ENGR 399

- Open the in-class quiz now… today, quiz questions will be distributed throughout the lecture. Quiz access code = tomato

- Asynchronous assignment 3 is posted, and is due by Sunday midnight. There are three options… do ONLY ONE of the three options

- Dr. Torres will have Zoom Office Hours on Thurs to give hints on Asynch 3A: Superintelligence

From CWRU General Bulletin...

Definition of a Credit Hour

Program Integrity Rules issued by the U.S. Department of Education require institutions to establish a definition of "credit hour" CWRU's definition was approved by the Faculty Senate on 4/25/12 and applies to all degree programs (undergraduate through graduate/professional):

1. The assignment of credit-hours to a course occurs through a formal review process conducted at the appropriate levels of faculty governance.
2. For courses in lecture format, 1 credit hour represents the subject content that can be delivered in one academic hour of contact time each week for the full duration of one academic semester, typically fourteen weeks along with a final examination period. For undergraduate courses, one credit-hour also includes associated work that can be completed by a typical student in 2-3 hours of effort outside the classroom. For graduate and professional courses taught in lecture format, 3-4 hours of outside work is expected for each academic hour of contact time.
3. For courses taught in other than lecture format (e.g., seminars, laboratories, independent study, clinical work, research, etc.), one credit-hour represents an amount of content and/or student effort that in aggregate is no less than that described in (2) above.

3 credit course:
3 hrs per week in-class
6-9 hrs per week outside of class

Thus 9-12 hrs per week total

https://bulletin.case.edu/about-university/university-registrar/#grading_systemtext

Are our course topics relevant concerns in real businesses?

(slides from last week)

Last week I went to the Marian K Shaughnessy Nurse Leadership Academy in Palm Springs, California

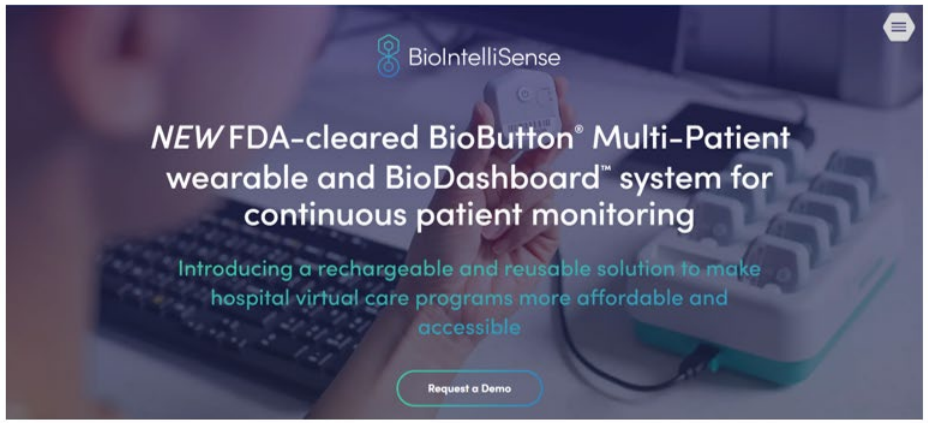
This talk was by a company that recruits nurses from lower-income countries to work in US hospitals

What are the ethical issues?

What are consequentialist and deontological views?

The company is taking the ethical issues seriously

This company gave a presentation at the academy



Relationship to our course (Async 1A; Async 2C):
They are developing pulse oximetry capabilities, and their talk addressed the historical problems with this technology not working well for dark skin, and their efforts to overcome this problem


NO CLIMBING
ON ROCKS

This lecture… what we will cover

1. Organizational strategies to preempt engineering failures
2. “Normalization of deviance”… and why to avoid
3. “Management of change review”… and why to require
4. “Inherently safer design”… and why to aim for this (if possible)

npr

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SPACE

Trump asks SpaceX to 'go get' two stranded ISS astronauts. They're not stranded

UPDATED JANUARY 29, 2025 · 1:16 PM ET

By Brendan Byrne

CNN Science Space Life Unearthed

Science / Space

Elon Musk says SpaceX will rescue two ‘stranded’ astronauts. Here’s why that is confusing

By Jackie Wattles, CNN

6 minute read · Updated 5:29 PM EST, Wed January 29, 2025

32 comments

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SPACE

Trump asks SpaceX to bring "abandoned" Starliner crew home, blames Biden administration for inaction

By William Harwood

January 28, 2025 / 10:56 PM EST / CBS News

Jan 28 1986

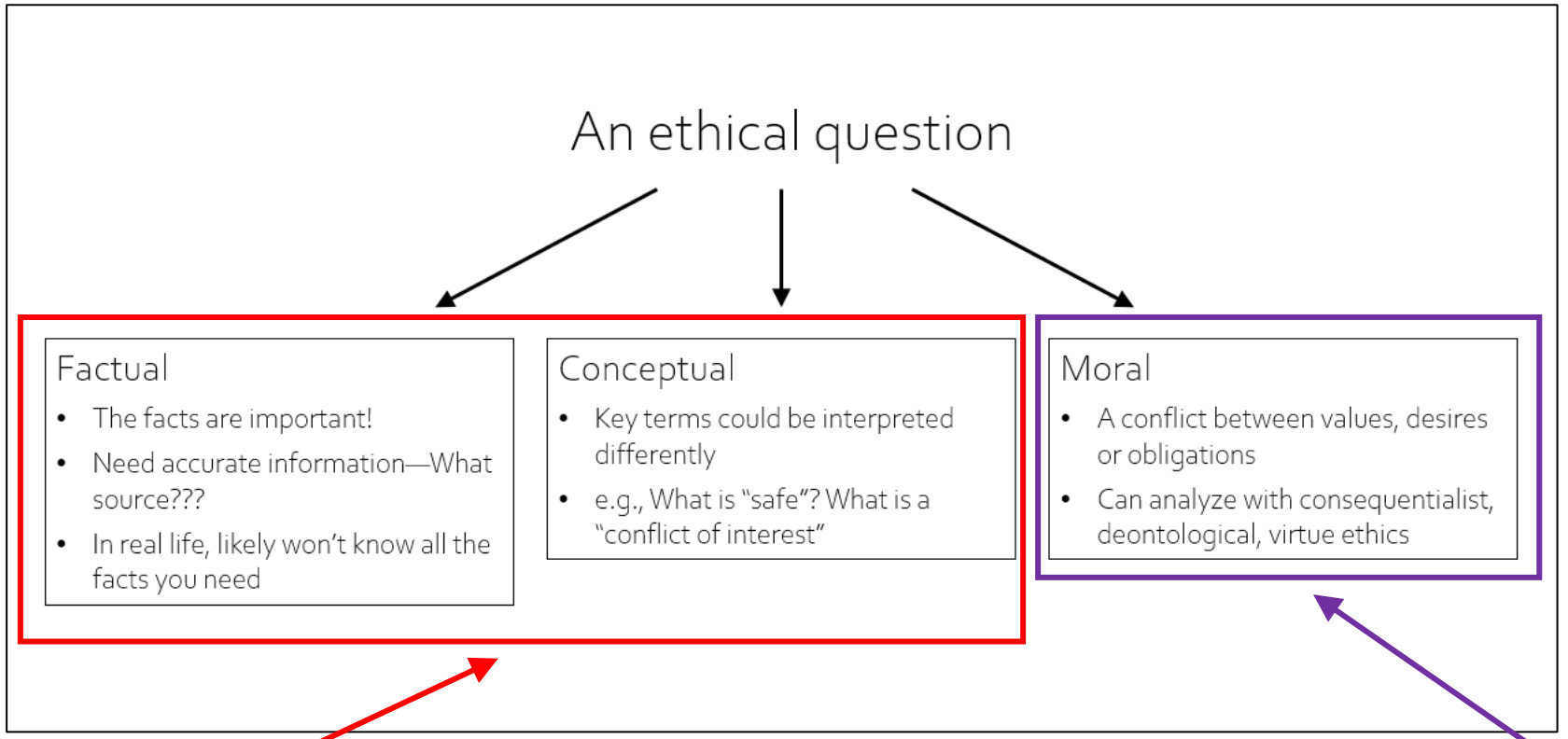
The standard story…

Heroic engineers knew there was a problem and tried to stop the launch, but unscrupulous managers were more concerned about budgets and ignored the warnings of the engineers

The real story is not so simple

(as per sociology professor Diane Vaughan in her highly regarded 1996 book:
The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA)

Remember this from Lecture 2…



Vaughan's analysis shows that the key problems were here

the "standard story" says the issue was all here

Important context

from Diane Vaughan
The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA (1996)

"The issue for decision makers at all levels was not whether NASA flying with known risks, but how large those risks were"

"With no design precedent and no ability to test the vehicle under full enivromental forces, data from in-flight performance was paramount"

"The distinction between managers and engineers was not as clear as the dichotomy suggests. All managers in work groups were trained engineers, [but differed in that they] interfaced with the outside world."

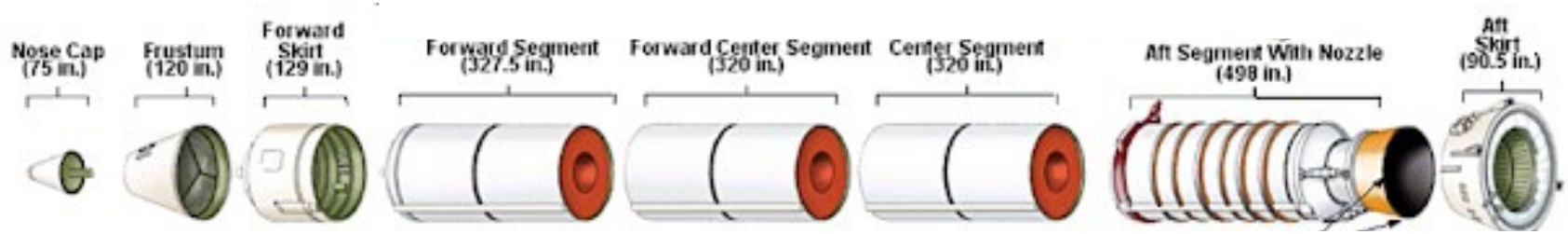
The disaster stemmed from a solid rocket booster

How do solid rocket boosters work?

- The inside of the SRB is simply fuel
- The fuel is ignited, making huge explosion
- The explosion is directed out the bottom of the SRB… and this causes thrust upwards

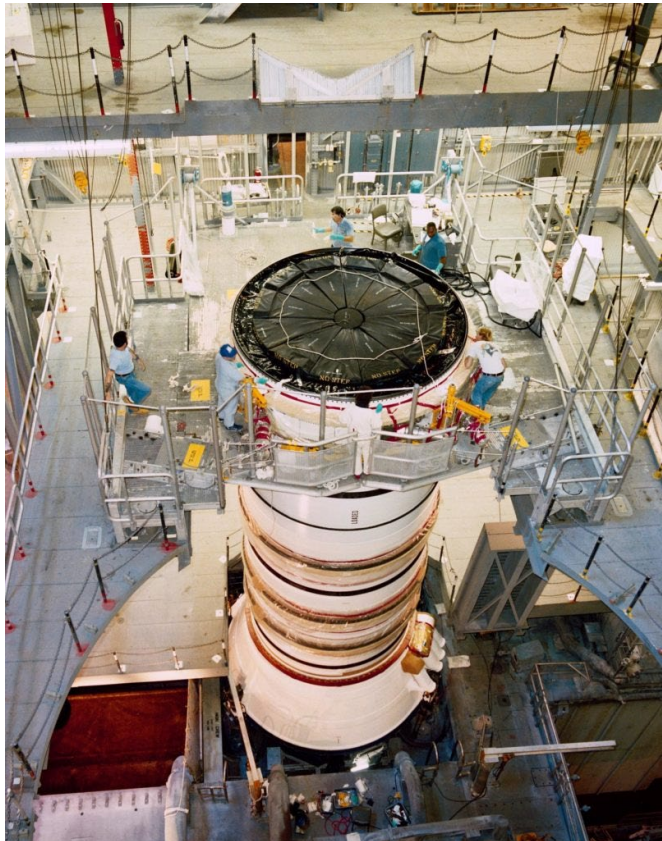
My former student, Joe Toth (BS 2015, PhD 2020), now works at the NASA Kennedy Space Center in Florida, where the rockets are launched

Solid rocket boosters are HUGE!!! They are 149 ft long!



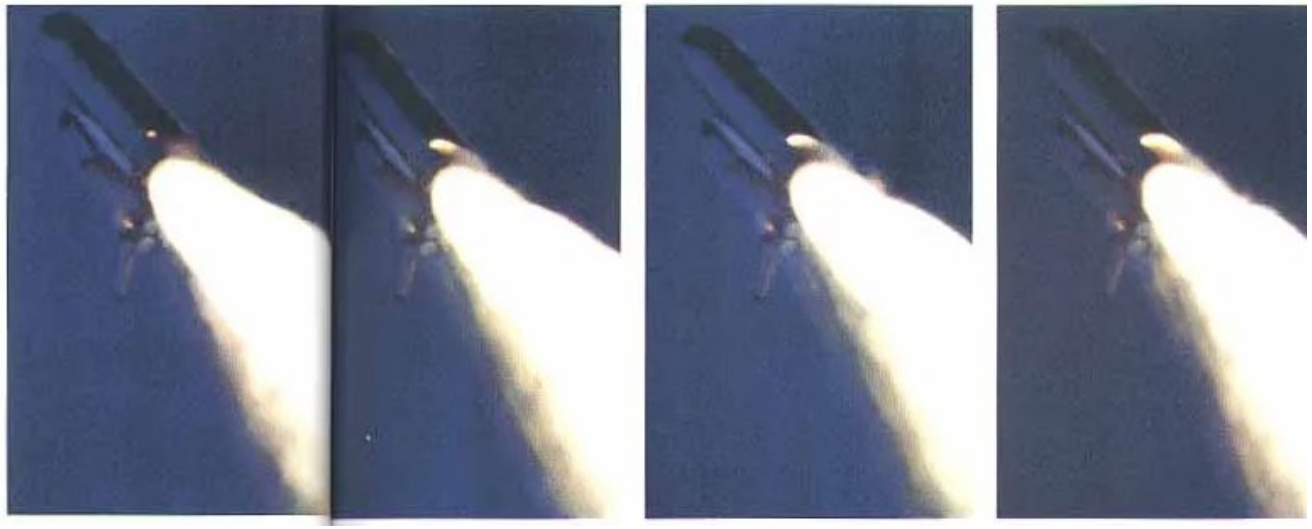
The solid rocket boosters are so big that they were manufactured and shipped in parts to be assembled at NASA

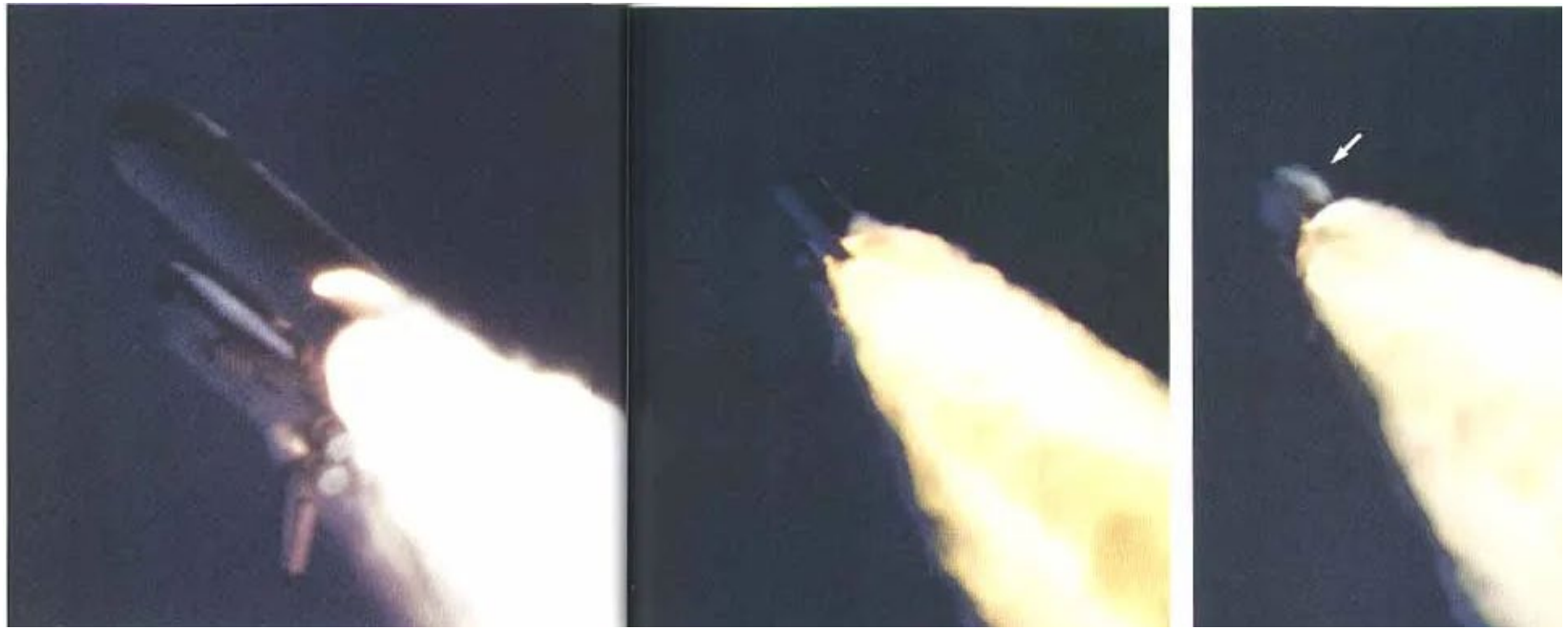
Designed and manufactured by contractor Morton Thiokol in Utah



Flames "leaked" out of a joint between solid rocket booster segments

... the leak gets bigger and bigger

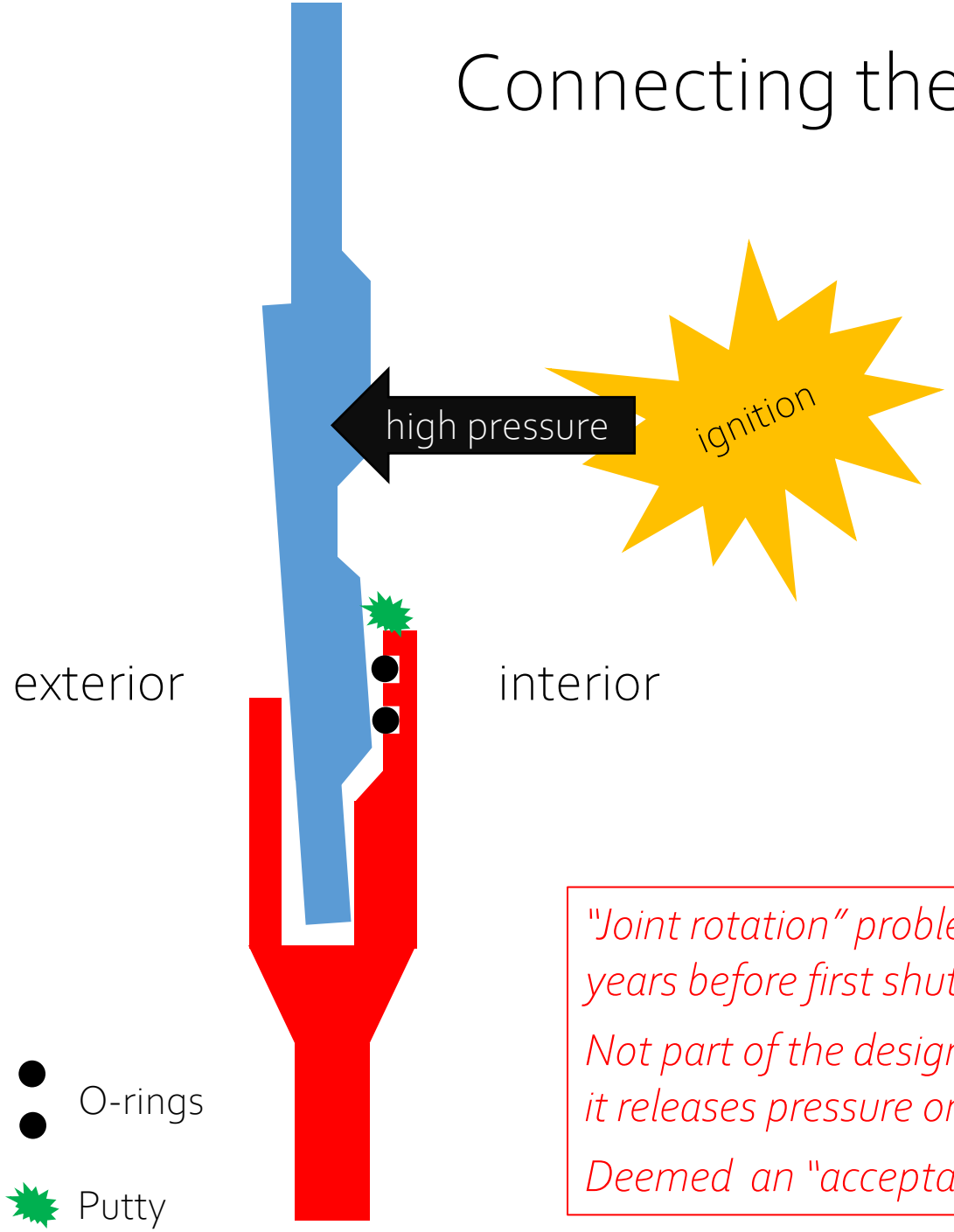


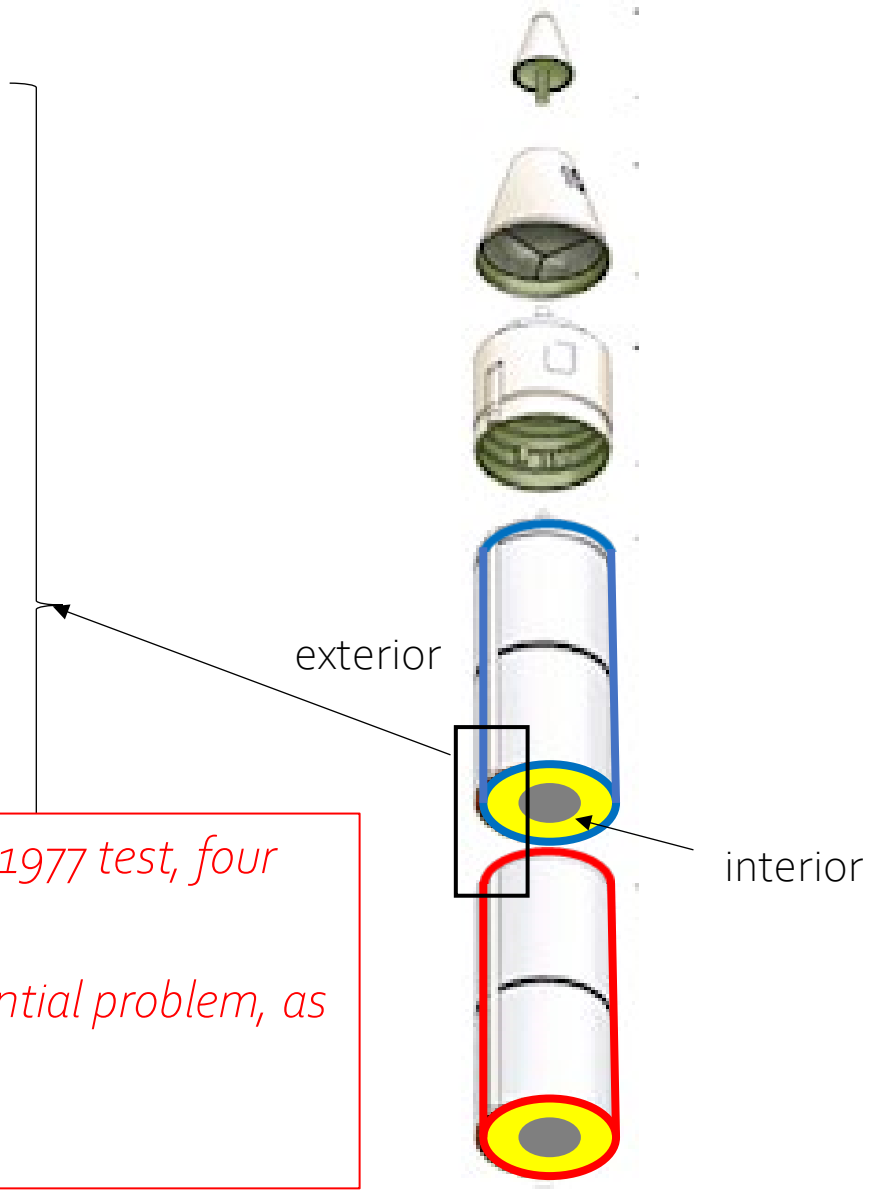


... the leak created thrust in wrong directions, caused solid rocket booster to come loose and damage external fuel tank, which began to leak its fuel

https://www.nasa.gov/history/rogersrep/v1p26.htm

Connecting the Solid Rocket Booster segments





"Joint rotation" problem found in 1977 test, four years before first shuttle launch

Not part of the design! It's a potential problem, as it releases pressure on seal

Deemed an "acceptable risk"

O-ring erosion found on second shuttle flight (1981)

The Solid Rocket Boosters are reusable: After a flight, the solid rocket boosters are disassembled and sent back to Morton Thiokol in Utah, so that new solid fuel can be added

After the second shuttle flight (Nov 1981), erosion was found on an O-ring

(this picture not from space shuttle… just an example of what erosion may look like)

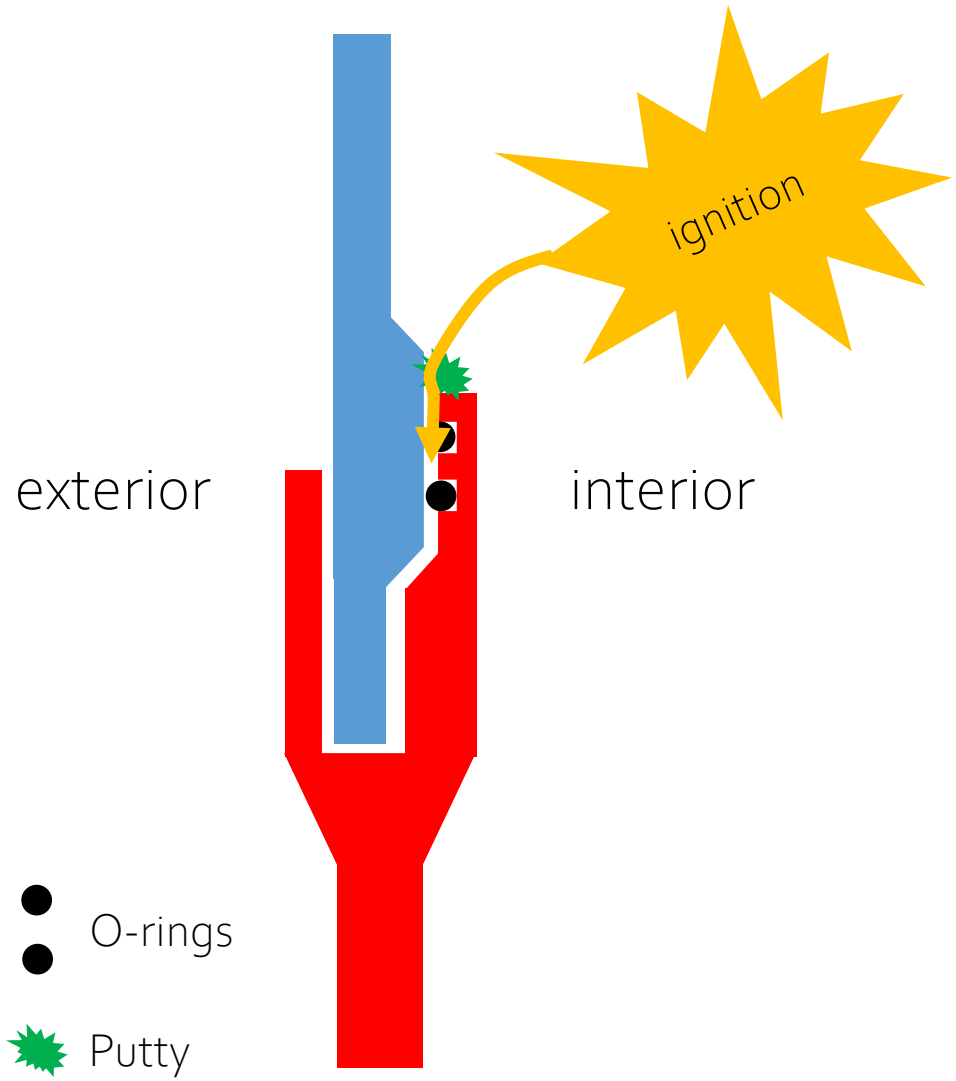
Cause:

- weak spots in putty caused by bubbles lead to blow holes
- hot gases passed through blow holes to cause erosion

Resolution:

- improved the putty to remove bubbles
- modeling, lab experiments show seal effective with this amount of erosion
- deemed an "acceptable risk"

O-ring "blow-by" found on eleventh shuttle flight (1984)



After the eleventh shuttle flight (Aug 1984), soot was found between the primary and secondary O-rings showing that hot gas had "blown-by" the primary O-ring

Cause:

- before pressure fully develops, there is a very short period at start where O-ring seal not complete
- some hot gas passed primary O-ring in this short period
- occured only now due to switch to higher-pressure leak test, which weakens putty but is more accurate leak test

Resolution:

- tiny amount of residue – confirmed engineering prediction that only VERY short period before primary O-ring seals
- deemed an "acceptable risk"

Flight or Motor	Date	(Solid Rocket Booster)	Joint/O-Ring	Leak test (psi)		Erosion	Blow-by	Joint Temp °F
				Field	Nozzle			
STS-1	04/12/81	-	-	50	50	-	-	66
STS-2	11/12/81	(Right)	Aft Field/Primary	50	50	X	-	70
STS-3	03/22/81	-	-	50	50	NA	NA	80
STS-4	06/27/82	Unknown: hardware lost at sea		50	50	NA	NA	80
STS-5	11/11/82	-	-	50	50	-	-	68
STS-6	04/04/83	(Right)	Nozzle/Primary	50	50	([1])	-	67
		(Left)	Nozzle/Primary	50	50	([1])	-	67
STS-7	06/18/83	-	-	50	50	-	-	72
STS-8	08/30/83	-	-	100	50	-	-	73
STS-9	12/28/83	-	-	100[2]	100	-	-	70
STS 41-B	02/03/84	(Right)	Nozzle/Primary	200	100	X	-	57
		(Left)	Forward Field/Primary	200	100	X	-	57
STS 41-C	04/06/84	(Right)	Nozle/Primary	200	100	X	-	63
		(Left)	Aft Field/Primary	200	100	([3])	-	63
		(Right)	Igniter/Primary	NA	NA	-	X	63
STS 41-D	08/30/84	(Right)	Forward Field/Primary	200	100	X	-	70
		(Left)	Nozzle/Primary	200	100	X	X	70
		(Right)	Igniter/Primary	NA	NA	-	X	70
STS 41-G	10/05/84	-	-	200	100	-	-	67
STS 51-A	11/08/84	-	-	200	100	-	-	67

erosion!

heat damage on O-ring (no erosion)

start of higher pressure leak test

erosion!

erosion and blow-by!

erosion and blow-by!

https://www.nasa.gov/history/rogersrep/v1ch6.htm

Where things stood thru 1984

Flight or Motor	Date	(Solid Rocket Booster)	Joint/O-Ring	Leak test (psi)		Erosion	Blow-by	Joint Temp °F
				Field	Nozzle			
STS-1	04/12/81	-	-	50	50	-	-	66
STS-2	11/12/81	(Right)	Aft Field/Primary	50	50	X	-	70
STS-3	03/22/81	-	-	50	50	NA	NA	80
STS-4	06/27/82	Unknown: hardware lost at sea		50	50	NA	NA	80
STS-5	11/11/82	-	-	50	50	-	-	68
STS-6	04/04/83	(Right)	Nozzle/Primary	50	50	(1)	-	67
		(Left)	Nozzle/Primary	50	50	(1)	-	67
STS-7	06/18/83	-	-	50	50	-	-	72
STS-8	08/30/83	-	-	100	50	-	-	73
STS-9	12/28/83	-	-	100[2]	100	-	-	70
STS 41-B	02/03/84	(Right)	Nozzle/Primary	200	100	X	-	57
		(Left)	Forward Field/Primary	200	100	X	-	57
STS 41-C	04/06/84	(Right)	Nozle/Primary	200	100	X	-	63
		(Left)	Aft Field/Primary	200	100	(3)	-	63
		(Right)	Igniter/Primary	NA	NA	-	X	63
STS 41-D	08/30/84	(Right)	Forward Field/Primary	200	100	X	-	70
		(Left)	Nozzle/Primary	200	100	X	X	70
		(Right)	Igniter/Primary	NA	NA	-	X	70
STS 41-G	10/05/84	-	-	200	100	-	-	67
STS 51-A	11/08/84	-	-	200	100	-	-	67

https://www.nasa.gov/history/rogersrep/v1ch6.htm

"at the end of 1984, consensus existed: erosion and blow-by were accepted and expected in future flights by the engineers and managers who worked most closely on it"
– D. Vaughan

From actual NASA documentation

FLIGHT READINESS ASSESSMENT FOR STS-51E (CONT)

- EVALUATION SUMMARY
  - STA-51-C PRIMARY O-RING EROSION ON TWO FIELD JOINTS
  - STS-51-C SOOT BETWEEN PRIMARY AND SECONDARY O-RINGS ON BOTH FIELD JOINTS -- FIRST TIME OBSERVED ON FIELD JOINT
  - EVIDENCE OF HEAT AFFECT ON SECONDARRY O-RING OF A68 (RIGHT HAND) CENTER FIELD JOINT BUT NO EROSION
- CONCLUSION
  - STS-51-C CONSISTENT WITH EROSION DATA BASE
    - LOW TEMPERATURE ENHANCED PROBABILITY -- STS-51-C EXPERIENCED WORST CASE TEMPERATURE CHANGE IN FLORIDA HISTORY
    - EROSION IN TWO JOINTS OBSERVED BEFORE -- STS-11 AND -14
  - STS-51-E COULD EXHIBIT SAME BEHAVIOR
  - CONDITION IS ACCEPTABLE

erosion on 2 joints!

Soot after primary O-ring...
FIRST TIME OBSERVED!

Heat damage on SECONDARY O-ring...
FIRST TIME OBSERVED!

T in teens night before,
53 °F at take-off!

They considered this carefully, with engineering analysis and modeling, and concluded it was acceptable

The second launch of 1985

Notwithstanding these issues, everyone was very confident about the safety…

…so confident, that the next flight included Senator Jake Garn, from Utah (Thiokol's home state), and chair of a Senate subcommittee that oversaw NASA's budget!

"Ironically, STS 51-D sustained the most extensive erosion found on a primary O-ring to date.
Despite moderate weather that put joint temperature at 67°F prior to ignition…
STS 51-D's first-ever 'outside the experience base' erosion did not alarm the work group, however."
- D. Vaughan

The third launch of 1985… from actual NASA documentation

"not unprecendented"

status closed = acceptable risk

PROBLEM	CONCERN	RESOLUTION	STATUS
UNUSUAL EROSION OBSERVED ON PRIMARY AND SECONDARY O-RINGS OF STS 51-B NOZZLE TO CASE JOINT (SRM 16 A) — PRIMARY O-RING APPARENTLY NEVER SEATED RESULTING IN WORST EROSION YET OBSERVED — SECONDARY O-RING HAD 32 MILS EROSION (1ST TIME OBSERVATION)	FLIGHT SAFETY	• EVIDENCE OF HOT GAS PAST PRIMARY O RING IS NOT UNPRECEDENTED	CLOSED
		• LEAK CHECK USED ON STS 51-B DID NOT VERIFY CAPABILITY OF PRIMARY O-RING TO SEAL	
		• LEAK CHECK USING 200 PSIG STABILIZATION PRESSURE ON STS 51-F AND SUBS PROVIDES CONFIDENCE THAT PRIMARY O-RINGS HAVE CAPABILITY TO SEAL • LEAK CHECK ASSURES SECONDARY O-RING WILL SEAL AGAINST MOTOR PRESSURE	
		• MAXIMUM EROSION THAT CAN OCCUR ON SECONDARY O-RING IN LIMITED TIME THAT FLOW EXISTS ON AND PAST PRIMARY O-RING IS 75 MILS (CONSERVATIVE ANALYSIS) • —2 SUBSCALE TESTS VERIFY THAT A PROPERLY SEATED O-RING CAN SUSTAIN A MINIMUM OF 125 MILS EROSION BEFORE SEAL IS COMPROMISED	

"worst erosion yet observed"

"Secondary O-ring had erosion (1st time observation)"

Believed the cause was O-ring was never sealed, due to problem like piece lint preventing seal

will include better leak test in future

Models and experiments show erosion won't be a problem due to secondary O-ring

STS 51-C	01/24/85	(Right)	Center Field/Primary	200	100	X	X	53
		(Right)	Center Field/Secondary	200	100	(4)	-	53
		(Right)	Nozzle/Primary	200	100	-	X	53
		(Left)	Forward Field/Primary	200	100	X	X	53
		(Left)	Nozzle/Primary	200	100	-	X	53
STS 51-D	04/12/85	(Right)	Nozzle/Primary	200	200	X	-	67
		(Right)	Igniter/Primary	NA	NA	-	X	67
		(Left)	Nozzle/Primary	200	200	X	-	67
		(Left)	Igniter/Primary	NA	NA	-	X	67
STS 51-B	04/29/85	(Right)	Nozzle/Primary	200	100	X	-	75
		(Left)	Nozzle/Primary	200	100	X	X	75
		(Left)	Nozzle/Primary	200	100	X	-	75
STS 51-G	06/17/85	(Right)	Nozzle/Primary	200	200	X[5]	X	70
		(Left)	Nozzle/Primary	200	200	X	X	70
		(Left)	Igniter/Primary	NA	NA	-	X	70
STS 51-F	07/29/85	(Right)	Nozzle/Primary	200	200	(6)	-	81
STS 51-I	08/27/85	(Left)	Nozzle/Primary	200	200	X[7]	-	76
STS 51-J	10/03/85		-	200	200	-	-	79
STS 61-A	10/30/85	(Right)	Nozzle/Primary	200	200	X	-	75
		(Left)	Aft Field/Primary	200	200	-	X	75
		(Left)	Center Field/Primary	200	200	-	X	75
STS 61-B	11/26/85	(Right)	Nozzle/Primary	200	200	X	-	76
		(Left)	Nozzle/Primary	200	200	X	X	76
STS 61-C	01/12/86	(Right)	Nozzle/Primary	200	200	X	-	58
		(Left)	Aft Field/Primary	200	200	X	-	58
		(Left)	Nozzle/Primary	200	200	-	X	58

erosion and worst-ever blow-by!
... and coldest launch... related?

worst-ever erosion
... in warm weather

a new worst-ever erosion
... and secondary O-ring erosion
... in warm weather

erosion and blow-by

no erosion...just heat damage

erosion

erosion and blow-by

erosion and blow-by

erosion and blow-by

"adversarial" not meant in a bad way... but as a way to push to deeper understanding... like an oral examination

"[Thiokol's] Boisjoly posited a correlation between cold temperature, resiliency, and the damage, on the basis of his observation of the blackened grease.

Marshall's Mulloy, taking his usual adversarial FRR role, questioned Boisjoly's conclusion that there was a causal relationship between cold temperature and erosion. Thiokol had already identified many different factors that caused O-ring erosion in the past: the putty pattern, a piece of lint in the putty, an O-ring in improper position, putty composition, unidentified imperfection in the O-ring composition, and so forth. If cold had caused the damage by reducing O-ring resiliency, why did damage occur on only some of the rings of the boosters? What engineering data did they have that showed it was the cold as opposed to another factor or combination of factors that explained what they saw?

The engineers viewed the cold spell as an isolated, idiosyncratic incident. Their intuition suggested that the cold may have contributed to the erosion on STS 51-C, but they had no "real data," and the cold was not likely to be a factor in the future. So although they began their research on O-ring resiliency, it was not driven by a sense of urgency; and because of the definition of the situation, few engineering resources were devoted to it."

From Vaughan's book

The day before the Challenger launch

Very cold temperatures predicted for the launch

That night, an impromptu meeting took place between the Thiokol and NASA solid rocket booster teams to discuss the potential implications of the cold temperature on the launch

Slides from Thiokol engineers in night-before meeting

CONCLUSIONS:

TEMPERATURE OF O-RING IS NOT ONLY PARAMETER CONTROLLING BLOW-BY

SRM 15 WITH BLOW-BY HAD AN O-RING TEMP AT 53°F
SRM 22 WITH BLOW-BY HAD AN O-RING TEMP AT 75°F
FOUR DEVELOPMENT MOTORS WITH NO BLOW-BY WERE TESTED AT O-RING TEMP OF 47° TO 52°F

DEVELOPMENT MOTORS HAD PUTTY PACKING WHICH RESULTED IN BETTER PERFORMANCE

AT ABOUT 50°F BLOW-BY COULD BE EXPERIENCED IN CASE JOINTS

TEMP FOR SRM 25 ON 1-28-86 LAUNCH WILL BE 29°F 9 AM
38°F 2 PM

HAVE NO DATA THAT WOULD INDICATE SRM 25 IS DIFFERENT THAN SRM 15 OTHER THAN TEMP

RECOMMENDATIONS:

- O-RING TEMP MUST BE $\geq$ 53°F AT LAUNCH

DEVELOPMENT MOTORS AT 47° TO 52°F WITH PUTTY PACKING HAD NO BLOW-BY
SRM 15 (THE BEST SIMULATION) WORKED AT 53°F

- PROJECT AMBIENT CONDITIONS (TEMP & WIND) TO DETERMINE LAUNCH TIME

This was questioned: Was there any engineering evidence for 53 °F?

Final Thiokol launch recommendation

MTI ASSESSMENT OF TEMPERATURE CONCERN ON SRM-25 (51L) LAUNCH

- CALCULATIONS SHOW THAT SRM-25 O-RINGS WILL BE 20° COLDER THAN SRM-15 O-RINGS
- TEMPERATURE DATA NOT CONCLUSIVE ON PREDICTING PRIMARY O-RING BLOW-BY
- ENGINEERING ASSESSMENT IS THAT:
  - COLDER O-RINGS WILL HAVE INCREASED EFFECTIVE DUROMETER ("HARDER")
  - "HARDER" O-RINGS WILL TAKE LONGER TO "SEAT"
    - MORE GAS MAY PASS PRIMARY O-RING BEFORE THE PRIMARY SEAL SEATS (RELATIVE TO SRM-15)
      - DEMONSTRATED SEALING THRESHOLD IS 3 TIMES GREATER THAN 0.038" EROSION EXPERIENCED ON SRM-15
  - IF THE PRIMARY SEAL DOES NOT SEAT, THE SECONDARY SEAL WILL SEAT
    - PRESSURE WILL GET TO SECONDARY SEAL BEFORE THE METAL PARTS ROTATE
      - O-RING PRESSURE LEAK CHECK PLACES SECONDARY SEAL IN OUTBOARD POSITION WHICH MINIMIZES SEALING TIME
- MTI RECOMMENDS STS-51L LAUNCH PROCEED ON 28 JANUARY 1986
  - SRM-25 WILL NOT BE SIGNIFICANTLY DIFFERENT FROM SRM-15

JOE C. KILMINSTER, VICE PRESIDENT
SPACE BOOSTER PROGRAMS

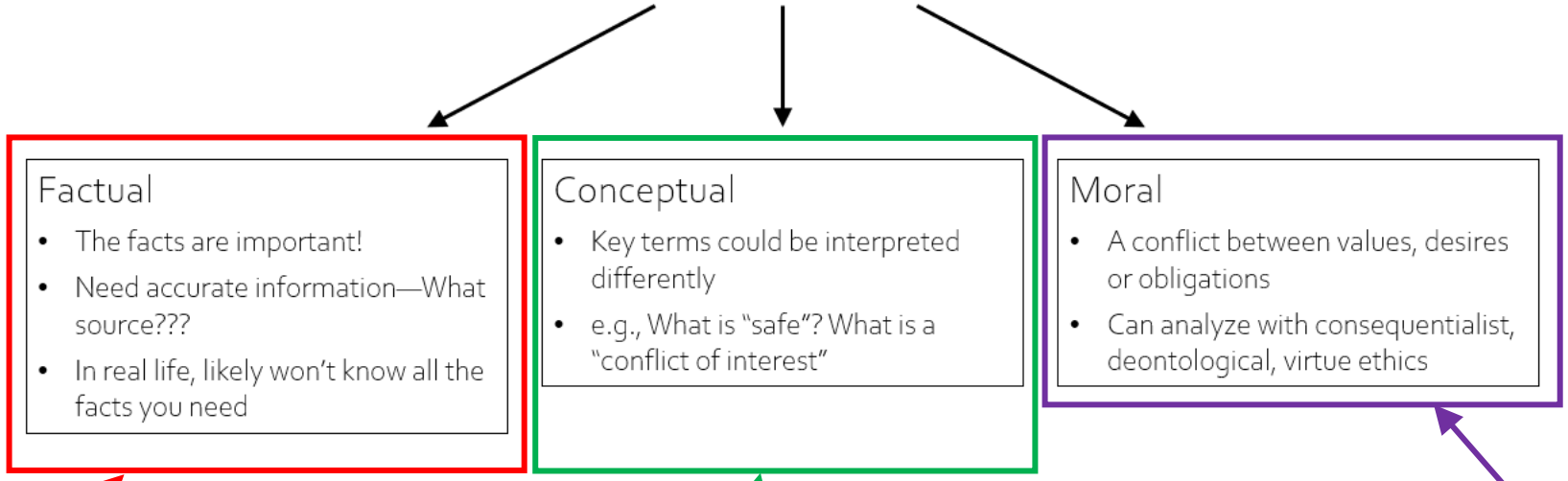
MORTON THIOKOL INC.
Wasatch Division

“Normalization of deviance”

> “The work group normalized the deviant performance of the SRB joint. By ‘normalized’, I mean that behavior the work group first identified as technical deviation was subsequently reinterpreted as within the norm for acceptable joint performance, then finally officially labeled an acceptable risk. They redefined evidence that deviated from an acceptable standard so that it became the standard.”

This is the key reason for the Challenger disaster
identified by Diane Vaughan in her book

An ethical question



Vaughan: "With no design precedent and no ability to test the vehicle under full enivromental forces, data from in-flight performance was paramount"
... key facts can only be known from actual flights

Vaughan: "The issue for decision makers at all levels was not whether NASA flying with known risks, but how large those risks were"
... what is an "acceptable" risk?

Vaughan: "Amorally calculating managers intentionally violating rules to achieve organization goals does not explain the Challenger disaster. Managers were, in fact, quite moral and rule abiding as they calculated risk."

Q1: What is the normalization of deviance, and what is one example of normalization of deviance that you have personally encountered?

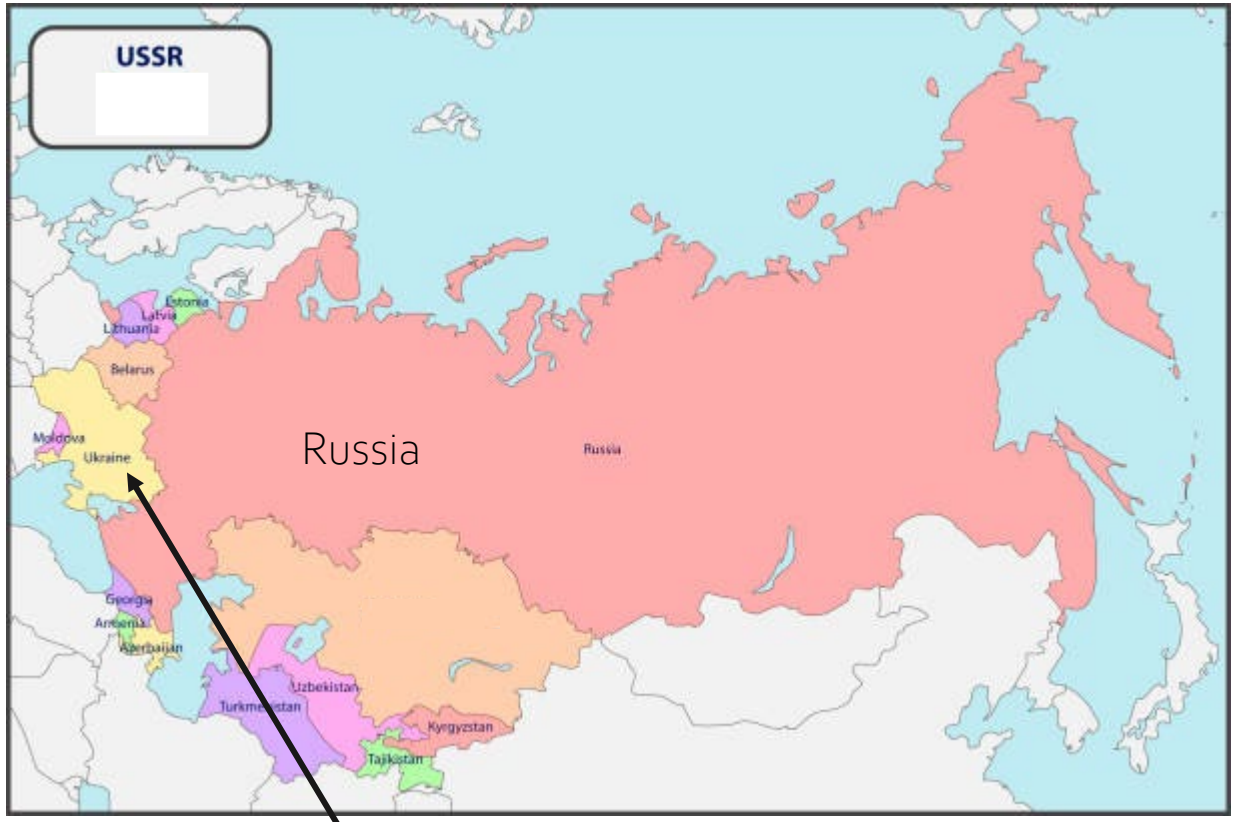

ГОТЕЛЬ ПОЛІССЯ


РЕСТОРАН


ПРИПЯТЬ
КАФЕ


HBO

Union of Soviet Socialist Republics (USSR): 1922-1991



The Russian Empire was overthrown in 1917. After a few years of civil war, the USSR was formed in 1922

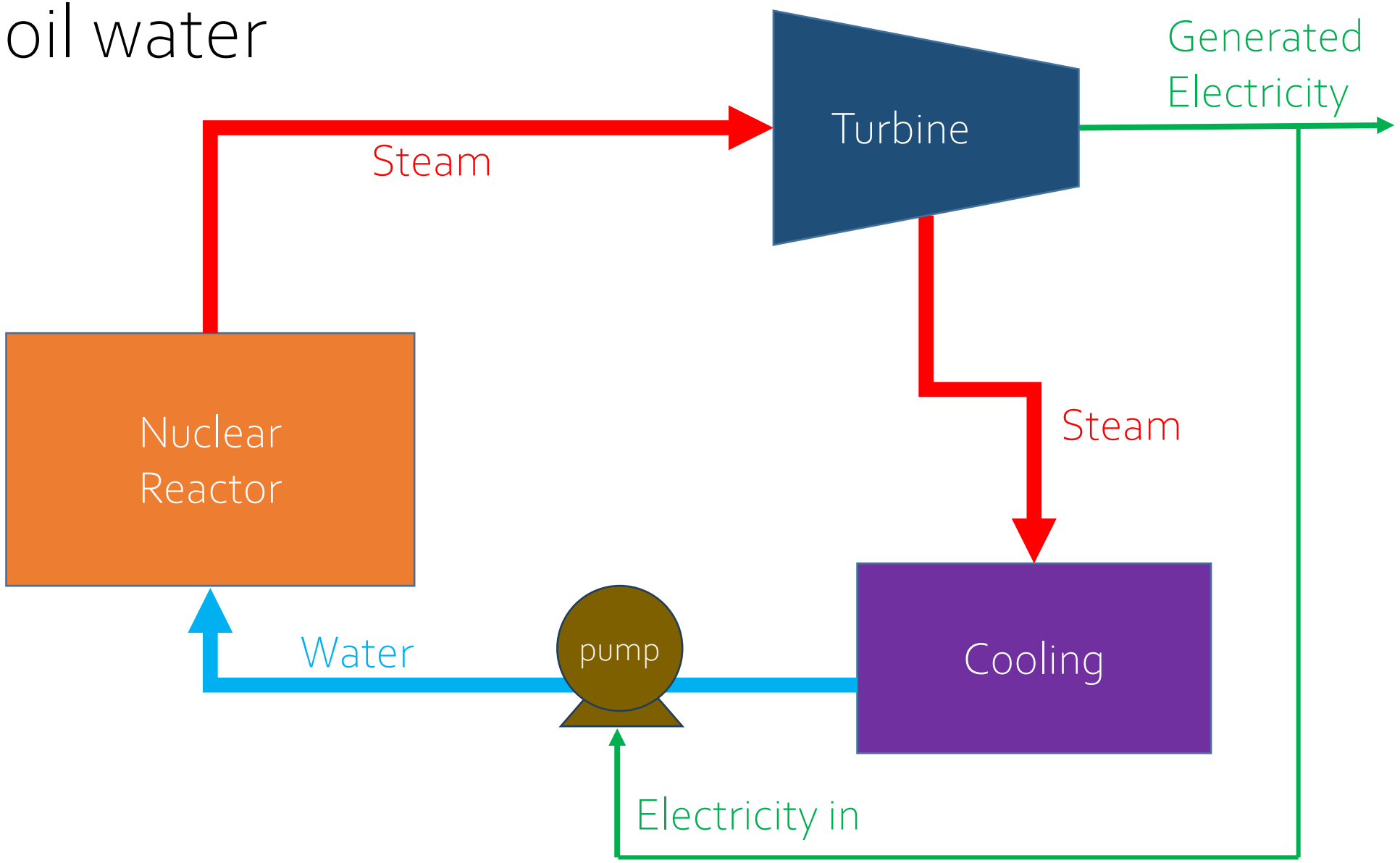
The USSR was dominated by Russia, but included 14 other republics including Kazakhstan, Uzbekistan, Turkmenistan… and Ukraine

The USSR broke up in 1991, and the republics became independent countries

A nuclear reactor is simply a way to boil water

Heat is transferred from reactor to water:

- *water is heated*
- *reactor is cooled*



Basics of nuclear fission

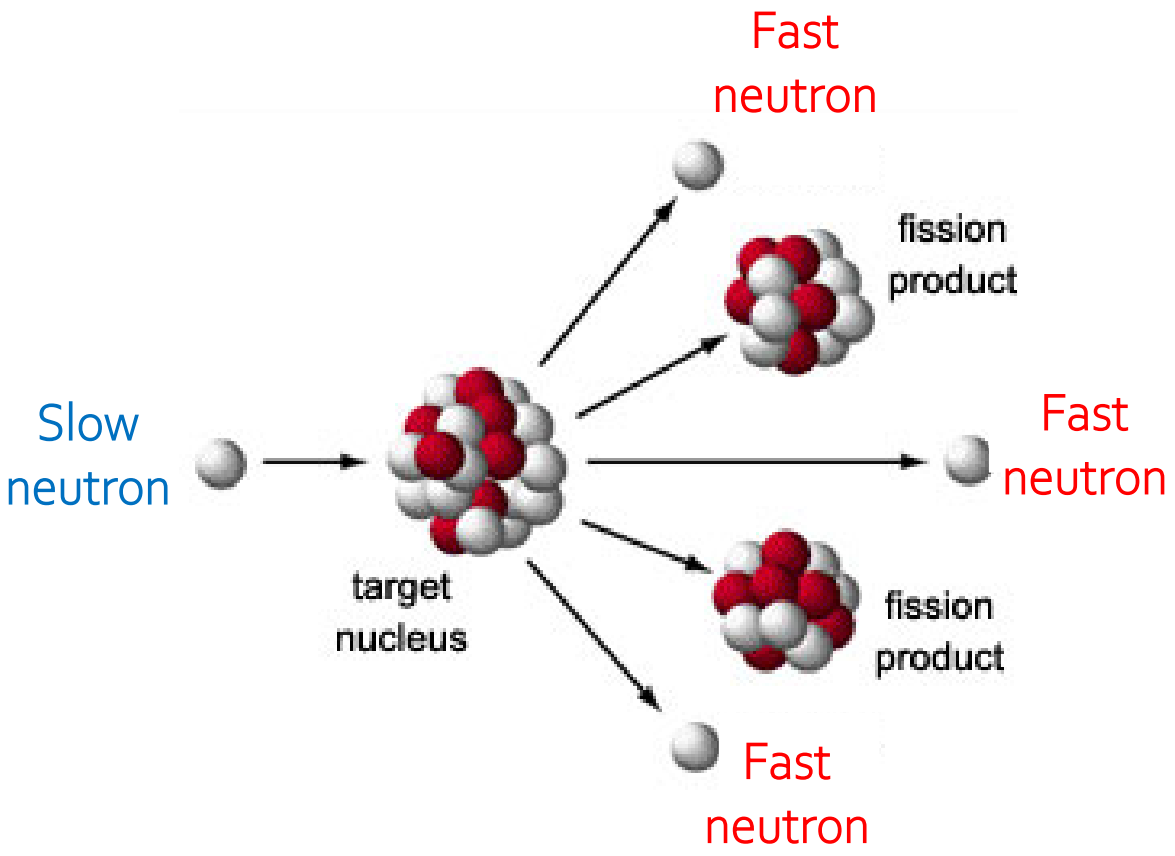
Slow neutrons cause fission of uranium 235, which releases more neutrons

These fission events release fast neutrons, which cannot cause more fission events

Thus need to convert fast neutrons to slow neutrons to get more fission.

To slow down the neutrons, reactors use either:

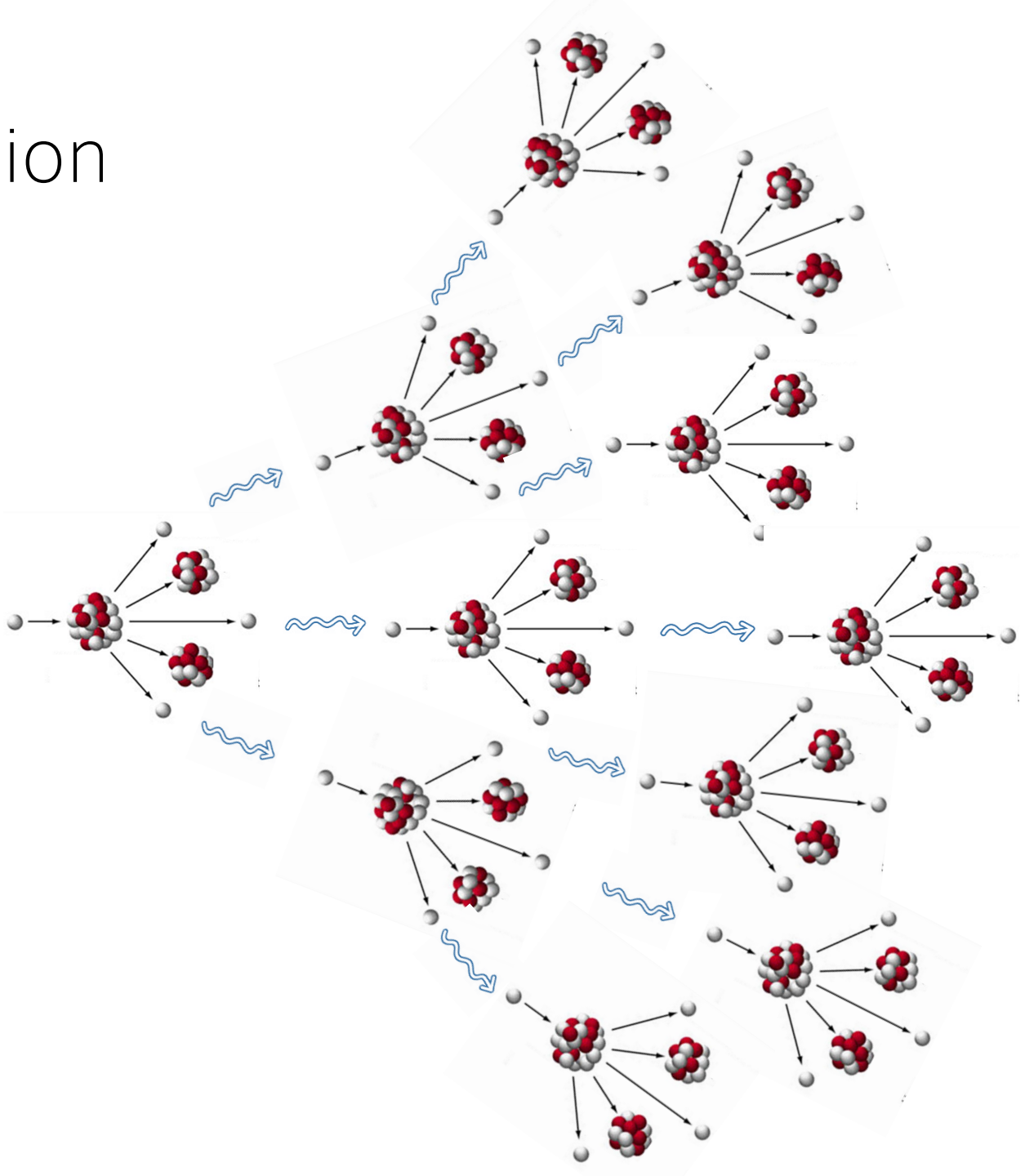
- Graphite (Chernobyl)
- Water (US reactors)



We'll see this is VERY important!

Nuclear chain reaction

We'll use this symbol for slowing down a fast neutron



Critical design difference

because graphite slows the neutrons

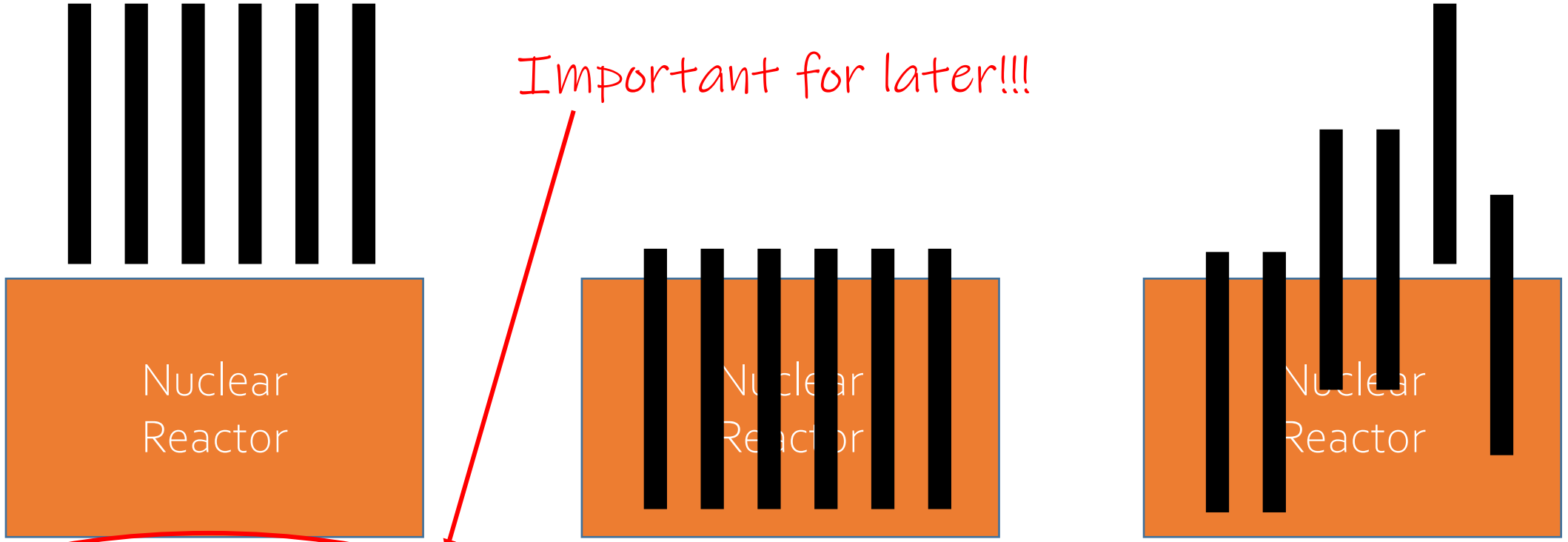
Role of water:		
Heat transfer	Cools reactor	Cools reactor
Nuclear reaction	Slows down neutrons	No impact
If water flow to reactor stops:		
Re heat transfer	Reactor T increases	Reactor T increases
Re nuclear reaction	Reaction stops	Reaction continues

"Inherently Safe Design"
a problem occurs → reaction stops

if theres a problem...
it's going to get worse!

The "on-off switch" and "volume-control knob"

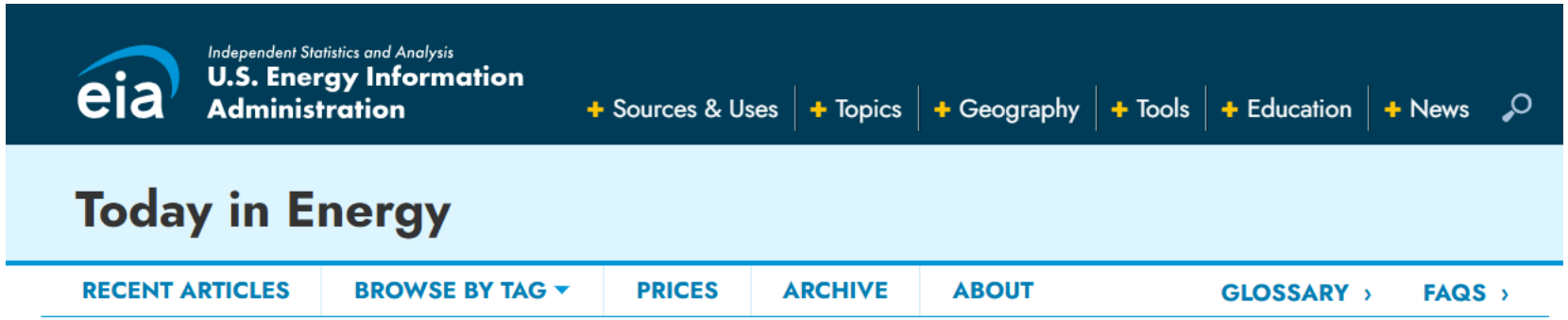
Control rods are made of material that absorbs neutrons



Control rods fully out –
No neutrons absorbed,
no control of chain reaction

Control rods fully in –
Maximal neutrons absorbed,
chain reaction stopped

Intermediate positions –
Control fission rate



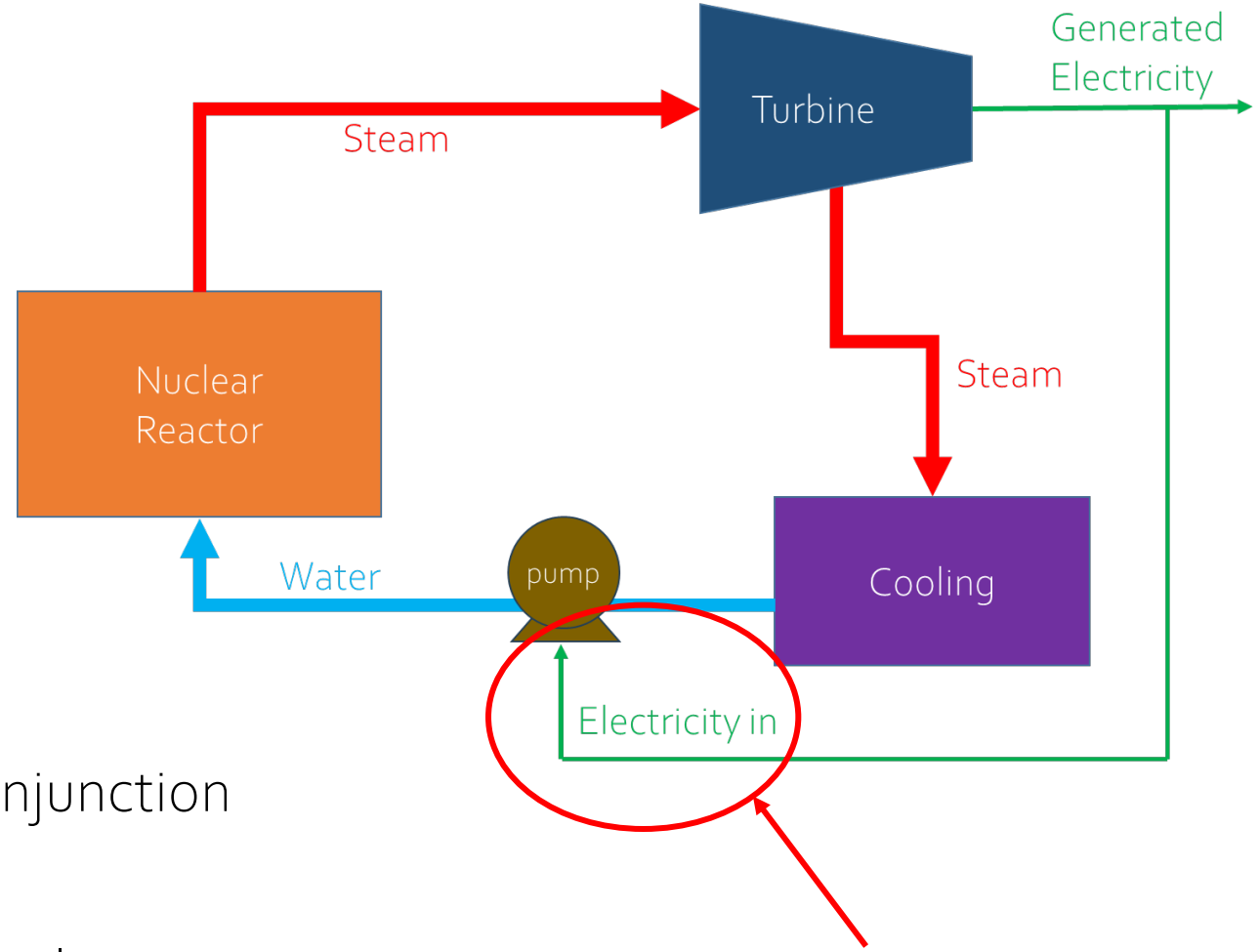
MAY 23, 2011

Nuclear power plants undergo seasonal scheduled outages

"Like most electric generators, nuclear reactor operators typically schedule maintenance in the spring and the fall to help ensure that the reactors are available to meet peak electric demand in the summer and winter. Although a reactor can hold several years of fuel, operators choose to refuel their reactors after approximately 18 or 24 months of full power operation."

April 1986

Chernobyl Reactor 4 had a scheduled shutdown for routine maintenance



A test to improve safety was planned in conjunction with the scheduled shutdown:

If steam to turbine stops, will the mechanical inertia of the turbine provide electricity to power water pumps long enough to transition to diesel generator?

If this electricity is lost, cannot pump water to cool reactor

Diesel generators available, but it takes ~1 minute to transition to these

April 25:

- Begin power reduction from normal level of 3200 MW to 700-1000 MW needed for test
- Fission product and neutron absorber Xe builds up during shutdown, causes power drop to 30 MW
- To compensate for the power being too low, most control rods are removed
- Emergency cooling system shut off so it doesn't interfere with test

April 26:

- 1 am: Decide to proceed with test at 200 MW (not the planned test power!)
- Test was at a lower power than planned, so the planned water flow for test was too high
- Steam pressure dropped, and automatic control system removed more control rods
- 1:23:04 am: Reactor appears stabilized, so the actual test starts: steam supply to turbine is cut
- Cutting steam means less generator power and thus less cooling water… power climbs sharply!
- 1:23:40am: Order given to move all control rods into reactor to shut off reaction
- Since control rods were almost completely withdrawn,this was too slow and too late
- 1:24am Buildup of steam caused explosion that breached reactor.

https://www.oecd-nea.org/jcms/pl_28271/chernobyl-chapter-i-the-site-and-accident-sequence

Long story short…

"Unapproved changes in the test procedure were deliberately made on the spot, although the plant was known to be in a condition very different from that intended for the test.

The personnel were unaware of some of the dangerous features of the reactor and, therefore, did not realize the consequences of the violations."

INSAG-7 The Chernobyl Accident: Updating of INSAG-1
A Report by the International Nuclear Safety Advisory Group

Management of Change Reviews for Small Modifications

Jody E. Olsen, P.E. ▪ JE Olsen Consulting, LLC

Management of change (MOC) reviews should not be do-it-yourself, even for small changes. Seek skilled specialists for all aspects of your MOC reviews.

One of the primary objectives of management of change (MOC) is to ensure that changes made to correct one problem do not introduce unintended consequences or new problems. MOC reviews are accomplished by considering the change from multiple perspectives rather than focusing narrowly on the problem at hand.

To ensure that the review process works, reviews are needed by individuals representing all disciplines associated with the change. To accomplish this goal, changes need to be screened to identify the impacted disciplines and the reviews need to be performed by qualified personnel.

Chemical Engineering Progress, December, 2022

Q2: How is “inherently safe design” relevant to Chernobyl? How is “management of change review” relevant to Chernobyl?

The Chernobyl explosion was in 1986!!!

… is Chernobyl still relevant?

The Economist

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Culture | The invasion of Ukraine

How a second nuclear disaster was avoided at Chernobyl in 2022

The Russian occupation underscored the risks posed by nuclear sites in wartime

Does this look familiar?

It's the same place I took my picture!

THE WALL STREET JOURNAL.

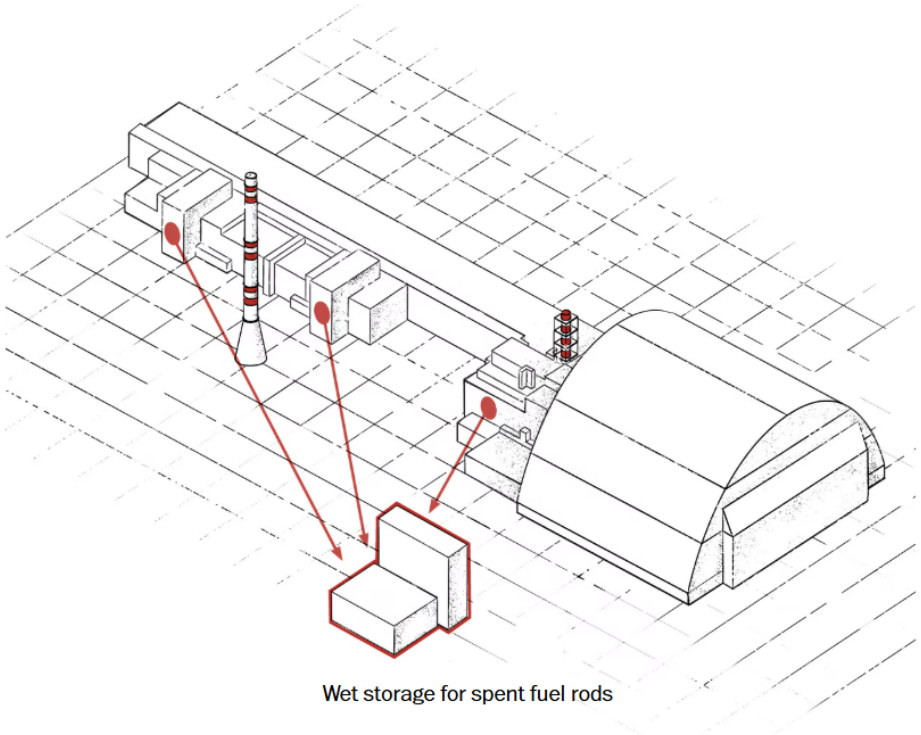
WORLD

Inside Chernobyl, 200 Exhausted Staff Toil Round the Clock at Russian Gunpoint

Trapped since their shift 3 weeks ago, the Ukrainians keeping the abandoned nuclear plant safe are ill-fed, stressed and desperate for relief

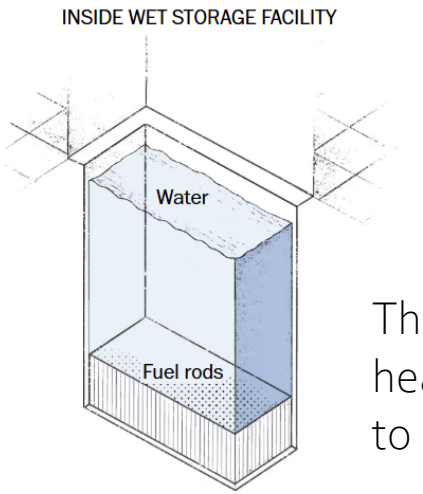
By *Joe Parkinson* Follow *and* *Drew Hinshaw* Follow

March 15, 2022 11:10 am ET

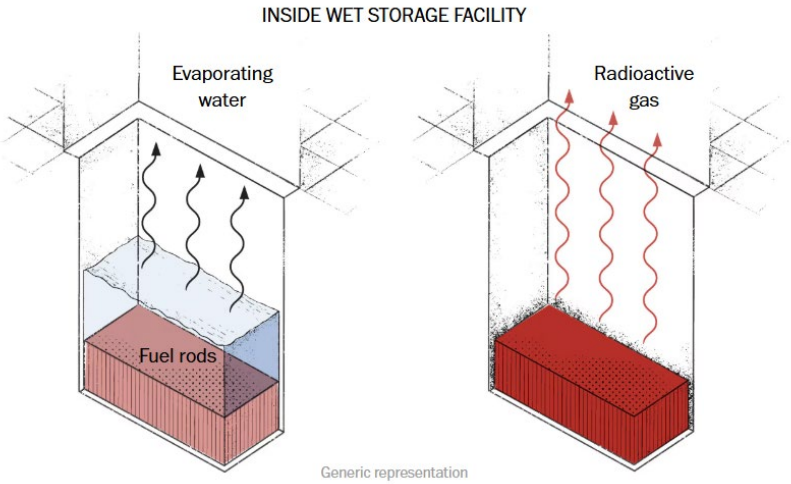


"We worked almost around-the-clock. We rested a few hours according to schedule. We became exhausted," said safety engineer Liudmyla Kozak. "We asked to be relieved because we were already walking around like ghosts."

Oleksii Shelestii, chief electrical engineer on the shift, said he was close to a nervous breakdown by the end of the second week.



The fuel rods generate heat… water circulates to keep them cool



Without power, water circulation and cooling stop… water can evaporate, and hot fuel rods catch fire and release radioactive Ce 137

https://www.washingtonpost.com/world/2022/03/11/chernobyl-nuclear-risk/

THE WALL STREET JOURNAL.

EUROPE

Chernobyl Workers Pick Up the Pieces After Russian Occupation

Catastrophe was averted, but employees at the site of the world's worst nuclear disaster say the facility was ransacked

Ukrainian forces damaged a bridge near Chernobyl to slow Russian troops' advance.

By Vivian Salama Follow *and Maksym Golubenko | Photographs by Justyna Mielnikiewicz/MAPS for The Wall Street Journal*

June 6, 2022 5:30 am ET

Q3: Immediately after the explosion, firefighters heroically rushed in to contain the fire and prevent a much larger disaster. Many of the firefighters died within the next month from radiation poisoning.

If you were in charge of the situation, would you send in the firefighters knowing that many will die, but also knowing that if they do not go in this nuclear disaster could claim MANY more lives? Do you follow a consequentialist, deontological or virtue ethics approach?