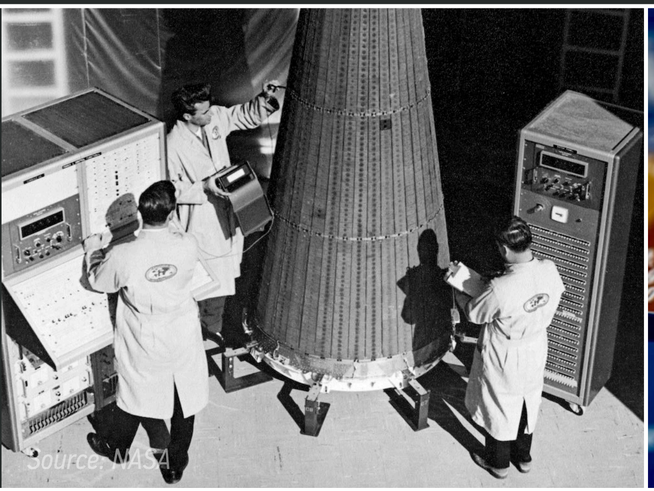
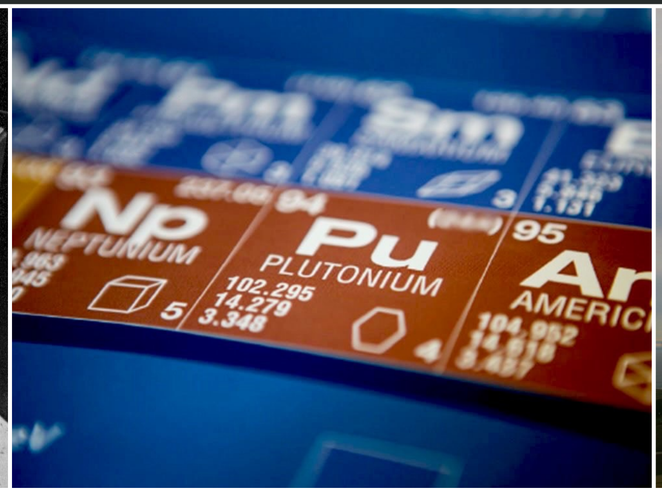
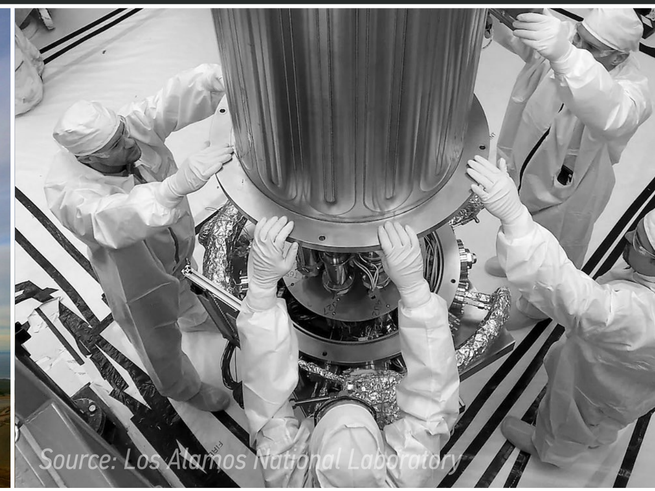

Source: NASA






Source: Los Alamos National Laboratory

PRELAUNCH VERIFICATION

OF THE OUTER SPACE TREATY

Raven Witherspoon and Alexander Glaser

Program on Science and Global Security
Princeton University

Workshop on Nuclear Problems in the Atmosphere and Cosmos

Massachusetts Institute of Technology, August 20, 2026

Revision 0.2

BACKGROUND

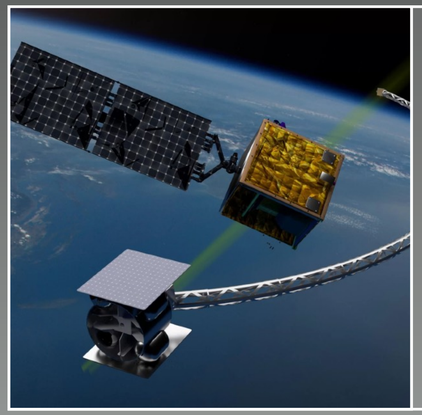
ENSURING THE FUTURE OF THE OUTER SPACE TREATY

WITH MORE TRANSPARENCY AND NON-INTRUSIVE VERIFICATION



NUCLEAR PAYLOADS AND THE NEED FOR MORE TRANSPARENCY

Space launches that include nuclear payloads (for power generation or propulsion) could further increase geopolitical tensions, especially when there are concerns about the peaceful nature of these missions and compliance with the Outer Space Treaty



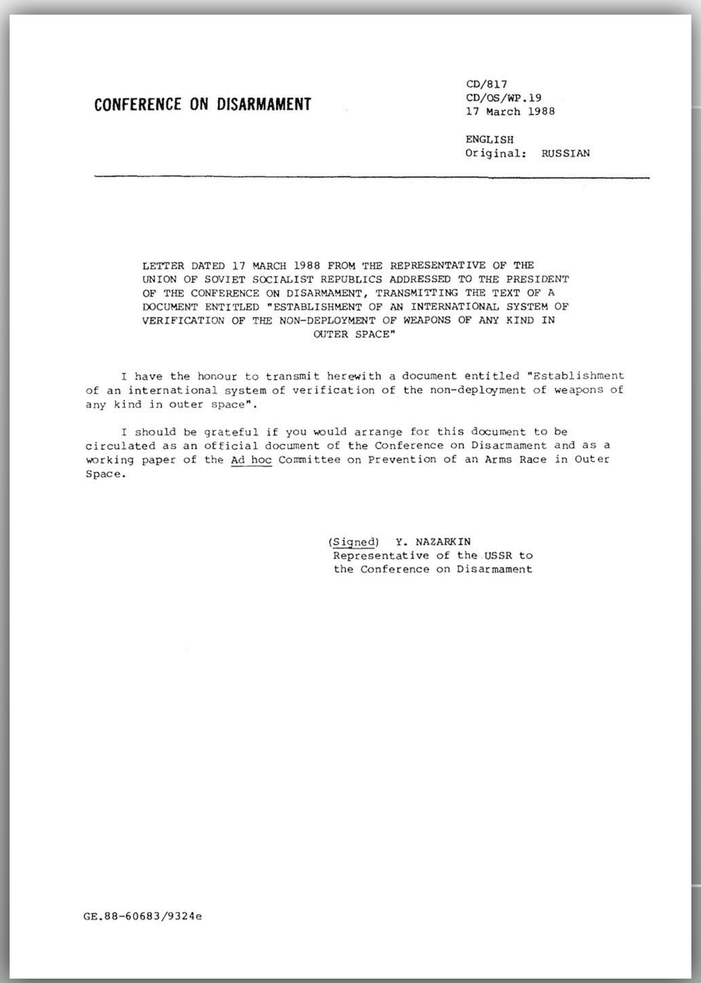
STRENGTHENING THE 1967 OUTER SPACE TREATY

New technical developments could (finally) allow for verification of the Outer Space Treaty

Pre-launch or post-launch inspections could provide confidence in the civilian nature of planned missions involving fission power or other nuclear systems

Source: esa.int (top) and thinkorbital.com (bottom)

1988 SOVIET VERIFICATION PROPOSAL



CONFERENCE ON DISARMAMENT

CD/817
CD/OS/WP.19
17 March 1988

ENGLISH
Original: RUSSIAN

LETTER DATED 17 MARCH 1988 FROM THE REPRESENTATIVE OF THE UNION OF SOVIET SOCIALIST REPUBLICS ADDRESSED TO THE PRESIDENT OF THE CONFERENCE ON DISARMAMENT, TRANSMITTING THE TEXT OF A DOCUMENT ENTITLED "ESTABLISHMENT OF AN INTERNATIONAL SYSTEM OF VERIFICATION OF THE NON-DEPLOYMENT OF WEAPONS OF ANY KIND IN OUTER SPACE"

I have the honour to transmit herewith a document entitled "Establishment of an international system of verification of the non-deployment of weapons of any kind in outer space".

I should be grateful if you would arrange for this document to be circulated as an official document of the Conference on Disarmament and as a working paper of the Ad hoc Committee on Prevention of an Arms Race in Outer Space.

(Signed) Y. NAZARKIN
Representative of the USSR to
the Conference on Disarmament

GE.88-60683/9324e

"On-site inspection directly before launch is the simplest and most effective method of making sure that objects to be launched into and stationed in space are not weapons and are not equipped with weapons of any kind."

digitallibrary.un.org/record/160618?ln=en&v=pdf

TWO BASIC SCENARIOS

FOR SPACE LAUNCHES & PRELAUNCH INSPECTIONS

I

NON-NUCLEAR MISSIONS

I

NON-NUCLEAR MISSIONS

INSPECTIONS DURING PAYLOAD ASSEMBLY & PREPARATION FOR LAUNCH



Neutron survey meter

Possible activities during payload integration could include visual inspection, simple radiation measurements, swipe samples, and the use of tags and seals

Photos: aerospacelab.com (for illustration purposes only) and berthold.com

PRELAUNCH INSPECTIONS

AT PAYLOAD ASSEMBLY AND INTEGRATION FACILITIES



BUILDING ON THE CONCEPT OF COMPLEMENTARY AND MANAGED ACCESS

Activities would seek to assure the absence of undeclared nuclear material at a facility where the payload is assembled, integrated, and/or prepared for launch

Could build on IAEA experience and use some of the same (accepted) methods and procedures



CHALLENGES OF PRELAUNCH INSPECTIONS AT ASSEMBLY AND INTEGRATION SITES

Difficult to see how the concept could be broadly implemented today

Fundamentally intrusive in nature, unless convenient “key measurement points” can be identified

Hardest for most relevant (military) sites and missions

Source: IAEA Imagebank (top) and airbus.com (bottom)

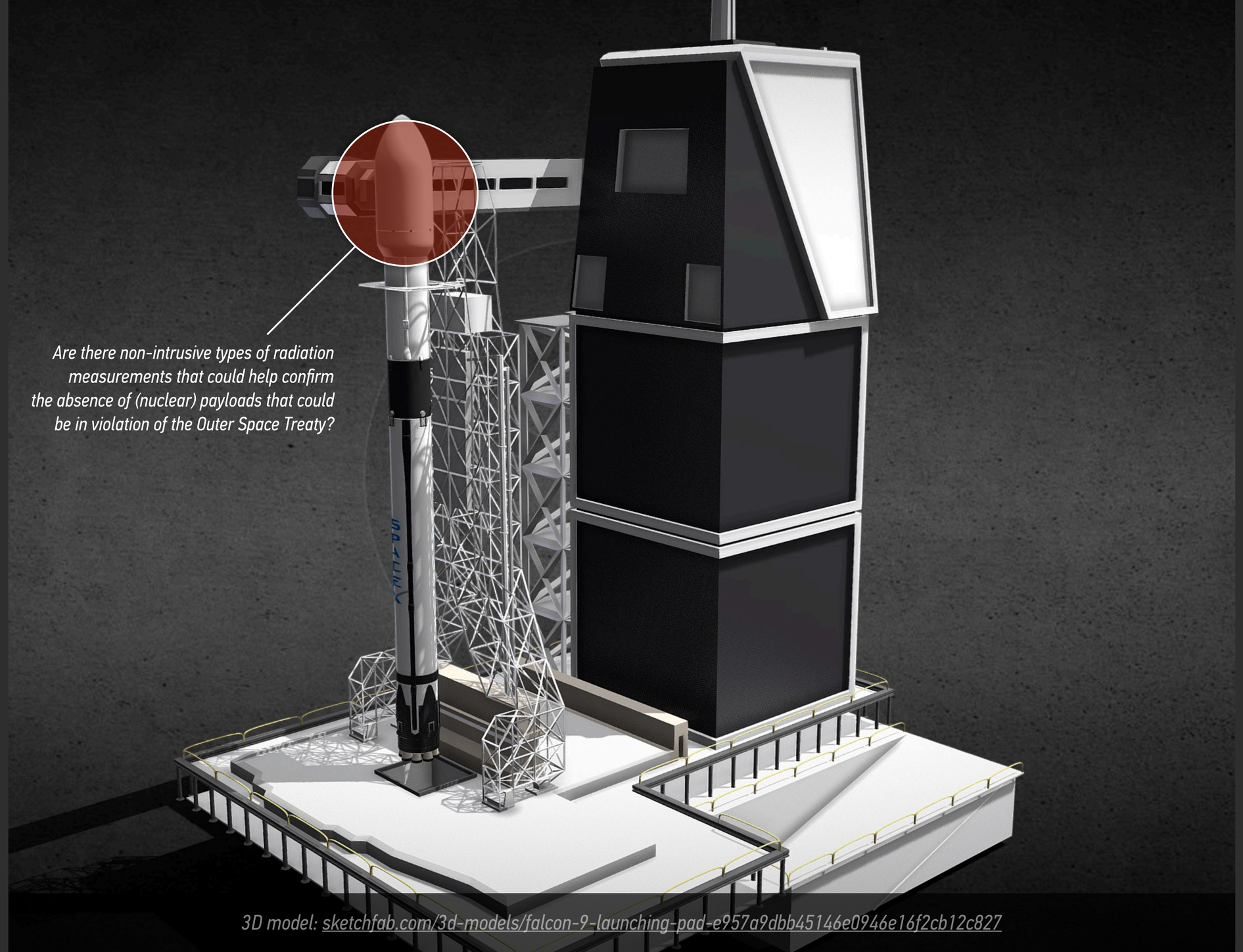
I

NON-NUCLEAR MISSIONS

LAUNCHPAD MEASUREMENTS



Source: SpaceX



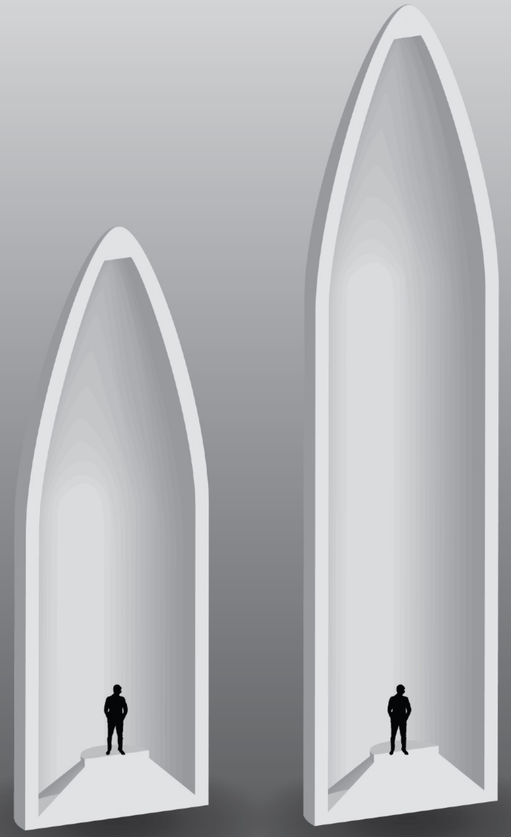
3D model: sketchfab.com/3d-models/falcon-9-launching-pad-e957a9dbb45146e0946e16f2cb12c827

ULA

SPACEX

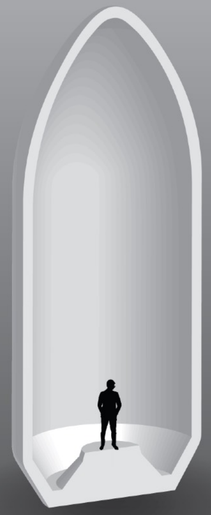
BLUE ORIGIN



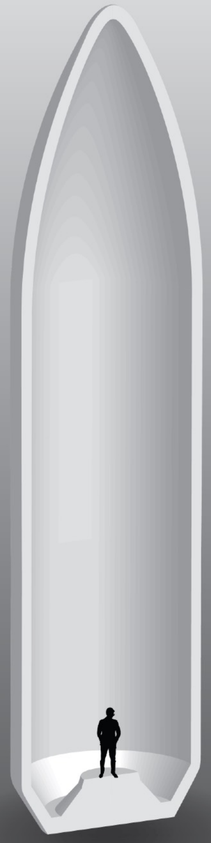


Vulcan

Vulcan
Extended Fairing



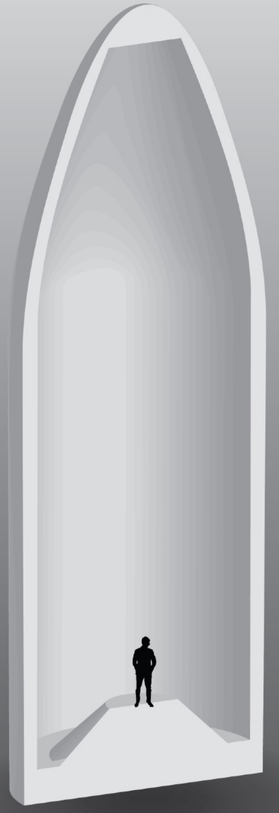
Falcon 9 / Heavy



Falcon Heavy
Extended Fairing

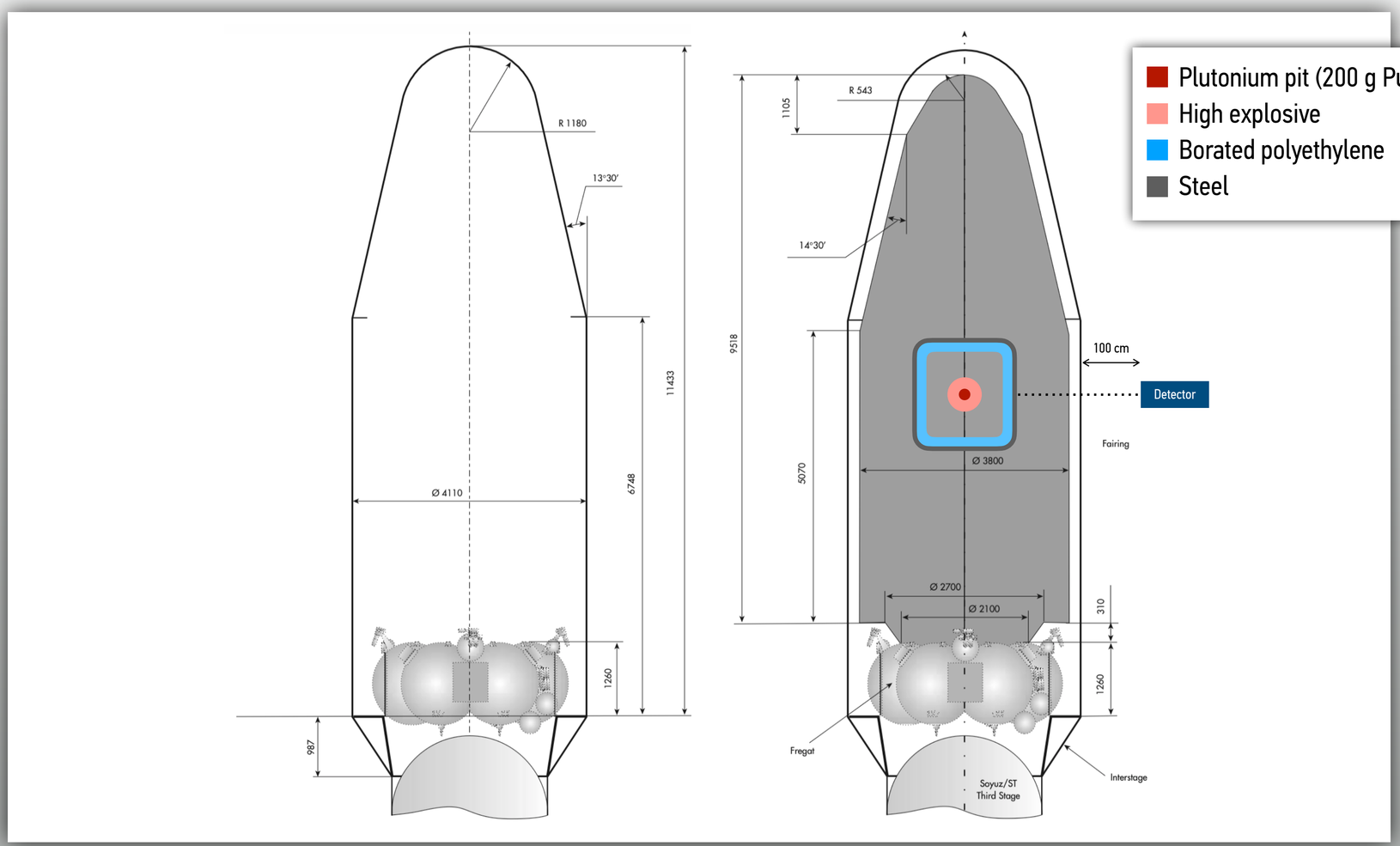


Starship



New Glenn

FALCON-9 FAIRING



Falcon 9 User's Guide, Version 8, SpaceX, March 2025

plutonium-based

NEUTRONS EMERGING FROM A WARHEAD

"From a typical primary, ~ 10^6 neutrons per sec emerge. These neutrons are thermalized and attenuated as they travel through the warhead, but about 10% make it out."

Net emission rate from warhead: 100,000 n/s

Verification of Dismantlement of Nuclear Warheads and Controls on Nuclear Materials, JASON, JSR-92-331
The MITRE Corporation, McLean, VA, January 1993, fas.org/irp/agency/dod/jason/dismantle.pdf

SIMPLIFIED NEUTRON DETECTION MATH

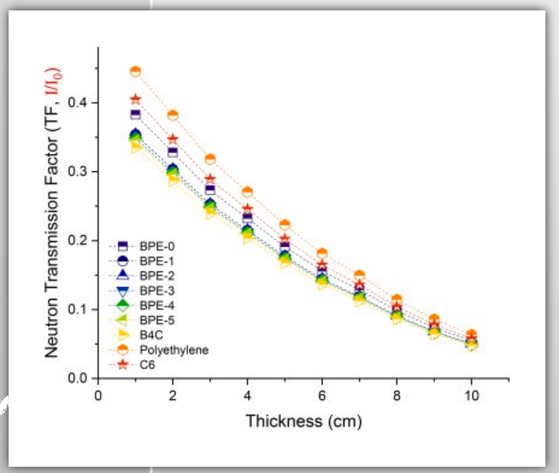
We are about 3 meters away from the center of the rocket/device

Surface area at 3 m is about 113.1 m^2

Assume our detector has an effective area of 1 m^2, i.e., 0.8–0.9% of the total area

Assume 100,000 n/s emerge from a concealed object

Assume 90% are shielded using external materials: 10,000 n/s
Assume 99% are shielded using external materials: 1,000 n/s



8–80 neutrons reach the detector per second; half of them are detected: 4–40 cps

1 cps background (tbc) = 3600 counts over a one-hour period
Reference number (used for New START inspections): 4 x $B^{0.5}$ = 240 counts above background

One-hour measurement time: at least 14,400 counts from warhead

MUON TOMOGRAPHY

(AND POSSIBLY ALSO MUON-INDUCED FISSION WITH NEUTRON DETECTION)

Science and Global Security, 16:37–53, 2008
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DOI: 10.1080/08929880802335758

Routledge
Taylor & Francis Group

Tomographic Imaging with Cosmic Ray Muons*

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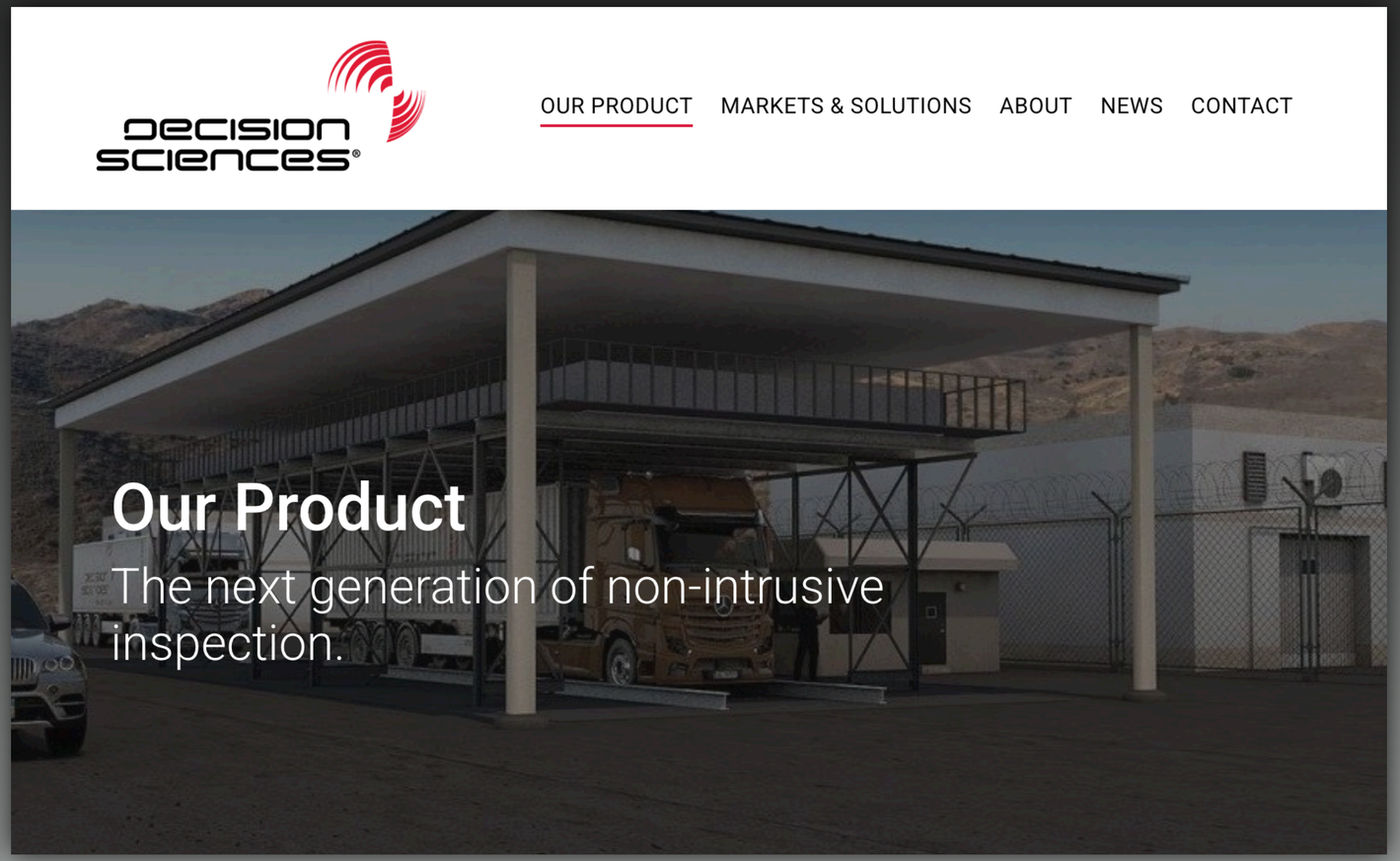
[1]Los Alamos National Laboratory, Los Alamos, NM, USA
[2]University of South Carolina, Columbia, SC, USA

Over 120 million vehicles enter the United States each year. Many are capable of transporting hidden nuclear weapons or nuclear material. Currently deployed X-ray radiography systems are limited because they cannot be used on occupied vehicles and the energy and dose are too low to penetrate many cargos. We present a new technique that overcomes these limitations by obtaining tomographic images using the multiple scattering of cosmic radiation as it transits each vehicle. When coupled with passive radiation detection, muon interrogation could contribute to safe and robust border protection against nuclear devices or material in occupied vehicles and containers.

INTRODUCTION

One of the strategies to make weapons of mass destruction (WMD) unavailable to terrorists is by controlling nuclear material at its source. An additional reduction in risk can be obtained by increasing the likelihood of detection of

*LA-UR-07-3100, Los Alamos National Laboratory.
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Address correspondence to Chris Morris, Los Alamos National Laboratory, Los Alamos, Group P-25, Mailstop H846, NM 87544, USA. E-mail: cmorris@pobox1663.lanl.gov



C. L. Morris, C. C. Alexander, et al., Tomographic Imaging with Cosmic Ray Muons, Science & Global Security, 16 (1–2), 2008 and www.decisionsciences.com

II

NUCLEAR MISSIONS

DO WE NEED NUCLEAR POWER IN SPACE?



NUCLEAR RESTRAINT IN OUTER SPACE

"The use of nuclear power sources in outer space shall be restricted to those space missions that cannot be operated by non-nuclear energy sources in a reasonable way."

Principles Relevant to the Use of Nuclear Power Sources in Outer Space, RES 47/68, United Nations, December 14, 1992



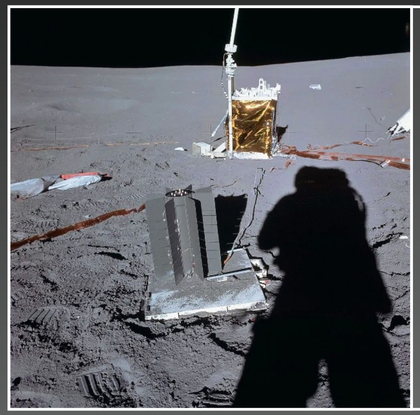
"YES" … IF ONE ACCEPTS SOME PREMISES OF HUMAN SPACE EXPLORATION

- Lunar outposts, permanent human presence on the Moon (20–30 kW per person)
- Nuclear propulsion for deep-space missions; off-Earth production of chemical fuels (e.g. on Mars)
- Nuclear power sources in Earth orbit for high-power (military) applications

Source: nasa.gov (top) and esa.int (bottom)

VERIFICATION CHALLENGES

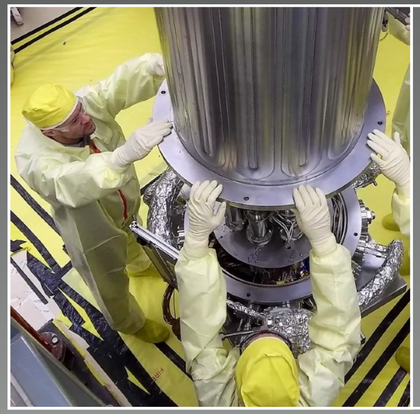
ASSOCIATED WITH NUCLEAR POWER SYSTEMS IN SPACE



DIVERSITY OF (POSSIBLE) NUCLEAR POWER SYSTEMS

Traditionally, radioisotope thermoelectric generators (RTGs) have dominated,
but there may be renewed interest in fission power systems as energy demand increases

No standardized designs; many types of nuclear material (Pu-238, Sr-90, Am-241 / HALEU, HEU)



CAN ONE DISTINGUISH A NUCLEAR WEAPON FROM A NUCLEAR POWER SYSTEM?

Preference for unclassified reactor and fuel designs
Separation of nuclear and non-nuclear components until payload integration (for inspectability)
Visual access and inspection of nuclear payloads would be best

Source: NASA (top) and Los Alamos National Laboratory (bottom)

CONCLUDING REMARKS

KEEPING CIVILIAN & MILITARY APPLICATIONS SEPARATE

DEMONSTRATED ON EARTH — EVEN MORE IMPORTANT IN SPACE



SEPARATING CIVILIAN AND MILITARY NUCLEAR POWER ON EARTH

The United States has pioneered the concept, adopted both domestically and internationally

For example, multi-decade effort to convert research reactors to low-enriched fuel

Leading by example has significantly strengthened the nuclear nonproliferation regime of the NPT



MANAGING DUAL-USE ASPECTS OF SPACE ACTIVITIES

Space has been militarized from the outset, but the Moon can only be explored for peaceful purposes

NASA shall “encourage dual-use civil and defense operational architectures for deployed [fission surface power] systems in coordination with interagency partners” (NASA Directive, July 31, 2025)

Source: iaea.org (top) and nasa.gov (bottom)

KEEPING EARTH IN FOCUS



PERCEIVED URGENCY COULD COMPROMISE BEST PRACTICES & POLICIES … ON EARTH!

Many spacefaring nations might eventually develop and deploy nuclear systems in space

Nuclear power in space has potentially significant consequences for nuclear energy policy on Earth

Need for standards and best practices, especially with regard to safety and liability for accidents



AFFECTING THE SUPPLY CHAIN FOR SPACE NUCLEAR SYSTEMS

Strong incentive to use fuels with high enrichments, i.e., HALEU or HEU (20–90% enriched in U-235)

National security considerations (often associated with space activities) could encourage additional countries to pursue sensitive domestic nuclear capabilities — rather than relying on suppliers

Source: nasa.gov (top) and U.S. Department of Energy (bottom)

