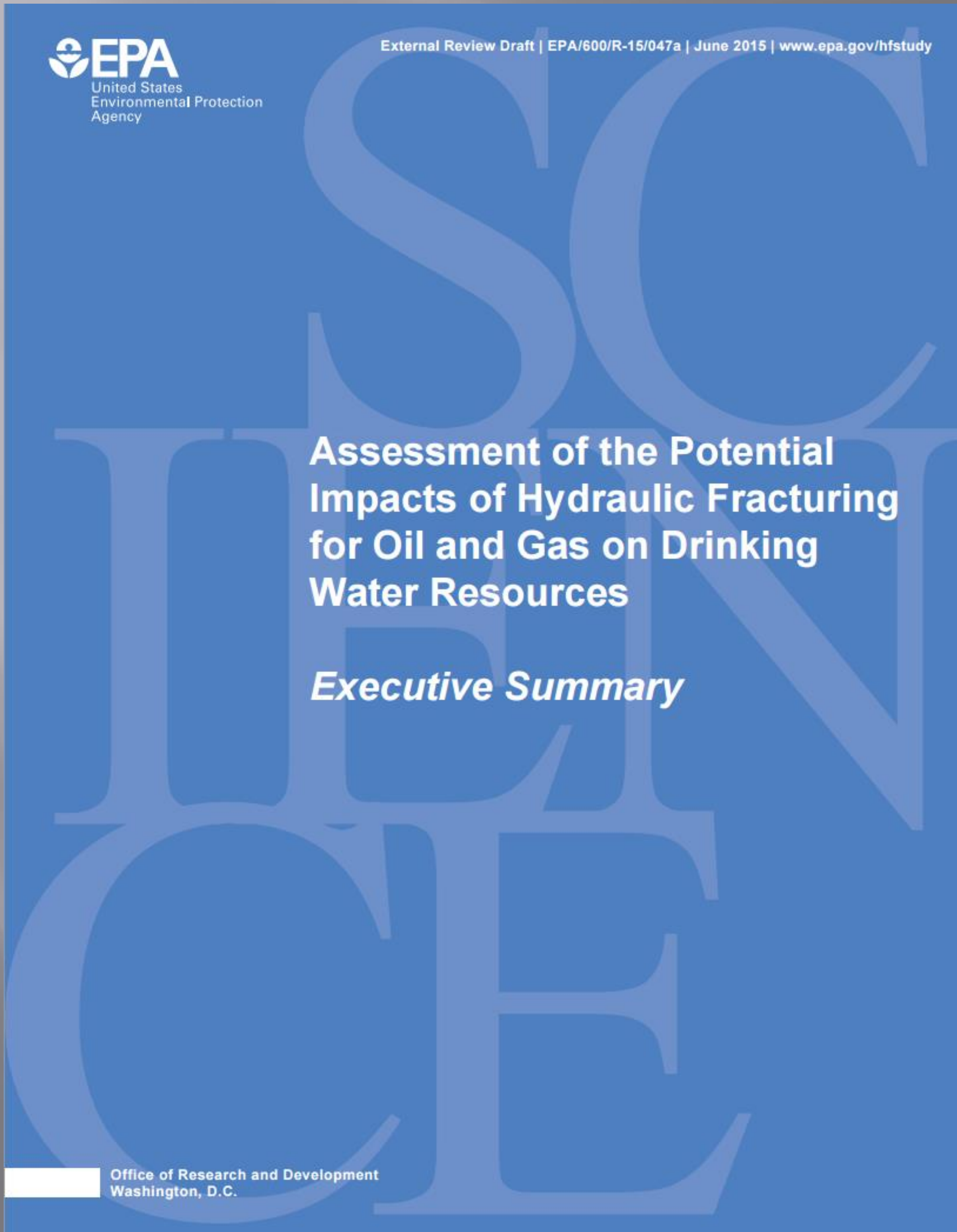
- Hazards: ^{85}Kr, ^{14}C (very low), tritium
- Solutions:

  Device – fission <<< fusion (tritium)
  shielding

  Gas Production – dilute*, delay, generate in remote areas*

  Tritiated Water – store, ship, re-inject

* Modelling suggests <0.64 to <1.0 mrem/yr for mixing model and <0.11 to <2.1 mrem/yr for power-generation model vs. ~100 mrem/yr natural background



External Review Draft | EPA/600/R-15/047a | June 2015 | www.epa.gov/hfstudy

EPA
United States
Environmental Protection
Agency

Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources

Executive Summary

Office of Research and Development
Washington, D.C.

"The number of identified cases where drinking water resources were impacted are small relative to the number of hydraulically fractured wells."

So ……….

Fear of radioactive gas, fear of contaminated groundwater overblown?

(Knee-jerk?) Distrust of Government – Big Oil

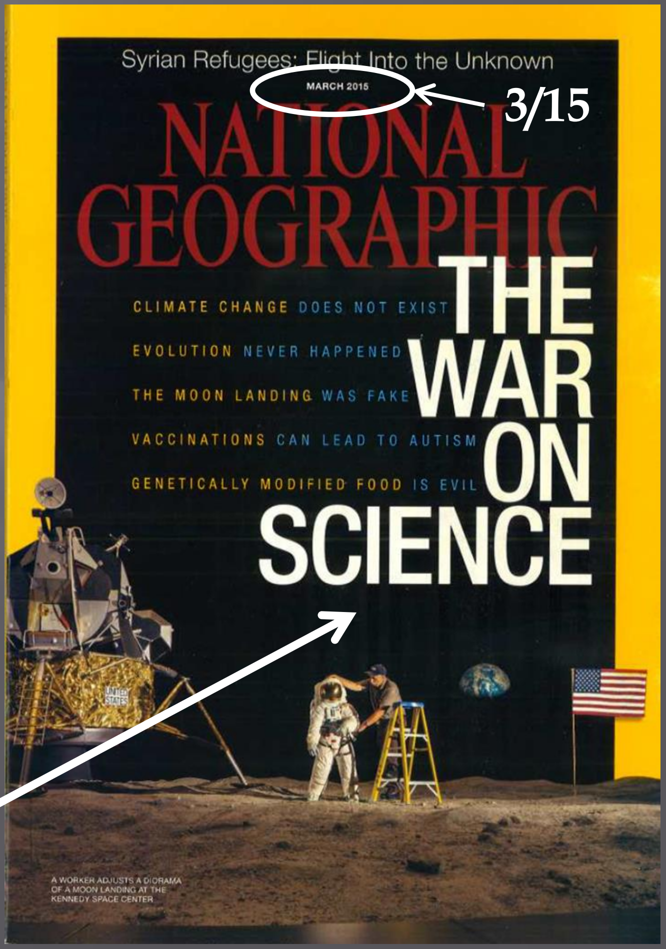
Then – Were the most qualified industry people scared off leaving only gov't scientists? Who was Austral Oil Company? Equity Oil Company? <u>Why no</u> Exxon, Texaco, Chevron, Mobil?

Now – Are geologists/engineers with environmental backgrounds being ignored by industry?

WHAT TO DO?

- Geoscientist recognition/acceptance of public concern (nuclear explosions or climate change) whether valid or not
- Fully educate the public about the process and
- Full disclosure of potential for harm (radioactive by-products or frac fluids)
- Enlist non-Big Oil support for process. (Note: 2015 EPA report)
- Acknowledge process not 100% safe; accept responsibility for accidents; strive to make process safer
- Financially protect public from all (including long-term) consequences

BUT (a new issue)



THANK YOU