BOEING

Engineering, Operations & Technology
Environment, Health & Safety

Sodium Reactor Experiment
Facts about the SRE Accident

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October 29, 2014
November 13, 2021 (Revised to correct some obsolete URL links)

Sodium Reactor Experiment (1956)

Sodium Reactor Experiment (1958)

Myths about the SRE Accident

- The SRE accident has been used by many as the spearhead for activist attention toward SSFL
- Many myths have been promulgated to perpetuate this attention
  - Nuclear research at SSFL was conducted in “secret.” Local residents had no knowledge of the nuclear reactors at SSFL
  - Information about the SRE accident was kept secret for 20 years until Dan Hirsch “exposed the facts”
  - Worst “nuclear meltdown” in US history
  - Released 400 times more radioactivity than Three Mile Island
  - Caused widespread radioactive contamination of the environment
  - Resulted in health impacts to the community
  - Two other “meltdowns” occurred at SSFL
- The following discussion will hopefully dispel these myths

SRE History

Why Was the SRE Built ?

- Development of the “next generation” commercial nuclear power plant to supersede boiling water reactors (BWRs) and pressurized water reactors (PWRs)
- Enhanced thermal efficiency and safety of low pressure sodium coolant (~50 psi) over high pressure water (1,000 - 2,000 psi)
- Precursor to sodium cooled U.S. reactor designs of the 1970s and 1980s
- Commercial sodium cooled reactors were subsequently built in France, Japan, UK and Russia

Construction & Operational Schedule

• Design began	June 1954
• Construction began	April 1955
• Construction completed	February 1957
• First critical	April 1957
• Full Power	May 1958
• Core damage accident	July 1959
• Restarted	September 1960
• Shutdown	February 1964
• Decommissioned	1978 - 1984
• Demolished	1999

Nuclear Research at SSFL was Widely Publicized in the Media

- TV - Ed Murrow Show - Nuclear Power for Moorpark - November 12, 1957 - Televised November 24, 1957
- KCOP-TV - “Science Lab” - Schoolgirl toured the Canoga Facility and SSFL - Shown the SRE and Hot Lab - 1958
- Numerous teacher and student tours of SSFL in the 1960s
- Weekly NAA “SkyWriter” newspaper covered all nuclear programs including SRE
  - Employees were free to take home, and share friends and neighbors

SRE Televised on Ed Murrow "See It Now" Show – November 24, 1957

SEE IT NOW—Cameraman Leo Rossi films demonstration of atomically-generated arc used in SRE dedication for showing on Edward R. Murrow "See It Now" TV program next Sunday on Channel 2. AI Cameraman Hal Williams, second from right, also films demonstratio park, in Simi Valley, will be included Town was cut off normal "juice" by Edi

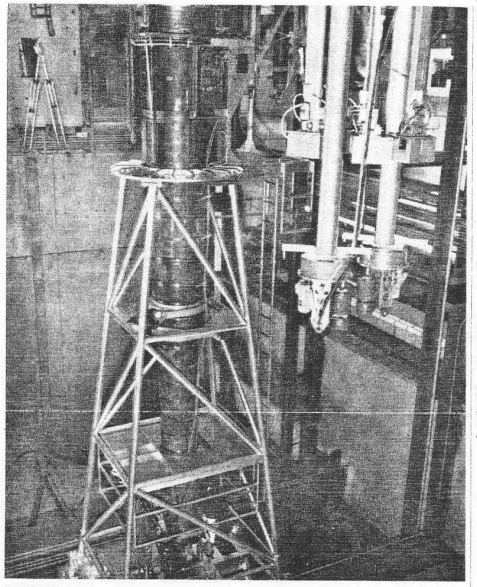
TV Show Sunday to Include Shots Filmed at SRE

Filmed scenes of Atomics International's Sodium Reactor Experiment (SRE)—including shots of the reactor control room, the reactor building and the top of the reactor core—are scheduled for showing on the Edward R. Murrow television program, "See It Now", this Sunday at 5 p.m. on Channel 2.

Columbia Broadcasting System cameramen made the film for Murrow's show, which will feature atomic energy projects in the United States and abroad. An interview with Lewis L. Strauss, chairman of the Atomic Energy Commission, was filmed for the program.

Moorpark Lighting

Also planned for the show were scenes of the lighting of the Simi Valley town of Moorpark. On Tuesday evening last week the "See It Now" camera crew pointed their lenses at the community of 1146 people as Southern California Edison Co. engineers "blacked out" the town for about 20 seconds. A switch was then closed and about 1000 kw. of electricity generated by Edison from heat produced in the SRE lighted Moorpark homes a d industries.



BIRD'S EYE VIEW—CBS Director Arthur Morse, left, chose fuel handling cask as vantage point for cameras to film SRE for "See It Now" TV show, which is to be telecast next Sunday.

Classified Ads

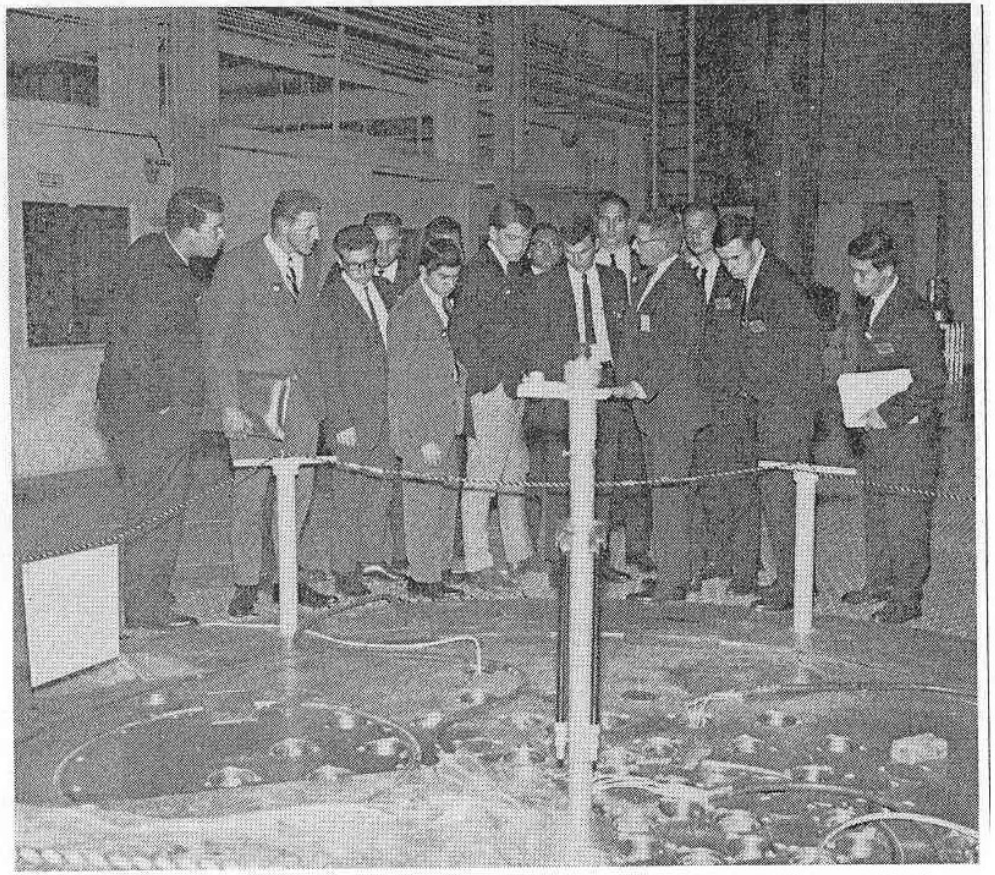
North American's current ... said, has a greater technical ...

Junior High Girl Tours SRE - Shown on Channel 13 TV Science Show - May, 1958

TV SCIENCE—Richard P. Johnson, AI, explains Lab Reactor to Doreen Melendy, top science student at Eliot Jr. High, Altadena, and Al Renner, Eliot science teacher, during filming for TV show to be seen May 22 at 4:30 p.m. on Channel 13.

Students Tour SRE – December, 1965

Page Two
DECEMBER 29, 1965



SRE TOUR — Business students from Fresno State College are briefed on operation of Sodium Reactor Experiment by Dutch Sturtevant, of Atomics International, on Santa Su tour.

Fresno College Students Tour Division Facilities

Fifteen students from Fresno State College toured AI's Santa Susana facilities last week and were briefed on the division's SNAP nuclear reactor and central station power accomplishments.

The students were all members of Alpha Kappa Psi, a business fraternity.

Roger D. Moeller, director of Special Programs at AI, spoke to the group on the role of government in nuclear energy, private investment needed to enter the atomic power field, and the early history and present state of the industry.

Afterward, the students departed for Santa Susana to tour the Sodium Reactor Experiment and the Sodium Components Test Installation.

SRE Design

SRE Engineering Design

• Fuel	2.7% enriched uranium metal
• Fuel cladding	Stainless Steel
• Moderator	Graphite
• Primary coolant	Sodium
• Secondary coolant	Sodium
• Electrical plant	Steam powered turbine
• Design Power level	20 megawatts (thermal)
• Electrical power generated	37 million kilowatt-hrs
• Operated	27,000 hours

SRE Layout

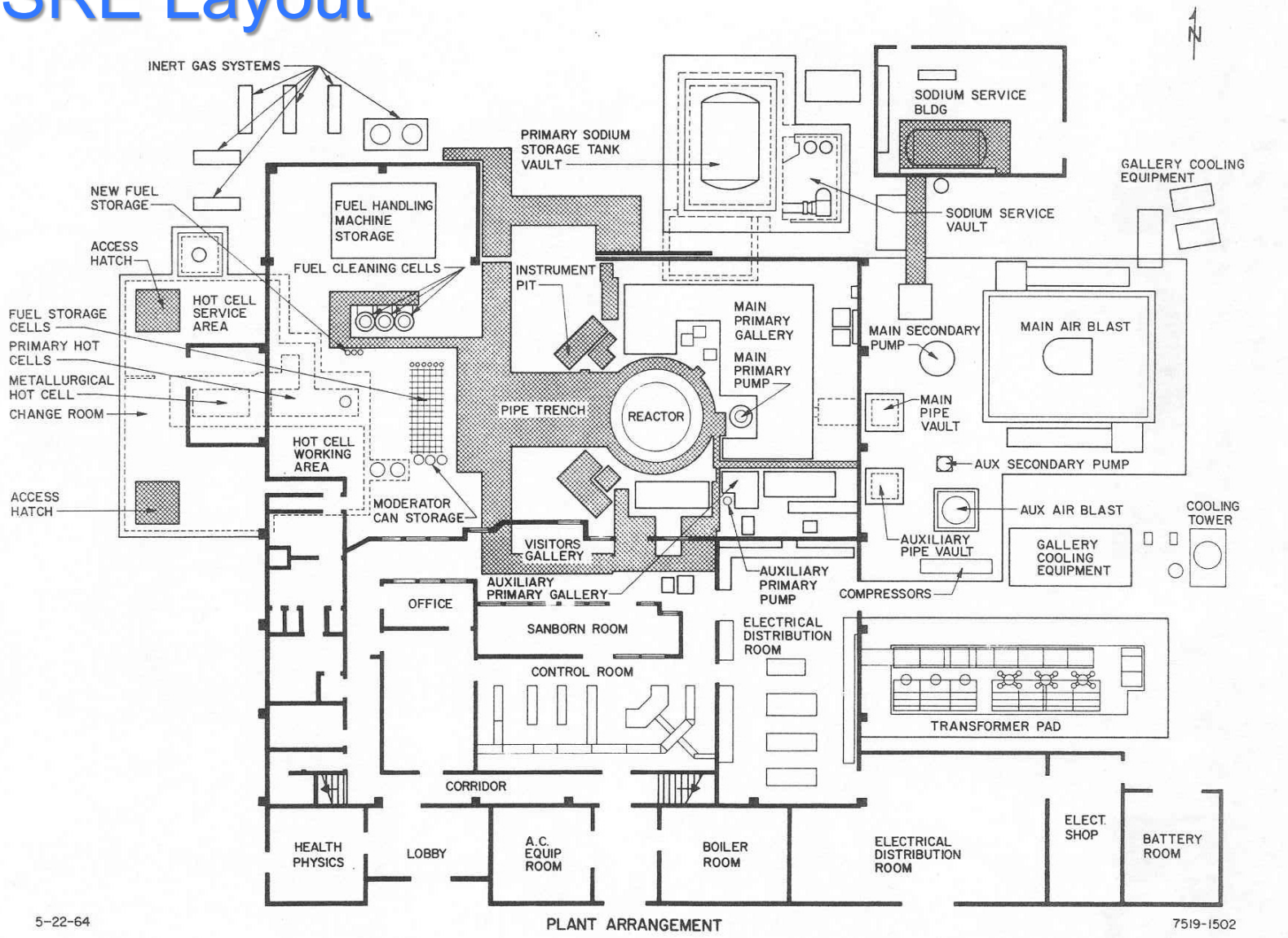


Figure 3. Building Layout

SRE Cutaway

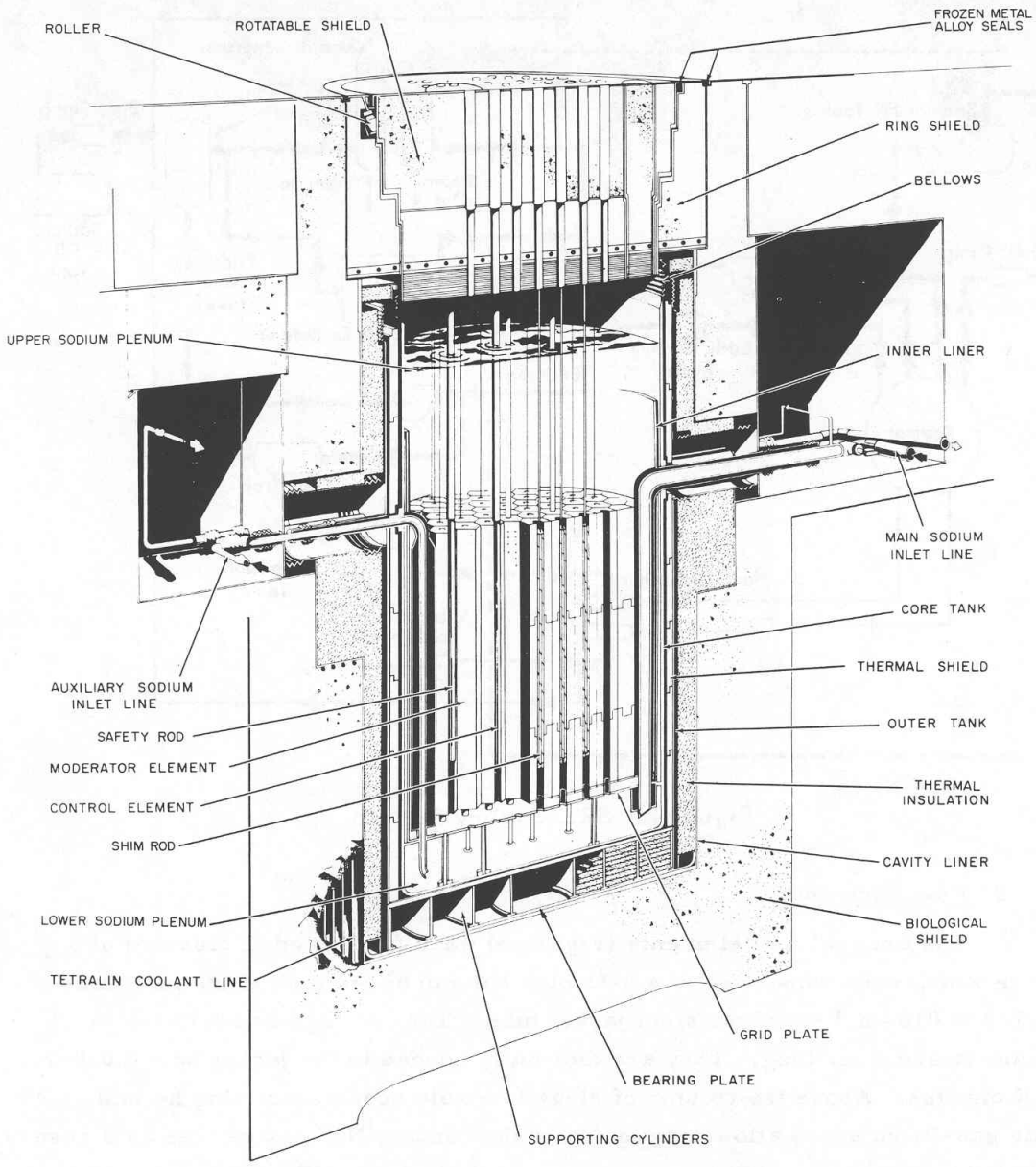
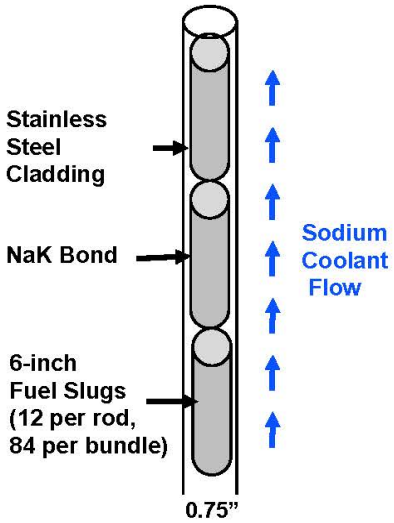
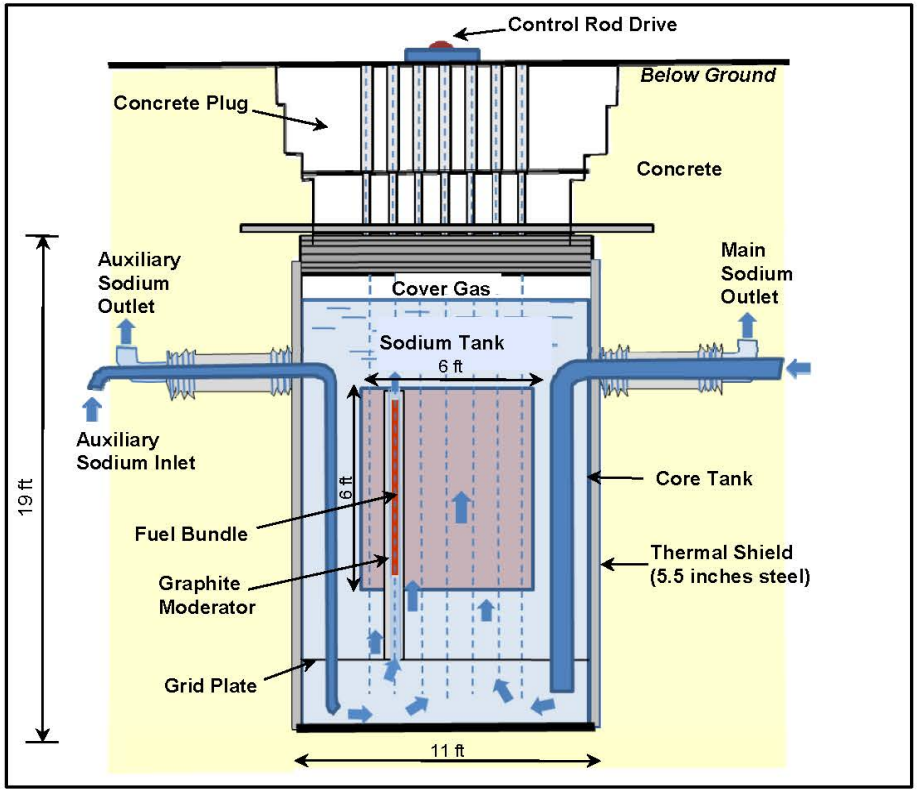


Figure 1. Cutaway View of SRE Reactor

SRE Fuel Bundle Cooling





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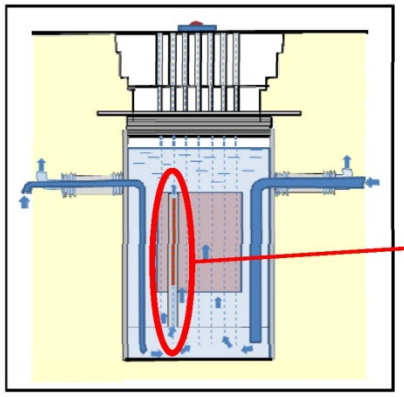
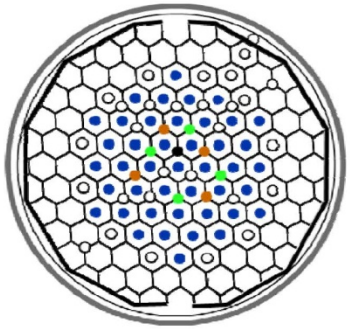
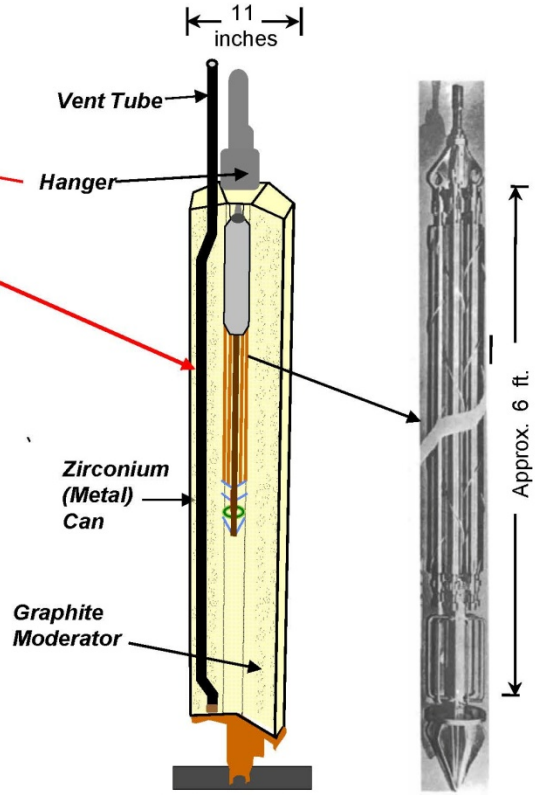
SRE Fuel Bundle and Moderator Can





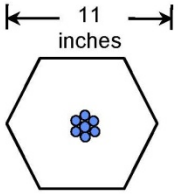
- Other Nonfuel Tubes
- Control Rod
- Safety Rod
- Fuel Bundle
- Neutron Source

Hexagonal Moderator Cans Containing Fuel Bundles (Top View)



Moderator Can Assembly

Fuel Bundle



Cross-section of moderator can containing fuel bundle comprised of 7 fuel rods

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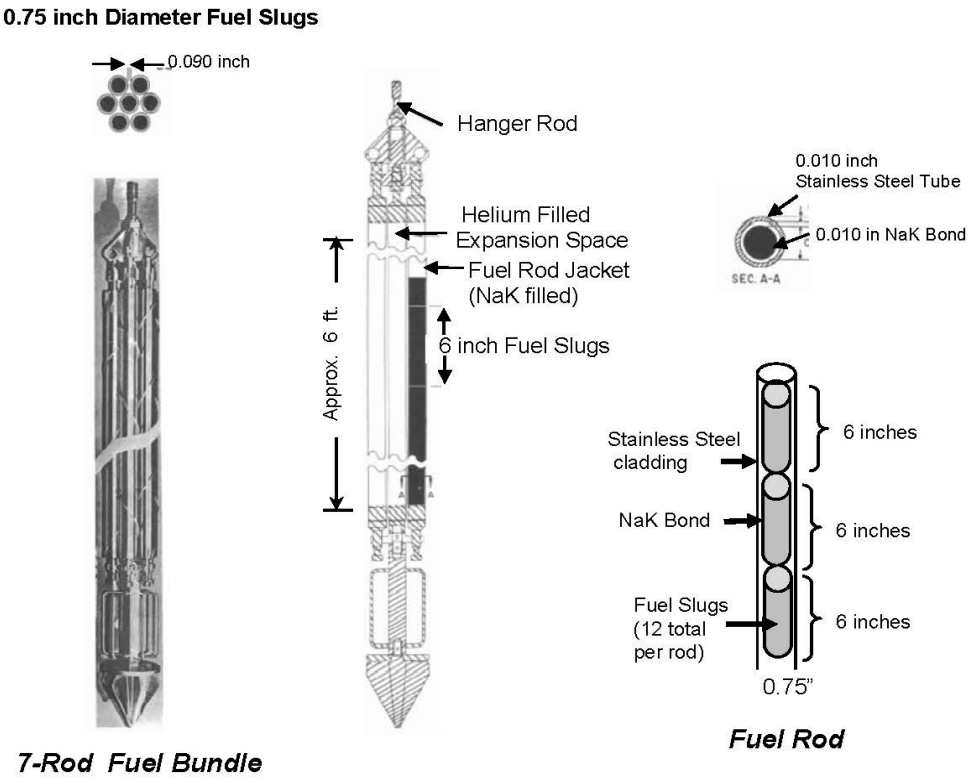
10

SRE Fuel Bundle

- **Uranium metal fuel**
- **2.7% U-235 enrichment (natural uranium is 0.7% U-235)**
- **Fuel slugs are 0.75 inch diameter and 6 inches in length**
- **Clad in stainless steel tubes**
- **Sodium-potassium (NaK) bonding between fuel and cladding**
- **Wire wrap around fuel bundles**



7-Rod Fuel Bundle

Fuel Rod

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11

SRE Accident

Cause of SRE Accident - July 1959

- Pump bearing coolant leaked into primary sodium coolant
- Some coolant flow channels became blocked and overheated
- Central portion of13 of 43 fuel assemblies were damaged
- Majority of the uranium fuel remained solid
- Pressure vessel remained intact
- Fuel continued to be immersed and cooled by sodium coolant
- Some contamination of building interior occurred due to leaks in vessel penetrations
- Fuel was removed and shipped offsite
- A new core and original sodium coolant was loaded and the reactor continued operation from 1960 until 1964

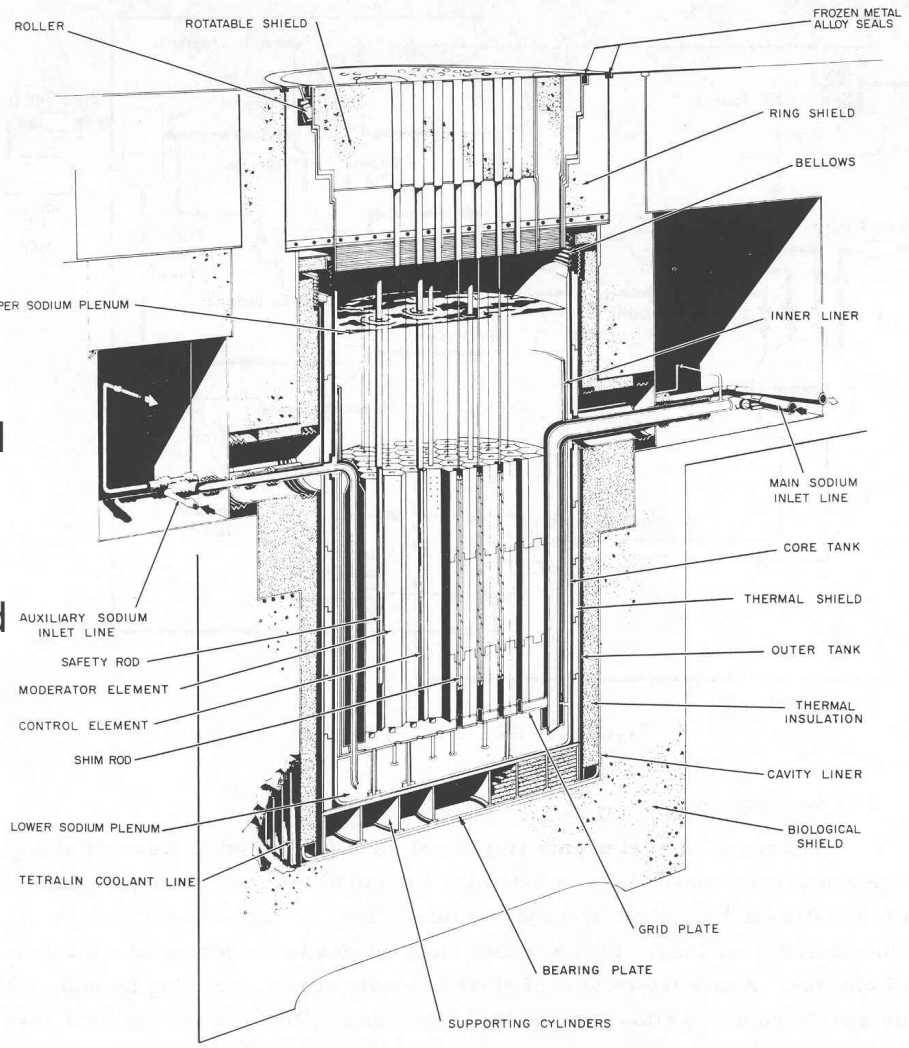

Figure 1. Cutaway View of SRE Reactor

SRE Damaged Fuel Description

- 13 out of 43 total fuel bundles damaged
- Damaged fuel bundles showed evidence of local melting and cladding failure
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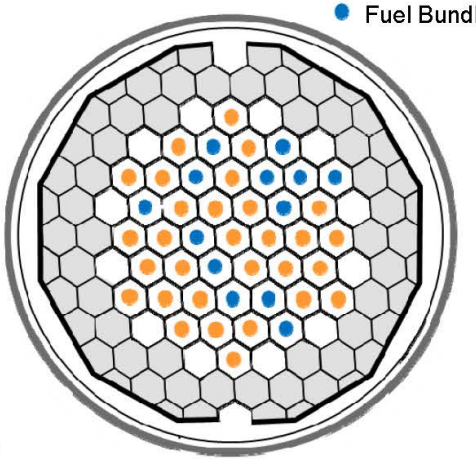
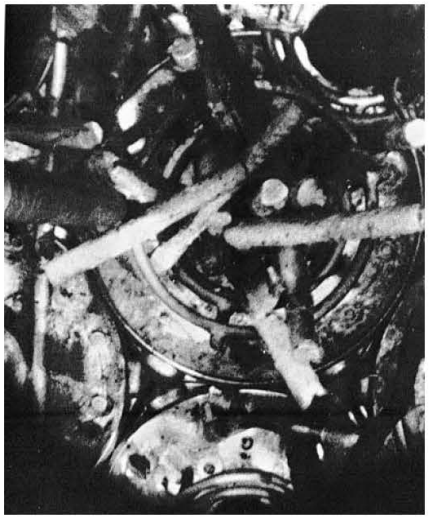
- Most fuel slugs were still intact (i.e., had not melted)



Bottom section of damaged fuel bundle

Mid-section of damaged fuel bundle



Intact fuel slugs on top of core during damaged fuel bundle removal

Mechanisms

- Fuel/cladding melting
- Thermal cycling, cladding failure

23

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What Happened During the SRE Accident?

Majority of uranium metal fuel did not melt

- Temperatures did not reach the melting point of uranium metal (2,075 ^{O}F) or steel cladding (2,750 ^{O}F)
- Limited melting of an iron-uranium eutectic (alloy) involving ~1% of the uranium fuel occurred at 1,337 ^{O}F

Majority of iodine-131 stayed in fuel as solid; no elemental vapor released

- Approx. 1% was released from the fuel into the sodium coolant
- Formed sodium iodide (a solid) and remained in the coolant

Majority of cesium-137 remained in fuel

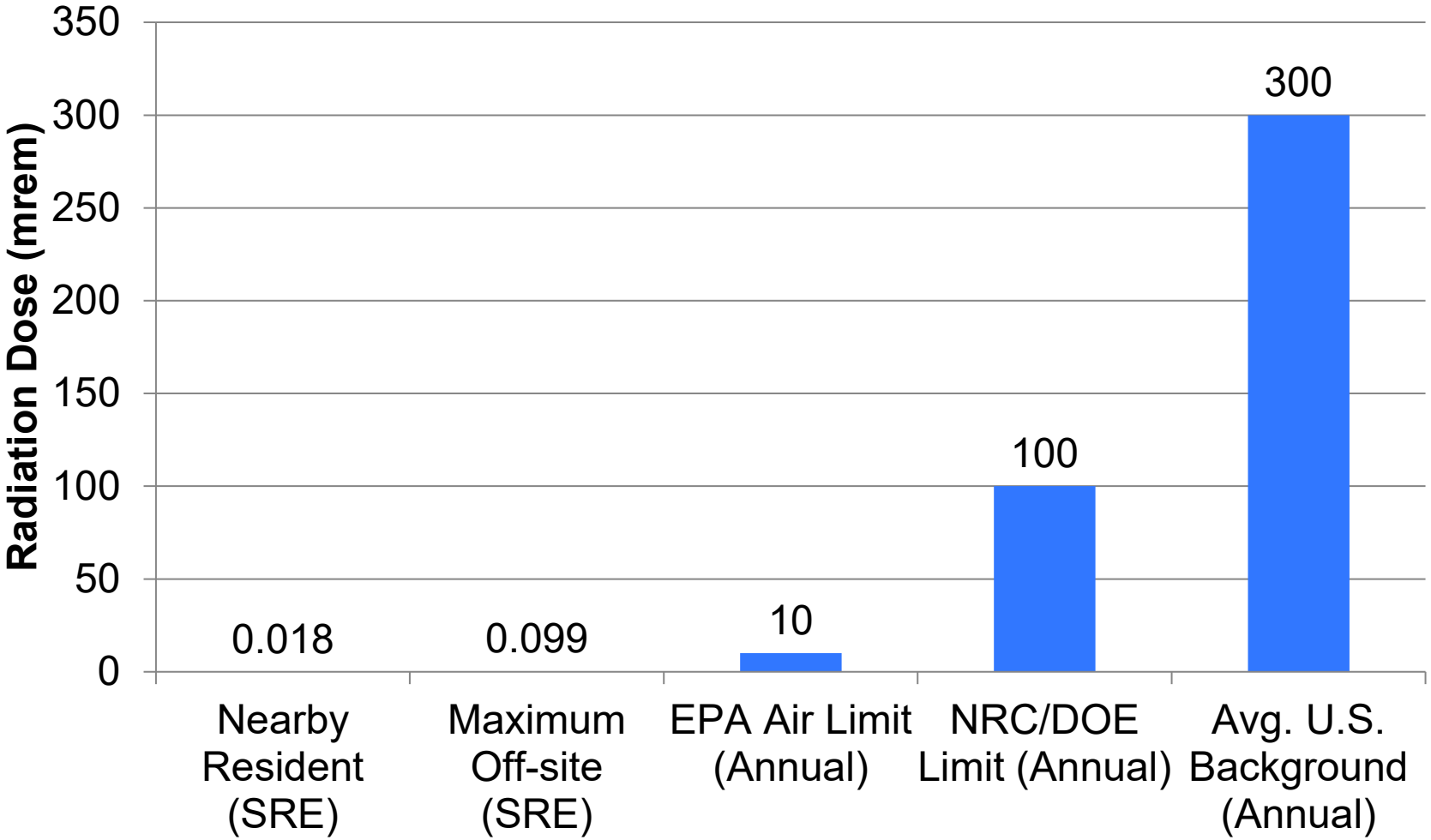
- Approx. 1% was released from the fuel into the sodium coolant
- All remained dissolved in the coolant

Very limited quantities of noble gases were released to the cover gas

- Only noble gases (xenon-133 and krypton-85) were detected
- No iodine-131 or cesium-137 was detected in cover gas

Exposures Low Compared to Federal Limits and Background

From July 20th through the end of September, 28 curies of noble gases (xenon-133 and krypton-85) were released in a controlled manner to the environment in compliance with federal release limits



Valley Green Sheet - August 31, 1959

Press release on the SRE accident was vague and non-informative

Parted Fuel Element Seen at Atomics International

During inspection of fuel elements on July 26 at the sodium reactor experiment, operated for the Atomic Energy Commission at Santa Susana by Atomics International, al. a division of North Americ Aviation Inc., a parted fuel element was observed.

The fuel element damage is not an indication of unsafe reactor conditions. No release of radioactive materials to the plant or its environs occurred and operating personnel were not exposed to harmful conditions.

In Steel Tubes

The occurrence is of portance from a techni ndpoint and a detail underway to d

fuel element of t is a cluster of seven less steel tubes, each approximately three-fourths hes in diameter and six feet long.

Each tube contains a column of six-inch long uranium metal slugs. These tubes are capped at the two ends.

The elements are suspended in the core of the reactor by means of hanger rods from slugs in the upper shield.

To date, 34 of the 43 elements comprising the fuel loading of the core have been examined by means of the fuel handling cask television system. Six elements have only an upper portion of the element attached to the hanger rod.

Scheduled for Removal

In each case, all seven tubes of the fuel element cluster were parted and a portion of er end of the fuel ele-ment remained in the core.

This fuel loading, nearing the end of its useful life, was scheduled to be removed in the near future.

Preliminary indications are that the damage could have been caused by restrictions in the coolant passages resulting from inadvertent introduction of an organic material into the reactor. This material could have come from leaks in a primary coolant pump where tetralin an organic compound, is used in freeze seals to eliminate sodium leakage into the pump bearings and drive.

First Developed

Preliminary investigation of the stainless steel fuel cladding of one element indicates the element was damaged through formation of a uranium-iron alloy in the cladding in the area of the failure.

The SRE is the first experiment in the Commission's program to develop a sodium graphite reactor, one of the five original reactor concepts in the Commission's 1954 five year civilian power program.

It was designed to produce 20,000 kilowatts of heat and 6500 kilowatts of electricity.

The purpose of the SRE is to develop the technology associated with the sodium-graphite type of reactor and to provide a flexible tool develop the advanced tec nology necessary to achi ve economically competitive power.

This concept holds promise because of the high tempera ture, and high efficiences, at which heat transfer systems using liquid metals can be operated without pressurization.

Plan Second Core

The reactor has been in operation since April 1957 and has demonstrated the feasibility of the sodium graphite reactor concept. On May 22, 1959, the SRE achieved a maximum steam temperature of 1000 degrees Fahrenheit. This steam temperature is believed to be the highest ever produced by a nuclear reactor.

A second core loading of thorium-uranium alloy fuel elements has been fabricated and will be installed in the near future.

Open Communication With the Regulatory Agencies and With Industry

- Numerous reports were written and openly published and distributed among the scientific community
- Papers were presented at national and international conferences, describing the causes of the SRE accident and methods used to recover damaged fuel and restart the SRE
- The regulatory community and the nuclear industry used the SRE accident as an important lessons learned exercise to prevent similar occurrences from happening in the future

Independent Studies of the SRE Accident (2005)

- In 2005, two independent studies were completed that confirmed Boeing's earlier findings that only small quantities of noble gases were released following the accident and that no iodine-131 or cesium-137 was released
  - "Chemical Behavior of Iodine-131 During the SRE Fuel Element Damage in July 1959", Jerry D. Christian Ph.D., May 26, 2005
  - "Investigation of Releases from Santa Susana Sodium Reactor Experiment in 1959", John A. Daniel Sr., May 27, 2005
- Dr. Jerry Christian is a past Scientific Fellow from the Idaho National Engineering and Environmental Laboratory (INEEL) and is an expert in nuclear fuel chemistry and the behavior of fission products in nuclear fuel
- John Daniel participated in the decontamination and recovery of the Three Mile Island (TMI) nuclear plant. He is an expert on nuclear power plant safety analysis and fission product transport and behavior

Advisory Panel Reports (2006)

- Committee to Bridge the Gap commissioned studies by
  - Union of Concerned Scientists (David Lochbaum)
  - Consulting in the Public Interest (Jan Beyea)
- Based on speculative assumptions and unsupported by hard data, the reports alleged releases of large quantities of iodine-131 and cesium-137
  - 6,500 curies of iodine-131
  - 1,300 curies of cesium-137
  - Estimates (guesses) based on assuming an upper bound 13/43 = 30% of fission products escaped to the environment
  - Acknowledged that releases could be much lower, even zero, so, best estimate release is half of 30% or 15%
- Off-site exposures and 260 cancers predicted based on these guessed releases

Independent Reviews of Advisory Panel Reports (2006)

Two independent reviews of the Advisory Panel Reports were commissioned by Boeing. Both concluded that no iodine-131 or cesium-137 were released from the 1959 SRE accident

"Review of the Beyea Study", John R. Frazier Ph.D., C.H.P.

- Dr. Frazier is a past President of the Health Physics Society (HPS), an elected member of National Committee on Radiation Protection and Measurement (NCRP), and a nationally renowned expert on radiological environmental monitoring and dose assessment

"Review of the Lochbaum Study", John R. Krsul

- Mr. Krsul is an expert on the measurement and behavior of fission products in metal-fueled, sodium-cooled reactors following fuel damage incidents including the EBR-II and Fermi-I reactors

Hypothetical Consequences of Alleged Cesium Release

- It has been alleged that 1,300 curies of cesium-137 were released from the SRE. This is incorrect. If this amount had been released, the following would be potential uniform contamination levels of top soil (6 inch depth) after decay correction to today

Radius (Miles)	Area (Square Miles)	Cesium-137 (pCi/g)
0.56	1	618
1.8	10	62
5.6	100	6.2
18	1,000	0.62
56	10,000	0.062

- No EPA off-site background samples exceeded the background threshold value (BTV) of 0.193 pCi/g (by definition)
- Of 3,542 on-site soil samples taken by EPA,
  - only 12 (0.3%) samples exceeded the ≤ 6.2 pCi/g EPA acceptable risk range for residential land use
  - only 2 (<0.06%) samples at the same location exceeded 62 pCi/g

Jan Beyea's Estimate of Off-site Impacts

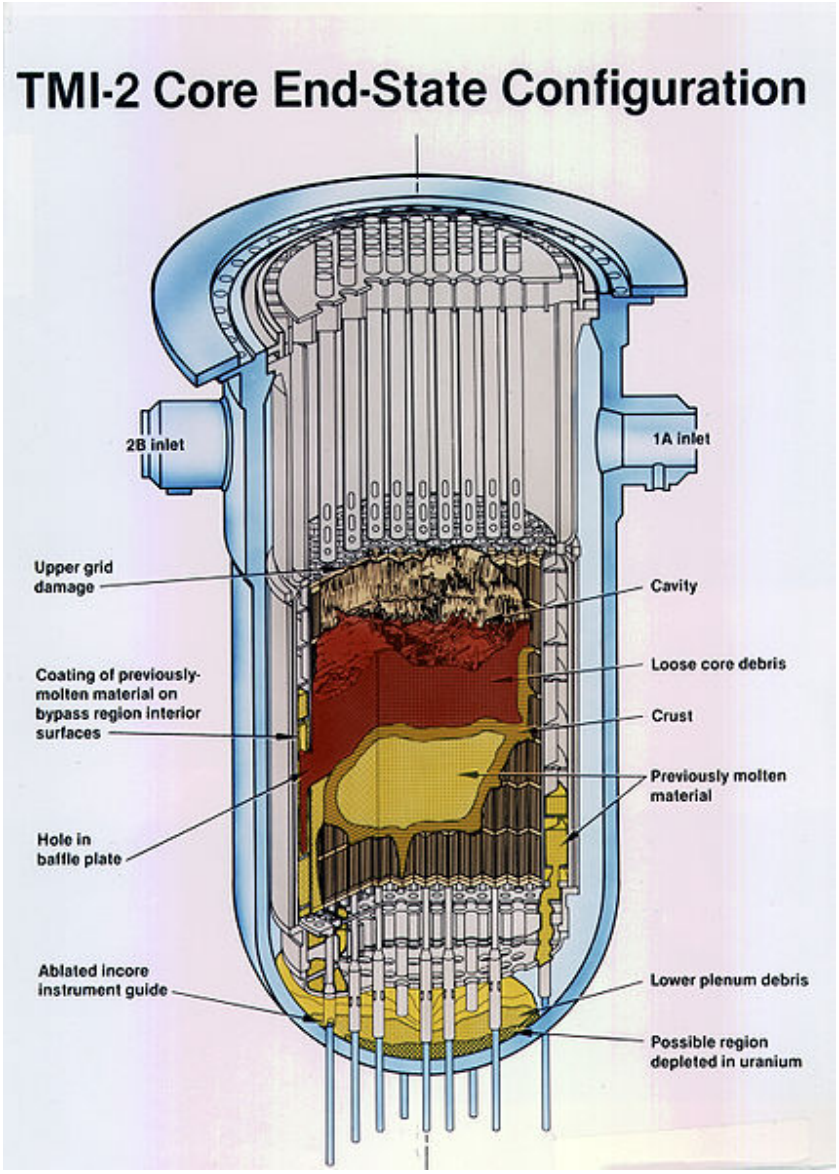
- The Beyea report uses the Lochbaum release guestimates to calculate a range of potential off-site doses and consequential cancers.
- Dr Beyea states "*These [260] cancers would have occurred among a background of millions of cancers in the population exposed in the LA Basin, including a contribution from natural background radioactivity that would have exceeded the contribution from SSFL in aggregate.*"

- It is instructive to expand upon these cautionary words
  - Beyer assumed "fallout" spread over a population of 8,000,000 in a 60 mile radius of SRE
  - 3,280,000 "natural" cancers would occur during their collective lifetimes (the risk of contracting cancer in the U.S. is approximately 41%)
  - Assuming that the linear no threshold (LNT) model of radiation risk is valid at exposures similar to background radiation, the number of theoretical cancers induced from exposure to background radiation would be approximately 205,200 (~6% of total "natural" cancer rate)

SRE is NOT Comparable to Three Mile Island

	SRE	TMI-2
Power Level (MWth)	20	2,568
Fission product inventory (curies)	1.1 million	10,000 million
Mass of fuel (metric tons)	3	138
Mass of fuel melted (metric tons)	0.03 - 0.9 (1% - 30%)	62 (45%)
Maximum Fuel Temperature (°F)	1,400	>5,200
Mass of molten fuel that formed a pool at the bottom of reactor vessel (metric tons)	0 (0%)	18 (13%)
Total fission products released (curies)	28	2.4 million - 13 million

Three Mile Island Meltdown (Courtesy NRC)



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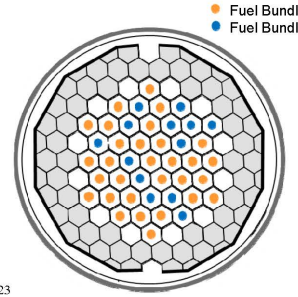
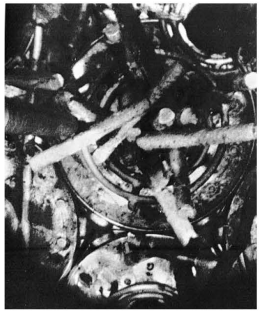


Bottom section of damaged fuel bundle

Mid-section of damaged fuel bundle



Intact fuel slugs on top of core during damaged fuel bundle removal

Mechanisms

- Fuel/cladding melting
- Thermal cycling, cladding failure

23

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Comparisons to Three Mile Island (TMI-2)

- The reported iodine-131 release from TMI-2* was 17 curies and the reported noble gas (xenon and krypton) release was between 2.4 million to 13 million curies, therefore releases from TMI-2 was at least 86,000 to 460,000 times worse than the SRE release

- The expected number of total additional cancers from TMI-2* was calculated to be 0.7 in a population of 2,000,000 living within 50 miles. This means that, most likely, one person may contract cancer as a result of TMI-2

- Considering the relatively small SRE release of 28 curies of noble gases, no-one is likely to contract cancer as a result of the SRE accident

* All Three Mile Island data has been taken from the President's Commission on Three Mile Island http://www.pddoc.com/tmi2/kemeny/index.html

DOE SRE Workshop (2009)

- On the 50th anniversary of the SRE accident, DOE hosted a one day workshop, attended by almost 200 members of the public, many of them retirees
- Three nationally renowned experts in nuclear reactor accident analysis, reviewed the historical record, presented their assessments, and answered questions from the audience
  - Dr. Paul Pickard, Sandia National Laboratories
  - Dr. Thomas Cochran, Natural Resources Defense Council
  - Dr. Richard Denning, Ohio State University
- The panel concluded that …
  - Damage to the SRE reactor was much less than the damage to the Three Mile Island reactor
  - Releases of radioactive material from the SRE were much less than from Three Mile Island
  - Individual exposures and risk to local community would be insignificant
  - Population cancer risk would be indistinguishable from the large number of natural real cancers and the large number of theoretical cancers from background radiation

Meltdown or No Meltdown?

- Much has been made of terminology
  - Meltdown
  - Partial meltdown
  - Core damage accident
- Much has been made of the severity and environmental impact of the event in comparison to other reactor accidents
- We have described what happened but it is also instructive to look at what did NOT happen in the SRE accident

Meltdown or No Meltdown?

What Did Happen in the SRE?	What Did NOT Happen in the SRE?
Small amount (~1%) uranium-steel alloy melted in central region of the reactor core	Majority of fuel did not melt.
Reactor was shutdown and power level decreased	No super-critical power excursion
Molten material re-solidified in cooler lower portions of core	No pool of molten fuel in bottom of reactor vessel
Fuel remained fully immersed (and cooled) in pool of sodium coolant	No loss of coolant of cooling function
Power supplies to the reactor remained operable	No loss of offsite or onsite emergency power
Reactor vessel, surrounding concrete shielding and reactor building remained intact	No melt-thru of reactor vessel
Most cesium-137 and iodine-131 retained in fuel or retained in the coolant	No release of cesium-137 or iodine-131 to environment
	No over-pressurization of reactor building
	No hydrogen explosions
	No catastrophic loss of building integrity

SRE is NOT Comparable to Other Nuclear Accidents

Abnormal Events	SRE	TMI-2	Fukushima	Chernobyl
Super-critical power excursion	No	No	No	Yes
Reactor core explosive disassembly	No	No	No	Yes
Loss of off-site power supplies	No	No	Yes	N/A
Loss of on-site emergency power supplies	No	No	Yes	N/A
Loss of coolant from reactor vessel	No	Yes	Yes	N/A
Loss of cooling function	No	Yes	Yes	N/A
Melting of major portion of nuclear fuel	No	Yes	Yes	N/A
Pool of molten fuel in bottom of reactor vessel	No	Yes	Yes	N/A
Molten fuel penetrates reactor vessel	No	No	Yes	N/A
Reactor building pressurized with steam	No	Yes	Yes	N/A
Hydrogen explosions	No	Yes	Yes	N/A
Catastrophic loss of building integrity	No	No	Yes	Yes

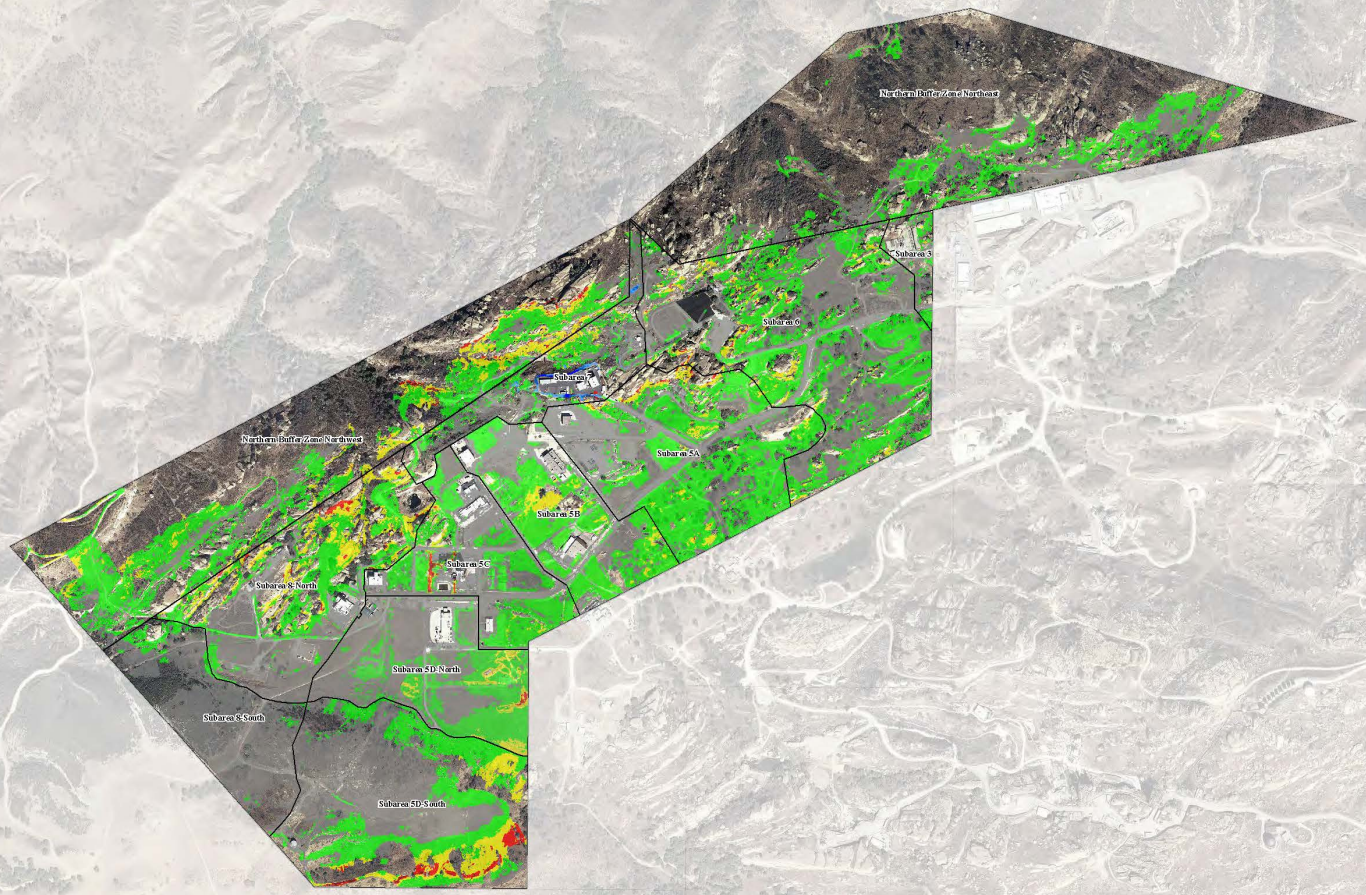
No Other Meltdowns Occurred

- SNAP 8 Experimental Reactor (S8ER) - Building 4010
  - During 1964-65, 80% of fuel rods swelled, causing cracks in the metal cladding
  - Caused by thermal cycling to test the capability of the fuel design
  - No fuel melting occurred
  - Fission products migrated to the sodium/potassium coolant
  - No release to the environment occurred
- SNAP 8 Developmental Reactor (S8DR) - Building 4059
  - In 1969, similar fuel rod swelling and cracking occurred in 34% of the fuel due to fuel rod bowing and flow mal-distributions
  - No fuel melting occurred
  - Fission products migrated to the sodium/potassium coolant
  - No release to the environment occurred

EPA's Conclusions from the Area IV Radiological Survey

- "EPA received $41.5 million of DOE and Recovery Act Funds from the Federal government to conduct one of the most robust technical investigations ever undertaken for low-level radioactive contamination"
- "In general, EPA found elevated radiation levels in the areas where we expected to find them, isolated to a number of former process or disposal areas"
- "Level of radiation throughout most of the Area IV study area was lower than the offsite background locations"
- "This survey resulted in the discovery of several areas of elevated radiation levels, but none posed a health risk to personnel"

EPA Found Most of Area IV at Background Radiation Levels



HGL—Gamma Radiation Screening Report, SSFL—Ventura County, California

Figure 9.4
Area IV and Northern Buffer Zone
Gamma Results
Santa Susana Field Laboratory

U.S. EPA Region 9

Legend

Subarea Boundaries

N

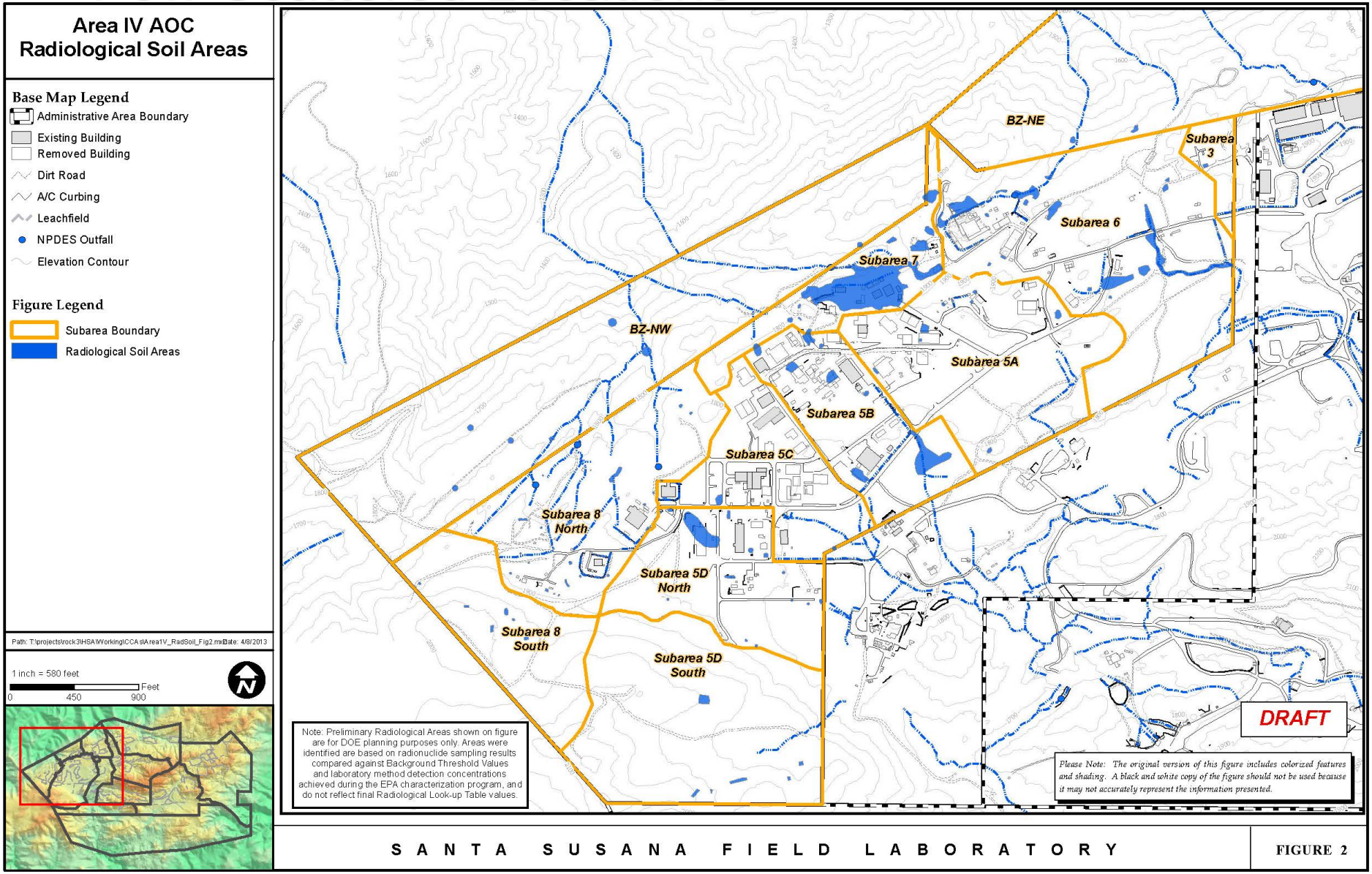
Lower Cs-137 Ratio Higher

0 2 4 6

Standard Deviations Above the Mean Total Count Rate

HGL

EPA Found Soil Above Background in Only a Few Scattered Locations



EPA Soil Survey Data Does NOT Confirm Widespread Radiological Contamination

Out of 3,542 soil samples and 128,020 separate analyses …

- Only 487 (0.38%) results exceed the EPA background levels
- Only 12 soil samples (<0.34%) exceed the EPA acceptable risk range for conservative residential land use
- Only 8 soil samples (<0.23%) exceed the former dose-based cleanup standard for conservative residential land use
- No results exceed the EPA acceptable risk range for open space land use
- Demonstrates that alleged massive, widespread contamination does not exist, and that past remediation has been effective in eliminating the majority of contamination that did exist

Studies Show NO Health Impacts from SRE

Numerous state and federal agencies and universities have concluded that there is no evidence of increased cancer rates in neighboring communities that can be attributed to SSFL operations, and specifically to radiation exposure *(Boeing, 2014)*

- *"These analyses suggest that people living near the SSFL are not at increased risk for developing cancers associated with radiation exposure" (DHS, 1992)*
- *"Three studies of cancer incidence in the vicinity of SSFL were reviewed…the combined evidence from all three does not indicate an increased rate of cancer in the regions examined. The results do not support the presence of any major environmental hazard" (DTSC, 1999)*
- *"ATSDR has not identified an apparent public health hazard to the surrounding communities because people have not been, and are currently not being exposed to chemicals and radionuclides from the site at levels that are likely to result in adverse health effects" (ATSDR, 1999)*
- *"The results from this study suggest little or no association between residential distance from SSFL and the incidence of total cancers or the group of (radiosensitive) malignancies thought to be affected by ionizing radiation" (Morgenstern,U. of Michigan, 2007)*
- *"It is not possible to completely rule out any offsite carcinogenic effects from SSFL. No evidence of measurable offsite cancer causation occurring as a result of emissions from the SSFL was found. Further, no evidence of any cancer causation by any environmental factor was found" (Mack, USC, 2014)*

Additional Information

Additional information on the SRE can be found on DOE's ETEC web site

- SRE Operations & Decommissioning
  http://www.etec.energy.gov/Operations/Major_Operations/SRE.php
- SRE Accident
  http://www.etec.energy.gov/Operations/Major_Operations/SRE_Accident.php
- SRE 2009 Workshop
  http://www.etec.energy.gov/Community_Involvement/Public%20Meetings/SRE_Workshop.php
- SRE Historical Documents
  http://www.etec.energy.gov/Library/Historical_Docs.php
- EPA Radiological Survey
  http://www.etec.energy.gov/Char_Cleanup/EPA_Soil_Char.php
- Community Health Studies
  http://www.etec.energy.gov/Environmental_and_Health/Community_Health.php