

The Stock Market Speaks: How Dr. Alchian Learned to Build the Bomb¹

Joseph Michael Newhard

August 27, 2013

ABSTRACT

At RAND in 1954, Armen A. Alchian conducted the world's first event study to infer the fissile fuel material used in the manufacturing of the newly-developed hydrogen bomb. Successfully identifying lithium as the fissile fuel using only publicly available financial data, the paper was seen as a threat to national security and was immediately confiscated and destroyed. The bomb's construction being secret at the time but having since been partially declassified, the nuclear tests of the early 1950s provide an opportunity to observe market efficiency through the dissemination of private information as it becomes public. I replicate Alchian's event study of capital market reactions to the Operation Castle series of nuclear detonations in the Marshall Islands, beginning with the Bravo shot on March 1, 1954 at Bikini Atoll which remains the largest nuclear detonation in US history, confirming Alchian's results. The Operation Castle tests pioneered the use of lithium deuteride dry fuel which paved the way for the development of high yield nuclear weapons deliverable by aircraft. I find significant upward movement in the price of Lithium Corp. relative to the other corporations and to DJIA in March 1954; within three weeks of Castle Bravo the stock was up 48% before settling down to a monthly return of 28% despite secrecy, scientific uncertainty, and public confusion surrounding the test; the company saw a return of 461% for the year.

¹Thanks to William R. Dougan, Robert D. Tollison, Harold Mulherin, Mike Maloney, and participants of the public economics workshop at Clemson University.

1. Introduction

Despite Eugene Fama's assertion that "the original event study" was conducted in 1969 (Fama, 1991), Armen A. Alchian was a pioneer of financial event studies in the early 1950s. In this paper I replicate a confiscated and destroyed event study of the Castle Bravo nuclear test conducted by Alchian at RAND in 1954. This event is chosen because of the historical importance it holds as the world's first event study, and due to the subsequent declassification of top secret information surrounding the test it also provides an excellent case study of market efficiency. Realizing that positive developments in the testing and mass production of the two-stage thermonuclear (hydrogen) bomb would boost future cash flows and thus market capitalizations of the relevant companies, Alchian used stock prices of publicly traded industrial corporations to infer the secret makeup of the fissile fuel component in the device in a paper titled "The Stock Market Speaks." Alchian relates the story in a 2000 interview:

We knew they were developing this H-bomb, but we wanted to know, what's in it? What's the fissile material? Well there's thorium, thallium, beryllium, and something else, and we asked Herman Kahn and he said, 'Can't tell you'... I said, 'I'll find out', so I went down to the RAND library and had them get for me the US Government's Dept. of Commerce Yearbook which has items on every industry by product, so I went through and looked up thorium, who makes it, looked up beryllium, who makes it, looked them all up, took me about 10 minutes to do it, and got them. There were about five companies, five of these things, and then I called Dean Witter... they had the names of the companies also making these things, 'Look up for me the price of these companies... and here were these four or five stocks going like this, and then about, I think it was September, this was now around October, one of them started to go like that, from \$2 to around \$10, the rest were going like this, so I thought 'Well, that's interesting'... I wrote it up and distributed it around the social science group the next day. I got a phone call from the head of RAND calling me in, nice guy, knew him well, he said 'Armen, we've got to suppress this'... I said 'Yes, sir', and I took it and put it away, and that was the first event study. Anyway, it made my reputation among a lot of the engineers at RAND.²

Alchian's study using only public information to successfully identify the fissile material of a US nuclear bomb tests provides powerful evidence in favor of market efficiency; it was

² *The Intellectual Portrait Series: A Conversation with Armen A. Alchian* (Indianapolis: Liberty Fund, 2000).

public information that the US was conducting atomic bomb tests, but it was not publicly known at the time how the bombs were constructed and even for top scientists working on the bomb, it was purely speculative what the best fissile fuel for hydrogen bombs would turn out to be; A timeline of notable dates in the secret development of lithium fissile fuel as well as public information on lithium appearing in the media is found in Table I. This original event study is a testament to Alchian's great contributions to economic thought; unfortunately, his work was so insightful that the paper was suppressed and is now lost and largely forgotten. Alchian provides some additional information on the relevant test in his essay Principles of Professional Advancement:

The year before the H-bomb was successfully created, we in the economics division at RAND were curious as to what the essential metal was—lithium, beryllium, thorium, or some other... For the last six months of the year prior to the successful test of the bomb, I traced the stock prices of those firms. I used no inside information. Lo and behold! *One* firm's stock price rose, as best I can recall, from about \$2 or \$3 per share in August to about \$13 per share in December. It was the Lithium Corp of America. In January I wrote and circulated [the memorandum]. Two days later I was told to withdraw it. The bomb was tested successfully in February, and thereafter the stock price stabilized.³

The first hydrogen bomb test, Mike shot of Operation Ivy on November 1, 1952, used liquid deuterium as its fuel. After Operation Ivy which involved a total of two tests in November 1952, Operation Upshot-Knothole followed with eleven detonations between March and June 1953. The purpose of these tests was to measure the effects of fallout and radiation and the testing of nuclear artillery. This was followed by Operation Castle, with seven detonations from March 1 (February 28, local time) to April 22, 1954. The first of these, Castle Bravo, was the first test of a dry fuel thermonuclear bomb, using lithium deuteride instead of the liquid fuel of previous tests. It also remains the largest detonation in US history, yielding 15 megatons, about 1000x the power of Little Boy or Fat Man. The lithium deuteride fuel generated an unexpected

³ Alchian, *Collected Works I*, p. xxv-xxvi

boost to yield and Castle Bravo exceeded the predicted energy output by 150%, paving the way for powerful yet practical aircraft-deliverable weapons. Given its importance, its timing, and its fuel source, Castle Bravo is the most likely subject of Alchian’s suppressed paper. The following batch of tests called Operation Teapot were run from Feb 18 to May 15, 1955 and included 14 small 1 to 30 kiloton tests, but their purpose was to improve nuclear battlefield tactics, not bomb manufacturing.

Table 1: Timeline of Public and Private Events Regarding Lithium

| DATE | PRIVATE INFORMATION | PUBLIC INFORMATION |
|------------------|---|---|
| Late 1948 | Soviets theorize that lithium deuteride fuel could replace deuterium and tritium in nuclear weapons | |
| June 1951 | Edward Teller writes a memo on the possible advantages of lithium deuteride fuel | |
| June 17, 1951 | AEC agrees to begin producing lithium for possible use in the hydrogen bomb | |
| August 1952 | | <i>Popular Science</i> speculates that lithium may be used in the hydrogen bomb due to its use in producing tritium |
| November 1, 1952 | Ivy Mike, world’s first hydrogen bomb, using liquid deuterium fuel is a success. | |
| March 9, 1953 | | Foote Mineral Co. earnings down for 1952 due to in part to heavy non- capital expenditures in its lithium expansion program. – WSJ |
| March 18, 1953 | | “Much about the new development is secret. But what is known is this: the new device uses only three-quarters as much fissionable material as the bombs that destroyed the Japanese cities” |
| July 13, 1953 | | Foote Mineral Co. is completing new plants in NC and VA to produce various ores and |

| | | |
|-------------------|--|--|
| | | lithium chemicals, which are expected to increase assets, sales, and profits. – WSJ |
| August 1953 | Los Alamos is preparing a lithium fuel hydrogen bomb test for 1954 | |
| August 1953 | Soviets test their first lithium deuteride bomb | |
| August 7, 1953 | | Footo Mineral Co. sees a decline in earnings due in part to investments in new plants. A decline in sales was the result of its “temporary inability to fully supply the expanding market for lithium chemicals and ores,” but is increasing production. “Current market estimates indicate continued high demand for lithium ores and chemicals and Footo is intensifying its search for lithium-bearing deposits and other chemicals.” - WSJ |
| November 19, 1953 | | American Potash and Chemical Corp. is adding lithium ores from a new source in Africa. It will “handle lepidolite and petalite ore mined from a large deposit of high-grade lithium-bearing minerals near Fort Victoria, Southern Rhodesia.” “Lepidolite and petalite are used primarily by manufacturers of specialty glass and ceramics. Demand for all lithium products has been steadily increasing, and they have long been in short supply.” – WSJ |
| November 30, 1953 | | Lithium Corp. of America reports quarterly earnings ending Sep. 30 with a net income of \$53,448 or 10 cents per share, no indication of net income for same quarter in previous year. Its 9 month earnings ending Sep. 30 are reported to be \$113,071 for 1953 vs. \$16,446, in 1952, an increase in earnings per share from 3 cents to 26 cents. -WSJ |
| January 15, 1954 | | Footo Mineral Co. reports a record month in earnings for December due to its new lithium-producing plants. “In addition to lithium, which is finding expanding uses in lubricants, industrial coatings and other chemical applications, Footo produces a variety of other rare metallic articles used in |

| | | |
|------------------|--|--|
| | | electronics and atomic power fields.” – WSJ |
| January 28, 1954 | | “Lithium is one of several other scarce metals not previously refined in commercial quantities but now easier to extract as a result of research spurred by the A.E.C.’s need for this light metal. It is the key in making a new top-secret hydrogen bomb that’s simpler, cheaper, and easier to transport than earlier models. The increased knowledge and availability of this metal has now led its producers – Foote Mineral Co., American Potash & Chemical Corp., and Lithium Corp. of America – to embark on experiments aimed at developing commercial uses for it, too.” – WSJ |
| March 1, 1954 | Castle Bravo, the first US test of a lithium fuel hydrogen bomb exceeds expected yield. Navy and Japanese fishing ships are dusted with radioactive fallout. | |
| March 2, 1954 | | “‘Joint Task Force Seven has detonated an atomic device at the A.E.C.’s Pacific proving ground in the Marshall Islands. This detonation was the first in a series of tests.’ The statement did not make clear whether the ‘atomic device’ was of the fission or thermonuclear (hydrogen) type.” - NYT |
| March 4, 1954 | | Foote Mineral Co. directors approve expansion of production facilities for lithium ores and chemicals. - WSJ |
| March 7, 1954 | | “The United States detonated last week its forty-sixth nuclear device and prepared to test in the next couple of weeks its first operating model of a hydrogen bomb.” - NYT |
| March 9, 1954 | | “Markets for lithium products have developed even more rapidly than anticipated,” with Foote Mineral Co. planning to increase output. “Lithium compounds are used in wide temperature range lubricating greases, ceramics, welding rod coatings, alkaline type electric storage batteries, air conditioning materials and atomic energy development.” - WSJ |
| March 10, 1954 | | “An expansion since 1946 of approximately |

| | | |
|----------------|--|---|
| | | 1,000% in the consumption of lithium in the ceramic, grease, air conditioning, metallurgical and organic chemical fields, according to K. M. Leute, president of Lithium Corp. of America, Inc., is behind that firm's \$7 million expansion program at Bessemer City, NC adjacent to deposits of lithium ore acquired by the company in the past 8 years and said to be the largest single reserve of lithium ore in the world." – WSJ |
| March 11, 1954 | | "A hydrogen bomb designed for combat may produce history's greatest man-made blast in the Marshall Islands between March 16 and 28... The first blast in the current series of tests was March 1. The commission announced that an atomic device had been detonated, indicating that the hydrogen bomb was yet to come since hydrogen bombs are usually referred to as thermonuclear." - NYT |
| March 12, 1954 | | "Twenty-eight Americans and 236 natives were "unexpectedly exposed to some radiation" during recent atomic tests in the Marshall Islands." - WSJ |
| March 12, 1954 | | "The United States is expected to set off the mightiest nuclear explosion in history sometime between March 15 and 28." - NYT |
| March 14, 1954 | | "A high government official indicated today that the United States has set off the most powerful hydrogen blast yet achieved... a few days ago." - NYT |
| March 18, 1954 | | "Shattering power hundreds of times greater than any previous man-made explosion was unleashed when the US set off its hydrogen explosion No. 2." - NYT |
| March 18, 1954 | | "That hydrogen blast two weeks ago jarred a Pacific isle 176 miles distant. It unleashed power hundreds of times greater than any previous weapon." - WSJ |
| March 19, 1954 | | "A Japanese fishing boat, 800 miles away from the test site when the US set off a hydrogen bomb March 1 at Bikini Atoll was found to be radioactive." - WSJ |
| March 19, 1954 | | "The March 1 explosion had left an area of total destruction about twelve miles in diameter." - NYT |
| March 20, 1954 | | "A Congressional investigation of the immense hydrogen explosion in the Pacific March 1 has been started to determine whether adequate security and safety precautions were taken in the |

| | | |
|----------------|---|--|
| | | area.” - NYT |
| March 22, 1954 | | “Commentators and some congressmen are busily telling us that the horrors implied by the latest explosion are beyond belief.” - WSJ |
| March 25 1954 | | “All fish brought into Japanese and West Coast ports are being checked for radioactivity.” - WSJ |
| March 26, 1954 | | “Atomic Energy Commission reported plans to step up US production of hydrogen and other atomic weapons.” - WSJ |
| March 26, 1954 | MK-21 bomb based on Castle Bravo test begins production | |
| March 27, 1954 | Castle Romeo test is successful | |
| March 28, 1954 | | “The biggest explosion in the current nuclear tests in the Pacific will be set off next month, probably about April 22.” - NYT |
| March 29, 1954 | | “The hydrogen bomb test early this month is having some delayed but not necessarily surprising reactions... demanding an outright end to nuclear tests” - WSJ |
| March 31, 1954 | | “Churchill rejected Laborite demands to try to persuade the U.S. to halt H-bomb tests.” - WSJ |
| April 1, 1954 | | American Potash & Chemical Corp’s new high grade lithium beryllium interests in Southern Rhodesia “have resulted in a ‘significant strengthening’ of the company’s position in [lithium].” – WSJ |
| April 5, 1954 | | Footo Mineral Co. “expects 1954 to be the best year in Foote’s long history... ‘the market is expected to absorb readily both the present and proposed capacity’ for lithium and its compounds, which Foote produces and markets.” - WSJ |
| April 7, 1954 | Castle Koon test | |
| April 23, 1954 | | “A ‘large portion’ of the first quarter sales were in lithium, L. G. Bliss, sales vice president, stated. He remarked that queries were often made as to what effect developments in nuclear physics may have on Foote’s prospects, and added ‘If the US government desires lithium for any purpose we believe we are in the best position of any firm in the industry to serve that need. You can draw any conclusion you wish from that’.” – WSJ |

| | | |
|--------------------|--------------------|--|
| April 26, 1954 | Castle Union test | |
| May 5, 1954 | Castle Yankee test | |
| May 14, 1954 | Castle Nectar test | |
| June 10, 1954 | | “The committee voted to give lead, zinc and lithium a 23% depletion rate on domestic mining operations. They now get 15% and would continue to get 15% on any overseas operation.” – WSJ |
| June 16, 1954 | | “Cash is also being poured into preliminaries for a German leap into the atomic age. Although Allied regulations forbid West German atomic research or production, chemists here are making all the preparations for the day when these rules are scrapped. They already extract atomic energy materials, such as lithium from the giant cinder dumps of the industrial Ruhr. And researchers, financed by industry and the government, are doing extensive ‘paper work’ in the atomic field.” – WSJ |
| July 30, 1954 | | “H. C. Meyer, chairman, said record sales and earnings figures could be attributed to increased production from new facilities added in 1953. He said the company’s current enlargement of facilities for production of lithium ore concentrates will be substantially completed by the end of this year and further expansion of lithium chemical refining plants should be in operation early in 1955.” – WSJ |
| August 31, 1954 | | For the 6 month period ending June 30, Lithium Corp. of America reports net income of \$152,387 in 1954 vs. \$77,980 for 1953 – WSJ |
| September 10, 1954 | | “Lithium Corp. of America thinks increased operating efficiency will put second half earnings ‘substantially in excess’ of the \$152,387 posted for the first six months of this year, which was up from \$77,980 in the 1953 first half, according to Herbert W. Rogers, president.” – WSJ |
| October 20, 1954 | | American Potash & Chemical Corp. plans to construct a lithium chemical plant in San Antonio, to be owned by the newly-formed |

| | | |
|-------------------|--|---|
| | | American Lithium chemicals, Inc. of which American Potash owns 50.1%. “Initially, lithium hydroxide will be produced there. Addition of the San Antonio plant is a major step in American Potash & Chemical Corp.’s program of expansion in the lithium chemicals field... ‘There is a large unsatisfied demand for lithium products as a result of substantial growth in their use in enamels, ceramics, all-weather greases, air conditioning and other fields’.” |
| October 29, 1954 | | “Foote Mineral’s Quarter Indicated Sales Jumped 85% over a Year Earlier” – WSJ |
| November 1, 1954 | | To get both stability and water resistance, more and more grease makers are turning to thickeners which replace sodium or calcium with lithium or barium, both of which are soft white metals. The new Cities Service, Tide Water and Gulf greases all are lithium based. Lithium or barium increases the water resistance and raises the melting point of greases.” – WSJ |
| December 12, 1954 | | “Development of the hydrogen bomb and intensive industrial promotion have raised the world’s lightest metal, lithium, from obscurity to a stellar role in half a dozen civilian and defense industries in the last five years.” – NYT |
| December 30, 1954 | | “Next mining boom may be in lithium, lightest of metals. It’s greatly needed for the hydrogen bomb. But it also has growing and important uses, in the form of lithium compounds, in all-weather greases for autos, enamels, special kinds of glass, air conditioning and in low temperature batteries.” – WSJ |

The efficient market hypothesis holds that prices are “accurate,” that they reflect all available information (Fama, 1969). As a test of market efficiency, several questions must be addressed surrounding Castle Bravo. First, to what extent was the Operation Castle test series kept secret before and after the tests, and how quickly and in what manner was the information

surrounding tests disseminated to the public? French and Roll (1986) observe that most information falls in a continuum between public and private, and Maloney and Mulherin (2002) and Maloney and Mitchell (1989) provide evidence that the stock market reflects secret or unknown information in the price discovery process. Operation Castle clearly entailed both public and private information components. Second, to what extent did the public understand the importance of lithium fuel in advancing the development of small high-yield thermonuclear weapons? Were there any unexpected positive developments regarding the use of lithium for commercial purposes that could have driven Lithium Corp.'s price upward in the time immediately preceding and subsequent to the successful Castle tests? As I demonstrate below, while stories mentioning lithium appearing in the New York Times or Wall Street Journal throughout 1953 – 1954 were consistent with a positive outlook for the lithium market, there were no sudden positive changes that alone would seem to explain very large increases in the valuation of Lithium Corp in the months surrounding Operation Castle.

Using daily closing bids of major publicly traded manufacturers of fissile fuel producers I find significant upward movement in the price of Lithium Corp. stock relative to other metal-producing corporations and to the Dow Jones Industrial Average (DJIA) in March 1954; within three weeks of Castle Bravo the stock was up 48% before settling down to a monthly return of 28% despite secrecy and public confusion surrounding the test. This greatly outperformed the other stock returns for the same month and the DJIA which saw an increase of 2.3% for the month. The price of Lithium Corp continued to rise for the remainder of 1954 and saw a return of 461% for the year, some of which was gained in the two months leading up to the test despite little price movement in the twelve months prior. Lithium Corp. was seemingly singled out not only in the lead-up to the test, suggesting insider information, but after the successful test as

well, suggesting successful dissemination of information relevant to the value of Lithium Corp. in the weeks and months following Operation Castle's success.

The paper proceeds as follows. I briefly describe the development of lithium fissile fuel in hydrogen bomb production as well as the market for radioactive metals generally in the early 1950s in section II; I observe price reactions of these manufacturers leading up to and after Castle Bravo in section III, and make some generalizations about the results in section IV, with concluding comments in section V.

II. The Market for Lithium

In late 1948, Soviet scientists proposed using lithium deuteride instead of deuterium and tritium in nuclear bombs. By early 1949, they were told to develop a bomb using lithium. But “at the time, this was just another theory ... and would not be revisited for five years.”⁴ Working in parallel in the United States, Edward Teller proposed exploring the use of lithium deuteride in bombs as an alternative fuel to liquid deuterium; being a solid at room temperature, it would not require being kept several hundred degrees below zero inside the bomb, although its high rate of radiation, nine times that of hydrogen isotopes, appeared much more difficult to ignite. “Assuming the ignition problem could be overcome, Teller thought that hundreds of kilograms of Li^6D might need to be produced.”⁵ In June 1951 Edward Teller wrote a memo noting the advantages of using lithium deuteride and “the AEC agreed to begin producing lithium deuteride as a possible fuel for both the equilibrium thermonuclear and a radiation-imploded Alarm clock” device.⁶ However, the usefulness of lithium fuel was still highly speculative, and in the lead-up to the first hydrogen bomb test as Ivy Mike, lithium fuel was regarded as too complicated and was put on the back-burner:

⁴ DeGroot, 168.

⁵ Rhodes, 306

⁶ Rhodes, 476

One early and important decision concerned which thermonuclear fuel to use. Lithium deuteride was one choice. Deuterated ammonia was another. Liquid deuterium was a third. Each had its advantages and disadvantages. Lithium deuteride—LiD—would be the simplest material to engineer because it was a solid at room temperature, but breeding tritium within a bomb from lithium required a complex chain of thermonuclear reactions that involved only one of lithium's several isotopes, Li^6 . "We were very much aware of lithium deuteride," Hans Bethe comments. "We were not totally sure how well it would work."... [They] soon settled on liquid deuterium despite its engineering challenges... primarily because it would give the cleanest physics... The description of the [thermonuclear] burning process of pure deuterium is much simpler than the description of the burning process with either Li^6 or normal lithium deuteride... To avoid discussing the lithium seemed like a virtue. Every departure from the simplest picture seemed like something to avoid.⁷

Despite the secrecy surrounding nuclear development, the September 1952 issue of *Popular Science* suggested that lithium may come to be used in hydrogen bombs due to its use in producing tritium, leading to an increase in demand for lithium in coming years: "For lithium, there seems good reason to believe, may be called 'the H Bomb metal.' It is expected to play a key part in making the hydrogen bomb, the most awesome military weapon ever projected... In addition, although this is pure speculation, lithium itself might actually be put into H-Bombs." In addition to being a source for tritium, the article noted that "Fusion-type atomic reactions between hydrogen and lithium are among those that could yield enormous energy [and] the purely mechanical problem of squeezing as much hydrogen as possible into a bomb might favor using lithium hydride—a solid lithium-hydrogen compound."⁸ But the author makes it clear this is all pure speculation. However, the scientists did come around to the use of lithium fuel despite earlier objections, and "by August 1953, Los Alamos was actively preparing to test (in 1954) a lighter, lithium-deuteride-fueled successor to Mike that could be weaponized quickly for delivery by air."⁹

⁷ Rhodes, 483-484

⁸ Armagnac 111- 112

⁹ Rhodes, 525

Even though lithium was viewed as a possible component for hydrogen bombs leading up to the Castle Bravo test, it is clear that the theoretical possibility still required successful design of a bomb that wouldn't fizzle. The Soviets had a parallel research plan that also was considering Lithium Deuteride and in August 1953, the Soviets successfully tested a bomb using lithium deuteride and uranium, their first hydrogen bomb."¹⁰ Although lithium deuteride was known secretly by American scientists to be a possible contributor to a workable H bomb, it was not until the successful March 1954 Castle Bravo test which used lithium deuteride instead of deuterium that its usefulness was substantiated; "This explosion was twice as large as expected and 40 times more powerful than [the soviet bomb]."¹¹

According to Alchian's interview, the fissile materials that he suspected of being used in the hydrogen bomb at the time of Operation Castle included beryllium, thallium, thorium, and lithium. To recreate the event study, I record stock prices of publicly traded manufacturers of the possible fissile components of early two-stage thermonuclear weapons from 1953 to 1954. Using the "Minerals Yearbook Metals and Minerals (Except Fuels) 1952" from the now-defunct US Bureau of Mines, I obtain information on radioactive materials including which firms produced them. (In Tables 2 and 3 I also include producers of radioactive material other than the four Alchian specifies.) I then determined which of these were publicly traded. Of these, I tracked down their daily closing bid prices for 1953 – 1954 in the Wall Street Journal archives on ProQuest. Table 2 lists radioactive material producers, and Table 3 identifies publicly traded ones.

¹⁰ Miller

¹¹ Degroot, 192-193

Table 2: Major Producers of Radioactive Metals

| Element | Major Producers |
|----------------|---|
| Uranium | - Anaconda Copper Mining Co - Homestake Mining Co - Kerr-McGee Oil Industries, Inc - United States Vanadium Co - Canadian Radium & Uranium Corp |
| Radium | - Canadian Radium & Uranium Corp |
| Thorium | - Lindsay Chemical Co - Maywood Chemical Works - Rare Earths, Inc - Westinghouse - Metal Hydrides, Inc |
| Polonium | - Monsanto Chemical Co - Mound Laboratories |
| Plutonium | - DuPont Company |
| Beryllium | - Beryllium Corp - Beryl Ores Co. - Brush Beryllium Co |
| Bismuth | - American Smelting & Refining Co - Anaconda Copper Mining Co - US Smelting Lead Refining Inc |
| Thallium | - American Smelting & Refining Co |
| Lithium | - Lithium Corp. of America - Foote Mineral Co - American Potash & Chemical |

Source: Bureau of Mines, Minerals yearbook metals and minerals (except fuels) 1952
Year 1952, Volume I United States Government Printing Office, 1955

Of the lithium producers, Foote Mineral Co. produced only lithium carbonate up to this time (used for glasses, adhesives, and batteries) and spent 1953-1954 expanding its lithium production capacity. American Potash & Chemical was also expanding into lithium at this time, and produced such a diverse range of chemicals that the stock price response to developments in the lithium market would be diluted. As such I use Lithium Corp to represent lithium production, as Alchian did. The New York Stock Exchange-traded companies Westinghouse, Monsanto, and DuPont are all too large and diversified to expect any significant price response based solely on their radioactive metal interests. American Smelting (ASARCO) is also a large producer but is

included as the sole publicly traded producer of thallium. All companies included in the event study are listed in bold in Table 3.

Table 3: Publicly Traded Manufacturers

| Metal | Company | Exchange | Pricing Source |
|--------------|---|-----------------|--|
| Beryllium | Beryllium Corp | OTC | WSJ OTC Industrials |
| Beryllium | Brush Beryllium | NYSE* | WSJ New York Stock Exchange Transactions |
| Thallium | American Smelting & Refining Co. | NYSE** | WSJ New York Stock Exchange Transactions |
| Thorium | Westinghouse Electric Co. | NYSE | WSJ New York Stock Exchange Transactions |
| Thorium | Metal Hydrides Inc. | OTC | WSJ OTC Weekly List |
| Polonium | Monsanto Chemical Corp. | London | WSJ London Stock Averages |
| Plutonium | DuPont | NYSE | WSJ New York Stock Exchange Transactions |
| Lithium | Lithium Corp. of America | OTC | WSJ OTC Industrials |
| Lithium | Foote Mineral Co. | OTC | WSJ OTC Industrials |
| Lithium | American Potash & Chemical Co. | NYSE | WSJ New York Stock Exchange Transactions |

* After 1956 ** In DJIA 1901 – 1958

III. Market Reaction to the Castle Bravo Detonation

3.1: The Operation Castle Tests

Operation Castle was part of the effort to develop powerful weapons that were small enough to be delivered by aircraft, a drive requiring innovative bomb designs. The relatively weak bomb at Nagasaki was only 17% efficient as measured by percent of material fissioned, while the Hiroshima bomb was only 1.4% efficient, yielding about 20 and 15 kilotons each, respectively.¹² Such pure fission atomic weapons used uranium or plutonium fuel. These were followed by the development of boosted fission atomic weapons which more than doubled the energy output of pure fission weapons. These in turn were replaced by a third design, the Teller-Ulam configuration, a radical innovation that greatly increased the efficiency of nuclear weapons

¹² Introduction to Nuclear Weapon Physics and Design, Nuclear Weapon Archive

utilizing a two-stage design with a primary fission trigger that compressed a fusion fuel capsule. Commonly called a hydrogen bomb, it was first tested at Ivy Mike in November 1952, resulting in a yield of 12,000 MT and was an important step in developing small, extremely powerful nuclear weapons.

In addition to the new design, other approaches for boosting the energy output of nuclear weapons were tested. “One of the new approaches – the use of non-cryogenic “dry” (lithium deuteride) fuel – was a spectacular (and disastrous) success with a yield far exceeding expectations.”¹³ Castle Bravo was the first “dry” (solid fuel) H-bomb the US detonated, using lithium deuteride in a natural uranium tamper. It was the basis for the MK-21 bomb which went into further development beginning on March 26; by December 1955, mass production began and 275 units were built through July 1956. In late 1957 it was upgraded to the MK-36 design.¹⁴ Yet just a few years earlier, the development of the hydrogen bomb had stalled prior to the 1951 development of the Teller-Ulam design¹⁵ and no plans were made to produce lithium enriched in Li⁶. As such, “it became a race to get a large lithium enrichment plant into production” once the working hydrogen bomb design was developed.¹⁶ Due to the lack of lithium-6, some of the Operation Castle tests used partially enriched or unenriched lithium instead. The second test, Castle Romeo used lithium deuteride fusion fuel consisting of cheap and abundant unenriched lithium. It was unknown *ex ante* whether unenriched natural lithium would be effective fuel; “In fact as late as October 1953, Los Alamos was considering not even testing this device. The decision to include it was thought to be a crap-shoot to see if this cheap fusion fuel would be

¹³ Nuclear Weapon Archive - Operation Castle

¹⁴ Ibid

¹⁵ Teller-Ulam is a two-stage thermonuclear device with a fission primary charge that generates heat to compress the fusion secondary charge.

¹⁶ Nuclear weapon archive

useful.”¹⁷ Despite this concern, it produced the 4th largest nuclear detonation in US history. Romeo was a test of the MK-17 bomb which was deployed months later after the test was successful.¹⁸ Once the effectiveness of lithium dry fuel was demonstrated in the first of the Castle tests, the Castle Jughead test of cryogenic (liquid deuterium) fuel was seen as obsolete and was canceled. Four more Castle tests followed, concluding with Castle Nectar on May 14, 1954.

3.2: Lead-up to the Test

Nuclear testing was shrouded in secrecy. Bomb design and even test schedule and location were classified. The article “Wide Open Secrecy” appearing in the Wall Street Journal on June 20, 1958 discusses how some information surrounding the tests was disseminated beyond the military:

While the Atomic Energy Commission keeps secret the timing of its series of atomic blasts now going on in the Pacific, another government agency is busy broadcasting warnings to planes telling pilots to keep out of the area. The Civil Aeronautics Administration has been sending unclassified, uncoded messages to everybody who wants to listen telling pilots of specific periods of time when the test areas will be hazardous to airplanes. A spokesman for the A.E.C. condones the C.A.A. on the ground that “telling people they ought to stay out of an area is not the same as saying a test has occurred.”

The article also notes that despite the secrecy surrounding tests, the Tokyo Meteorological Board detects the shock waves that nuclear tests generate at Bikini Atoll, 2424 miles away. The article “Ally for Peace” of March 18, 1953 discusses some unknowns regarding the new hydrogen bomb first tested 4 months earlier as Ivy Mike:

Much about the new development is secret. But what is known is this: the new device uses only three-quarters as much fissionable material as the bombs that destroyed the Japanese cities; when finally it is perfected it will be small enough to be carried to its target by a jet plane, yet it is the equivalent of 15,000 tons of TNT.

¹⁷ Citation

¹⁸ Citation

Operation Castle itself was mysterious and its timing and the nature of the tests were not clear to the public. The public was only informed about upcoming tests with a cryptic and brief statement from the military:

The only prior announcement was made Jan. 8. When the Atomic Energy Commission said that “men and materials” were being transported to the proving ground “to carry out a further phase of a continuing series of weapons tests of all categories.”¹⁹

This seems to have been the extent to which the public was informed of any specific upcoming nuclear testing by the US prior to Castle Bravo.

3.3: Dissemination of Information Following the Detonation

The Castle Bravo test was detonated on Monday, March 1, 1954 at 06:45 EST (February 28, 18:45 GMT) at Bikini Atoll. It was a surface burst producing a yield of 15 MT, 150% more powerful than the 6 MT that was expected and producing a crater 2 miles wide. On March 1, 1954, the US detonated its first lithium-deuteride-fueled thermonuclear weapon called Shrimp, code-named Castle Bravo.²⁰ “The room-temperature Shrimp device used lithium enriched to 40 percent lithium-6; it weighed a relatively portable 23,500 pounds and had been designed to fit the bomb bay of a B-47 when it was weaponized. It was expected to yield about five megatons, but the group at Los Alamos that had measured lithium fusion cross sections had used a technique that missed an important fusion reaction in lithium-7, the other 60 percent of the Shrimp lithium fuel component. “They really didn’t know,” Harold Agnew explains, “that with lithium-7 there was an n, 2n reaction [i.e., one neutron entering a lithium nucleus knocked two neutrons out]. They missed it entirely. That’s why Shrimp went like gangbusters.” Bravo exploded with a yield of fifteen megatons, the largest-yield thermonuclear device the US ever tested. “When the two neutrons come out,” says Agnew, “then you have lithium-6 and it went like regular lithium-6.

¹⁹ NYT March 2, 1954

²⁰ Rhodes, 542

Shrimp was so much bigger than it was supposed to be because we were wrong about the cross section.”²¹

The test is also one of the worst radiological disasters in U.S. history. The unexpectedly large yield combined with unfavorable weather patterns resulted in contamination of several inhabited islands including one where U.S. servicemen were stationed; evacuations were conducted only after victims received significant exposure to radiation. U.S. Navy ships and at least one Japanese fishing vessel were also dusted with fallout.²² “The US offered radiation specialists to treat the fishermen but refused to reveal fallout content for fear the Soviets would learn that the Shrimp had been fueled with lithium deuteride.”²³ The next day, the New York Times reported on a statement from the Atomic Energy Commission which the paper noted was not clear on whether an atomic or hydrogen weapon had been tested:

“Joint Task Force Seven has detonated an atomic device at the A.E.C.’s Pacific proving ground in the Marshall Islands. This detonation was the first in a series of tests.” The language of Admiral Strauss’ statement did not make clear whether the “atomic device” was of the fission or thermonuclear (hydrogen) type. There have been unofficial indications, however, that a variety of hydrogen weapons or devices will be tested during the next several weeks. The most powerful of these is expected to be an actual hydrogen bomb with perhaps twice the explosive power of the experimental device that disintegrated an island of Eniwetok Atoll on Nov. 1, 1952.

On March 7 and again on March 11 it was reported that a hydrogen bomb test was imminent. On March 12 it was announced that recent testing had resulted in radiation exposure to US servicemen and island natives. Not until March 14 was it reported that the test conducted in early March was a hydrogen bomb. Following the great success of the lithium fissile fuel in Bravo, “the Castle tests continued with tests of an unenriched lithium-deuteride device... “The results of Operation Castle,” Raemer Schreiber writes, “left me with the unpleasant job of

²¹ Rhodes, 542.

²² Nuclear Weapon Archive

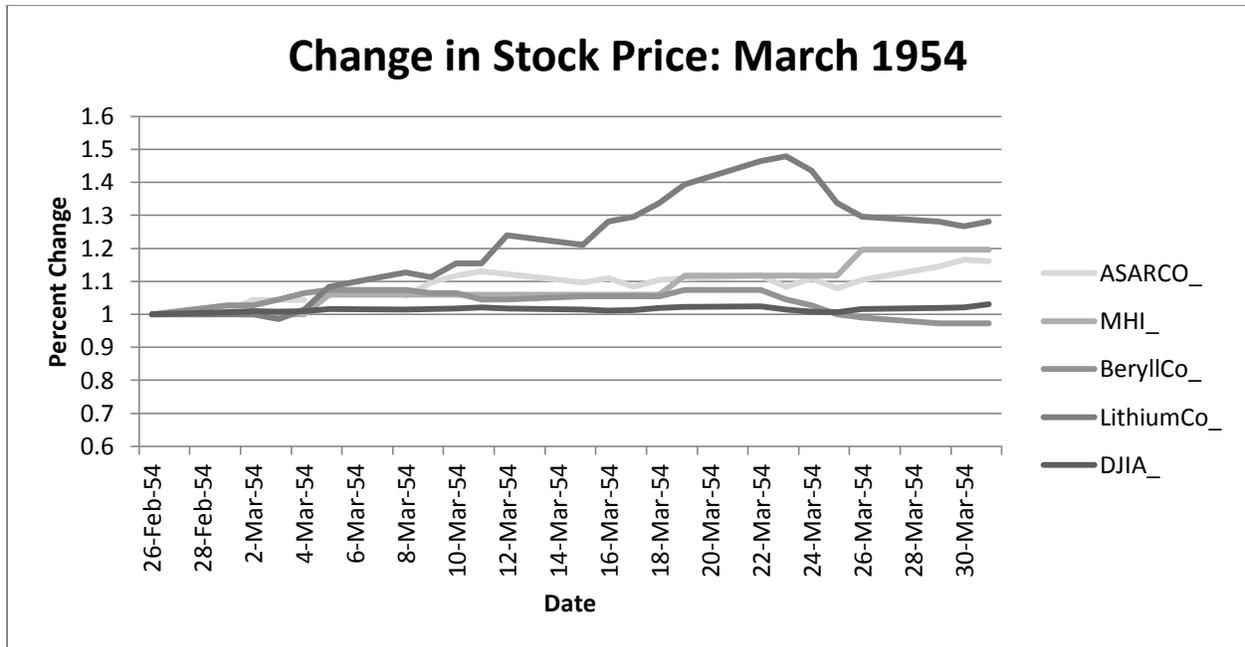
²³ Rhodes, 542

negotiating the closeout of a sizeable cryogenic hardware contract.”” Future US thermonuclear weapons would be fueled with lithium deuteride.”²⁴

3.4: Price Reaction

The pre-event period saw a run-up on the price of Lithium Corp that was not seen by the other stocks. The January preceding Castle Bravo, the price of Lithium Corp. began rising following a year where the stock didn't see much change in price. On January 2, 1953 it was priced at \$5.25 and ended the year at \$5.125 on December 31, 1953, having hit a low of \$3.50 in mid-September. Yet in the 2 months leading up to Castle Bravo, Lithium Corp. of America rose from \$5.125 on December 31, 1953 to \$8.875 on February 26, 1954. Castle Bravo was detonated on March 1. While there was no immediate price reaction to the successful test, within a week it was up 12.7% to \$10.00. Within three weeks it was up over 48% to \$13.125 on March 23 before settling down to \$11.375 on March 31 for a monthly return of 28%. By comparison the Dow Jones Industrial Average (DJIA) had only risen 2.3% in March. ASARCO and Metal Hydrides (MHI) both saw very high growth relative to both the Dow and to their own prior 3 month averages, but rose much less than Lithium Corp. Only in the case of Lithium Corp did the price rise seen in March represent the continuation of high returns in previous months.

²⁴ Rhodes, 542 – 543



Castle Bravo detonated on March 1. February 26 is last trading day prior.

March 1954 Stock Returns Following March 1 Castle Bravo Test

| | Lithium Co | Beryllium Co | ASARCO | MHI | DJIA |
|--|------------|--------------|--------|-------|------|
| March 1954 Return | .282 | -.054 | .147 | .196 | .023 |
| Prior 3 Month Average Return | .170 | .023 | .007 | -.048 | .016 |
| March 1954 St. Dev | 1.37 | .93 | 1.24 | .83 | 1.98 |
| Prior 3 Month's Average St. Dev | .54 | .57 | .75 | .42 | 2.42 |

By the end of the year, December 30, 1954, Lithium Corp was at \$28.75, a 224% return over the February 26 price, greatly exceeding the returns of the other companies as well as of the Dow, yet they all saw tremendous 10-month returns. Between the four companies, Beryllium Co. did the worst with only a 49% return by the end of 1954. From the beginning of January, Lithium Corp saw a return of 461% vs. 61% - 64% for the other 3 companies and 43% for the Dow.

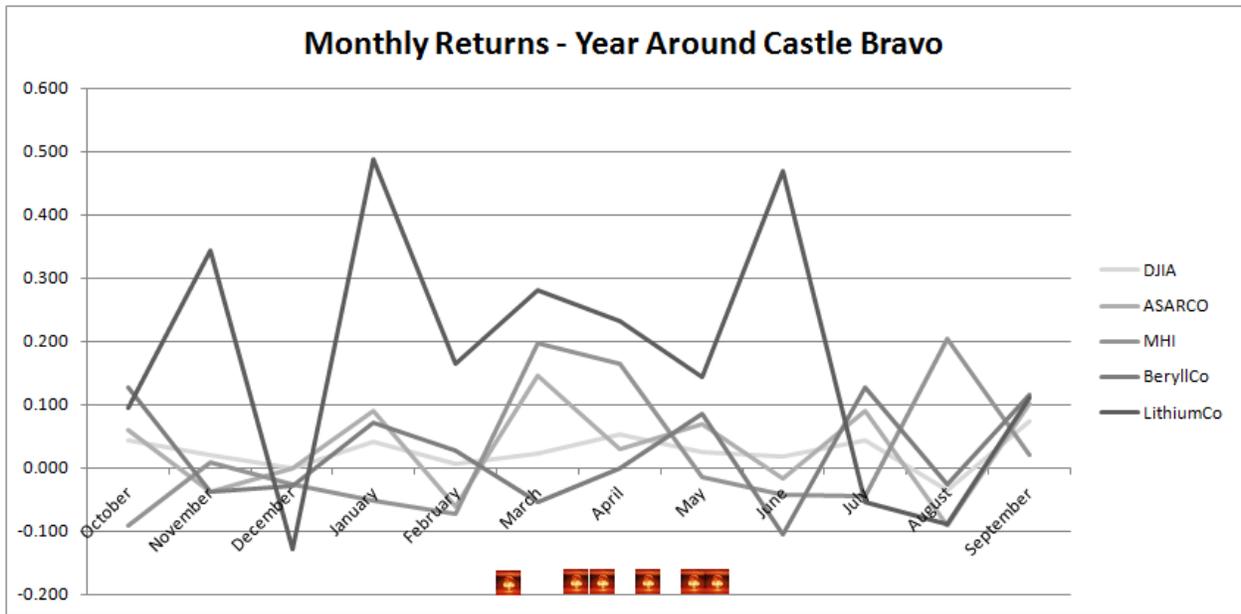


Table 4: Returns: Feb 26 – Dec 30, 1954

| | Lithium Co | Beryll Co | ASARCO | MHI | DJIA |
|---------------------|------------|-----------|--------|-------|--------|
| Feb 26 Price | 8.875 | 27.25 | 28.625 | 12.75 | 294.54 |
| Dec 30 Price | 28.75 | 40.5 | 45 | 23.5 | 401.97 |
| Return | 224% | 49% | 57% | 84% | 36% |

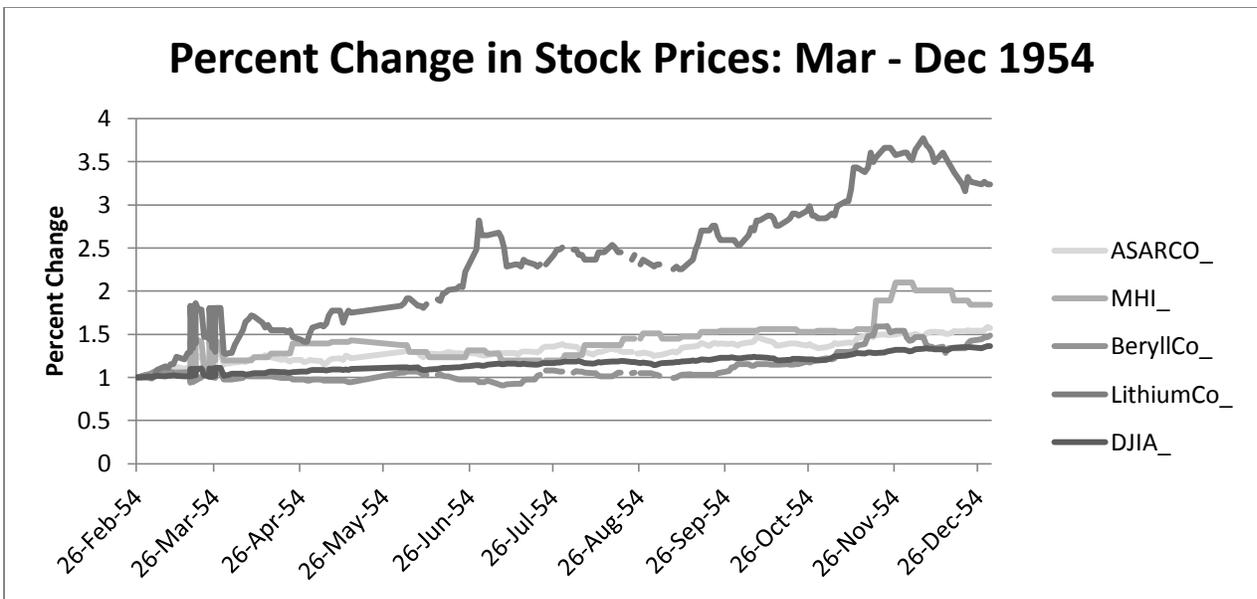
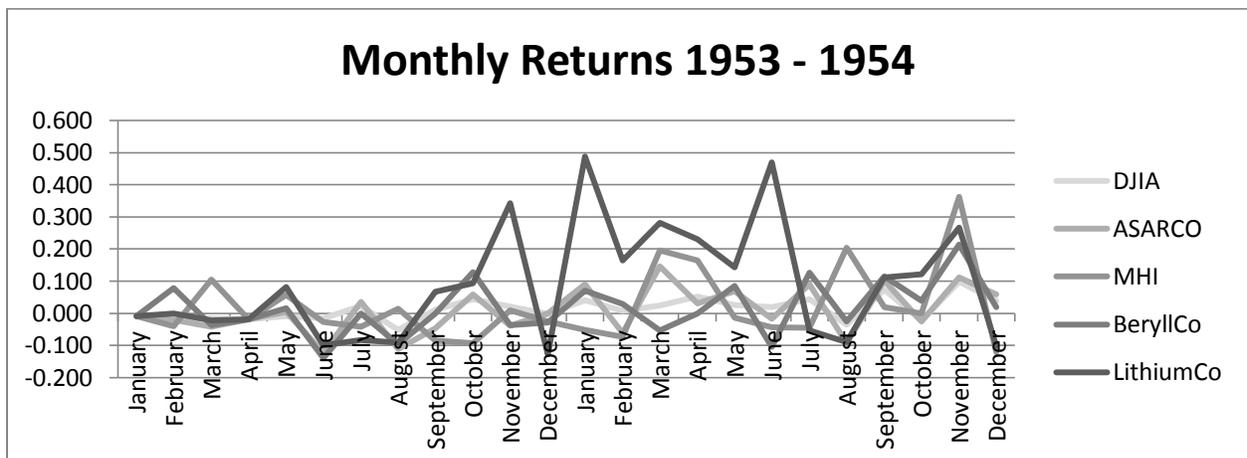
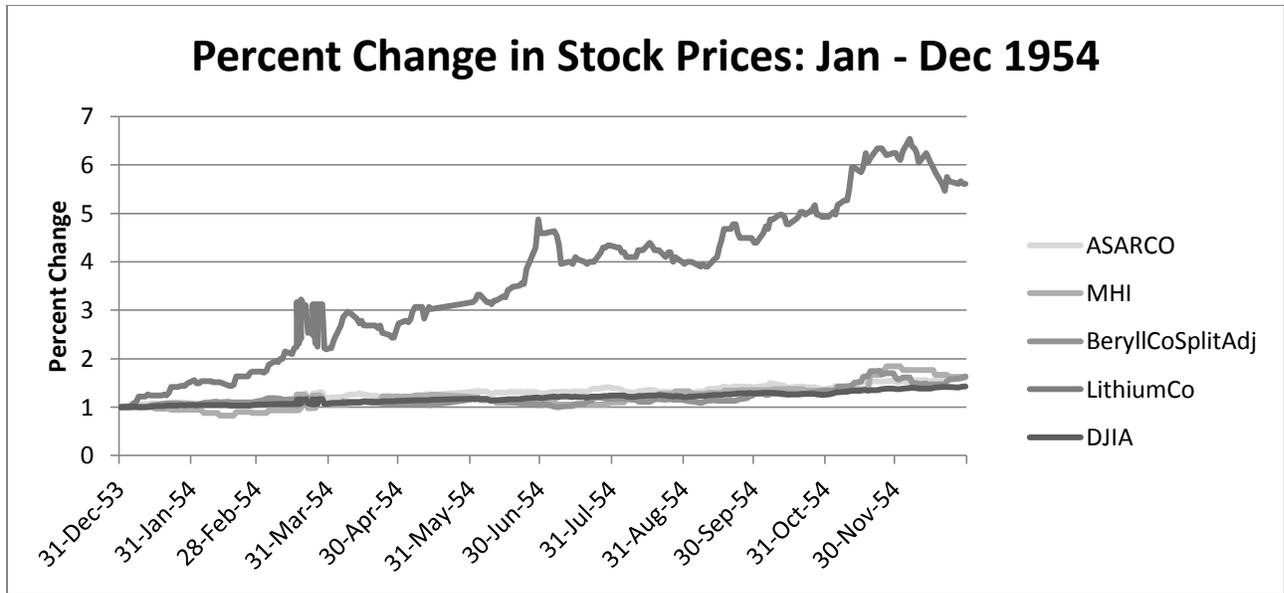


Table 5: Returns: Jan – Dec 1954

| | Lithium Co | Beryll Co | ASARCO | MHI | DJIA |
|------------------------|------------|-----------|--------|------|--------|
| Dec 31 53 Price | 5.125 | 24.75 | 28 | 14.5 | 280.90 |
| Dec 30 54 Price | 28.75 | 40.5 | 45 | 23.5 | 401.97 |
| Return | 461% | 64% | 61% | 62% | 43% |



3.5: Spot Prices

The 1954 Minerals Yearbook on Lithium specifically notes that lithium prices were not regularly quoted at the time.²⁵ However, annual prices collected by the Geological Survey reveal that the price and production went up from 1953 to 1954, but that the 1954 price was below the 1952 real price. This suggests that the increased valuation of Lithium Corp was not driven solely by a sudden increased spot price in lithium.

²⁵ Bureau of Mines / *Minerals yearbook metals and minerals (except fuels) 1954* Year 1954, Volume I (1958)

Table 6: Spot Price of Lithium 1950 – 1955

| Year | US Production | World Production | Value (\$/t) |
|------|---------------|------------------|--------------|
| 1950 | 347 | 18,000 | NA |
| 1951 | 444 | 25,200 | NA |
| 1952 | 505 | 25,500 | 2,380 |
| 1953 | 821 | 57,800 | 1,870 |
| 1954 | 1,140 | 93,200 | 2,200 |
| 1955 | 1,250 | 86,000 | 2,130 |

Source: *Lithium Statistics, U.S. Geological Survey*²⁶. Production is in metric tons.

IV. Generalizations

Market efficiency “gauges the extent to which stock prices quickly and accurately respond to new information.”²⁷ How secret was Operation Castle in its timing and the nature of the tests, including its role in developing the MK21 and MK17 weapons, and how quickly and by what means was this private information disseminated to the public? The large, sudden increase in price and volatility seen in Lithium Corp stock beginning in January 1954 indicates new, positive information being absorbed into the price discovery process that singled out Lithium Corp. among metal producers as suddenly warranting a higher valuation.

The government statements concerning the tests that occurred as part of Operation Castle were vague, neither revealing the exact dates nor the nature of the tests. The first reports following the test stated that it was not clear whether the tests were atomic or hydrogen bombs. Even to those who understood the importance of lithium in new hydrogen bombs, the success of Castle Bravo could not be interpreted positively for the lithium market without first ascertaining if the test was of an atomic or hydrogen bomb. Indeed the price of Lithium Corp. remained flat for several days after the test. To the extent that subsequent price movements were in response to Castle Bravo, this slow reaction reveals a gradual spread of information regarding its implications for profitability of lithium producers. The lead-up to the test also shows significant

²⁶ <http://minerals.usgs.gov/ds/2005/140/ds140-lithi.pdf>

²⁷ Maloney & Mulherin (2003)

gains in Lithium Corp, consistent with the possible leakage of insider information. Since Castle Bravo also represented a test of what was to become the MK21 bomb which was built and deployed thereafter, this knowledge would have made investments in lithium producers seem highly lucrative following the successful test.

For the public, how well-understood was the importance of lithium in the development of hydrogen bombs? The bidding up of the price of Lithium Corp in response to the Castle Bravo test relies on bidders not only being aware that the test was of a hydrogen rather than an atomic bomb, but that lithium deuteride was being used in the hydrogen bombs to increase their destructive power. Three stories appearing in the Wall Street Journal in 1953 to 1954 mention lithium with regard to atomic weapons. On January 28, 1954, the story “Firms Flock to Adapt Bomb-Making Research to Scores of Civil Uses” noted that lithium is used in newly-developed hydrogen. The March 9, 1954 story “Abreast of the Market” notes that lithium is used in atomic weapons. The December 30, 1954 story “A Special Background Report on Trends in Industry and Finance” also notes that hydrogen bombs use lithium. However, the fissile fuel used in atomic weapons, including hydrogen bombs, differed from test to test. Even Alchian who worked at RAND didn’t know which fuel was used in Castle Bravo, and the engineers refused to tell him. This suggests that nobody outside of a small circle of scientists knew that Castle Bravo was the first test of a hydrogen bomb using dry fuel in the form of lithium deuteride, and in any case its effects were only speculative before the test. Up to that point, lithium had been used only as a booster in a couple tests following Ivy Mike. It was in these tests that the importance of lithium in the construction of hydrogen bombs was discovered as it increased the destructive power of the bombs. Yet as late as Castle Romeo, there were doubts as to how useful lithium would be in hydrogen bomb construction.

The tests were announced by the military beforehand and reported on by major newspapers afterwards, but the exact dates were not known by the public ahead of time, nor did they know the internal bomb components, nor what was specifically being tested by the military, whether energy output, effects of radioactive fallout, or nuclear war-fighting strategy, or posturing to the Soviets, or some combination of intentions. Nor could they have known that Castle Bravo was in fact a test of the MK21 bomb prototype that was to be mass produced and deployed within the next 18 months as the US military's first deliverable hydrogen weapon pending the successful test. As news stories following the test reveal, information surrounding Castle Bravo was disseminated slowly, and some remained classified throughout the Cold War.

While Romer (1993) notes that “outside observers very often cannot identify any news that could plausibly have been the source of observed changes in stock prices,” this is expected in a market involving secret military weapons testing. Dow and Gorton (1993) argue that price responses to information may not be quick, with a resulting pattern of price discovery that is not obviously related to any specific news. To the extent that the stock price of Lithium Corp was responding to Operation Castle, some of the price movement must have emanated from what was once private information including the use of lithium fuel, the yield boost it generated, and the consequent mass production and deployment of lithium fuel hydrogen bombs, but such price responses need not have occurred on any specific day since the dissemination of this private information is expected to be gradual given its classified nature. In addition to hydrogen bomb manufacturing, lithium was used in a variety of products including ceramics, greases, glass, and batteries, and it is expected that the price of Lithium Corp. would respond to information regarding these products as well. Many of the news stories cover the expansion of lithium interests by major lithium producers. Of the 22 Wall Street Journal articles found that mention

lithium between 1953 – 1954, 11 are primarily on the expansion of lithium mines, the upfront costs these investments entail and thus the declines in earnings, even though they are expected to increase future profits as demand for lithium continues to increase. On April 23, 1954, Foote Mineral Co. announces that a large portion of first quarter sales were of lithium and that the company is well-positioned to supply lithium to the US government if it demanded it. On June 10, 1954, it is reported that a Senate committee votes to increase the depletion rate of lithium mines for tax purposes. On August 31, 1954, the Wall Street Journal reported earnings for Lithium Corp. of America for the 6 month period ending June 30. A net income (after federal taxes) of \$152,287 for 1954 was reported versus a 1953 net income of \$77,980, an increase of 95%.²⁸ It was clear in the press at the time that the market for lithium was doing well and that it was expected to continue growing due to both commercial and military uses of lithium.

5. Conclusion

This event study confirms Armen A. Alchian's report of the event study he conducted at RAND, revealing that he successfully determined the fissile fuel that started being used in hydrogen bombs at that time, contributing to his reputation among the scientists and engineers who developed them. He accomplished this 15 years before what Fama referred to as the original event study, conducted by Fama, Fisher, Jensen, and Roll in 1969 in a study that analyzed stock splits (Fama, 1991). The price responses of mineral producers seen before and after Operation Castle provide evidence in support of market efficiency through the dissemination of formerly private information into the public sphere. Whereas previous research by Maloney & Mitchell (1989) and Maloney & Mulherin (2002) demonstrates the ability of the stock market to place blame, Alchian's event study shows that it incorporates positive news just as well, including secret or unknown information, in contrast to DeLong et al. (1990) where "irrational" noise

²⁸ WSJ Aug 31, 1954

traders with “erroneous” beliefs drive rational traders out of the market and push stock prices away from fundamental values. Following the Operation Castle series of nuclear tests, it would have been apparent to insiders that the use of lithium fissile fuel in hydrogen bombs was a tremendous innovation that boosted the energy output of smaller weapons, and that whoever manufactured the components of what was to become the MK21 bomb stood to profit from the test’s success. There is some evidence that the Lithium Corp stock price reflected this positive implication for the lithium market due to the Castle Bravo test, information that was not immediately known to the public. Lithium Corp stock increased greatly in the two months preceding the test and then exploded for the remainder of 1954 with a return of 461% for the year.

Alchian’s event study also implies that through capital markets, inferences can be made about military secrets in countries that outsource military technology research and development to the private sector, and outsiders may be able to make such inferences about US military technology as well. Much as prediction markets can help predict political events (Wolfers and Zitzewitz, 2004), careful analysis of foreign stock exchanges may reveal secret government activities that affects the profitability of publicly traded firms.

Works Cited

- Alchian, Armen A. *The Intellectual Portrait Series: A Conversation with Armen A. Alchian* (Indianapolis: Liberty Fund, 2000)
- Alchian, Armen A. "Principles of Professional Advancement," *The Collected Works of Armen A. Alchian*, ed. Daniel K. Benjamin (Indianapolis: Liberty Fund, 2006)
- Alchian, Armen A. "Uncertainty, Evolution, and Economic Theory," *The Collected Works of Armen A. Alchian*, ed. Daniel K. Benjamin (Indianapolis: Liberty Fund, 2006)
- Armagnac, Alden P. "Lithium: The H-Bomb Metal" *Popular Science*, September 1952
- DeGroot, Gerard L. *The Bomb: A Life* (Cambridge: Harvard University Press, 2005)
- DeLong, Brad, Andrei Shleifer, Lawrence H. Summers and Robert J. Waldmann, "Noise Trader Risk in Financial Markets," *Journal of Political Economy* Vol. 98, No. 4 (Aug., 1990), pp. 703-738
- Dow, James and Gary Gorton, "Trading, Communication, and the Response of Asset Prices to News," *The Economic Journal*, Vol. 103, No. 418 (May, 1993), pp. 639-646
- Fama, Eugene. "Efficient Capital Markets: A Review of Theory and Empirical Work," *The Journal of Finance* Vol. 25, No. 2, Papers and Proceedings of the Twenty-Eighth Annual Meeting of the American Finance Association New York, N.Y. December, 28-30, 1969 (May, 1970), pp. 383-417
- Fama, Eugene. "Efficient Capital Markets: II," *The Journal of Finance*, Vol. 46, No. 5 (Dec. 1991), pp. 1575-1617
- Fama, Eugene, Lawrence Fisher, Michael C. Jensen, and Richard Roll, "The Adjustment of Stock Prices to New Information," *International Economic Review* 10 (1969), pp. 1-21

French, Kenneth R. and Richard Roll, “Stock Return Variances: The Arrival of Information and the Reaction of Traders,” *Journal of Financial Economics* 17 (1986) pp. 5-26

Maloney, Michael T. & J. Harold Mulherin, “The Complexity of Price Discovery in an Efficient Market: The Stock market Reaction to the Challenger Crash.” *Journal of Corporate Finance* 9 (2003) 453 – 479

Maloney, Michael T. & Mark Mitchell. “Crisis in the Cockpit? The Role of Market Forces in Promoting Air Travel Safety.” *Journal of Law and Economics* Vol. 32, No. 2 (Oct. 1989), pp 329 – 355

Miller, Richard L. *Under the Cloud: The Decades of Nuclear Testing*. (The Free Press, 1986)

Mitchell and Mulherin. “The Impact of Public Information on the Stock Market.” *The Journal of Finance* Vol. 49, No. 3, Papers and Proceedings Fifty-Fourth Annual Meeting of the American Finance Association, Boston, Massachusetts, January 3-5, 1994 (Jul., 1994), pp. 923-950

New York Times, various articles

Nuclear Weapon Archive. NuclearWeaponarchive.org

Rhodes, Richard. *Dark Sun: The Making of the Hydrogen Bomb* (New York; Simon & Schuster, 1996)

Romer, David. “Rational Asset-Price Movements without News,” *American Economic Review*, Vol. 83, No. 5 (Dec. 1993), pp. 1112-1130

Wall Street Journal, various articles

Wolfers, Justin and Eric Zitzwitz, “Prediction Markets,” *Journal of Economic Perspectives*, American Economic Association, vol. 18(2), pages 107-126, Spring.