The Patriot Missile Disaster – What Went Wrong?

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Patriot Missile System Overview

- Mobile missile defence system
- Designed by Raytheon, Hughes and RCA in 1969; produced in 1976 by Raytheon
- Backronym of “Phased Array Tracking Intercept Of Target”
- Initially designed as anti-aircraft system; extended to deter missiles.

How the System Works [1]

- Operates in battalions - usually composed of six batteries
- Each battery has:
  - Radar unit for target acquisition
  - Control station for manual/automatic control
  - Eight missile launchers
  - Communications station
- Targets detected by radar, acquired by control station, and engaged by launchers

Target Acquisition

Figure 3: Correctly Calculated Range Gate

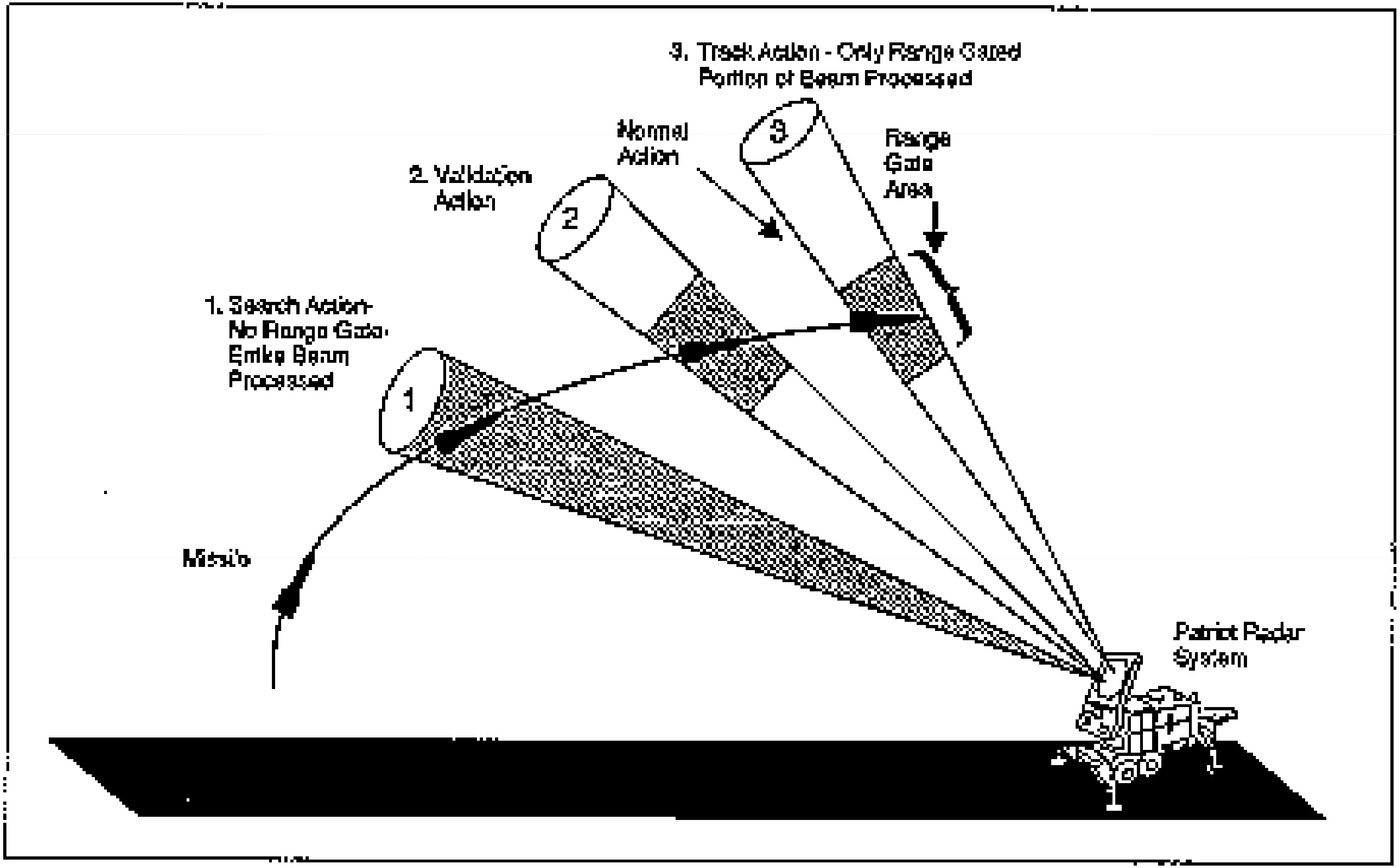

Image source: [1]

Target Destruction

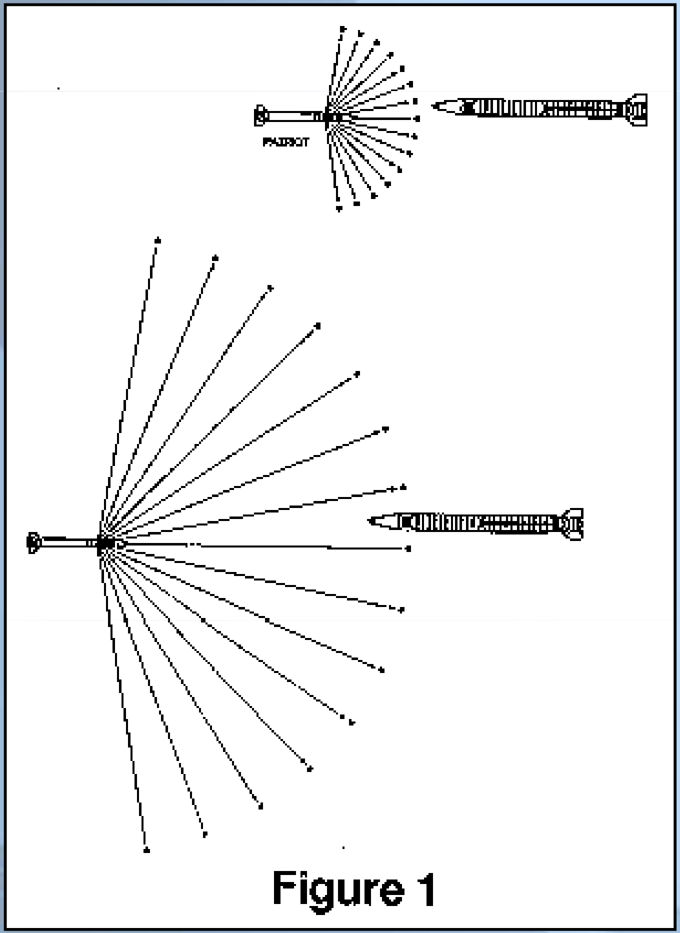

Figure 1

Image source: [3]

- Interceptor detonates in front of target
- Detonation sprays ~1000 pellets forwards in a wide pattern – like a shotgun
- Distance from interceptor to target is important! [2]
  - Ideal range 5-10 metres
  - At 100 metres, probability of hitting target is near-zero

Project Timeline [3][4]

- Development started in 1976 as an anti-aircraft system
- First deployment in 1982
- PAC-1 (1988) introduced limited capability against TBMs
- PAC-2 (1990) improved TBM capability
- PAC-3 (2002-) latest version, complete redesign tailored for TBM interception

The Patriot in the Gulf War

- Patriot deployed in the Persian Gulf War to halt ballistic missiles
- Debatable success rate: from Bush’s “97%” to Postol and Pedatzur’s “0%”!
  - What is a “successful” launch?
- January 25th, 1991: ballistic missile hit army barracks in Dhahran, Saudi Arabia
  - 28 soldiers killed, 97 injured
  - Patriot didn’t detect incoming missile

Failure to Launch

Dhahran, Saudi Arabia, 1991

Failure to Launch

- Dhahran protected by six Patriot batteries
- Alpha and Bravo batteries deployed at time of attack to protect Air Base
  - Bravo out-of-commission due to radar problem
  - Alpha running continuously for four days
- Incoming scud missile not engaged by Alpha
  - 28 casualties, more than 90 injured

Software Faults [1]

- Patriot computer only had 24-bit precision, so it chopped 0.0001% off timing values
- System fell behind by 0.0034 sec (7m) per hour.
- Accuracy threshold is 20 hours.
- System had been running for 100 hours, losing 0.3433 seconds, or 687 metres.
- Range gate affected cumulatively by timing error – looked in the wrong place!

Range Gate Inaccuracy

Figure 5: Incorrectly Calculated Range Gate

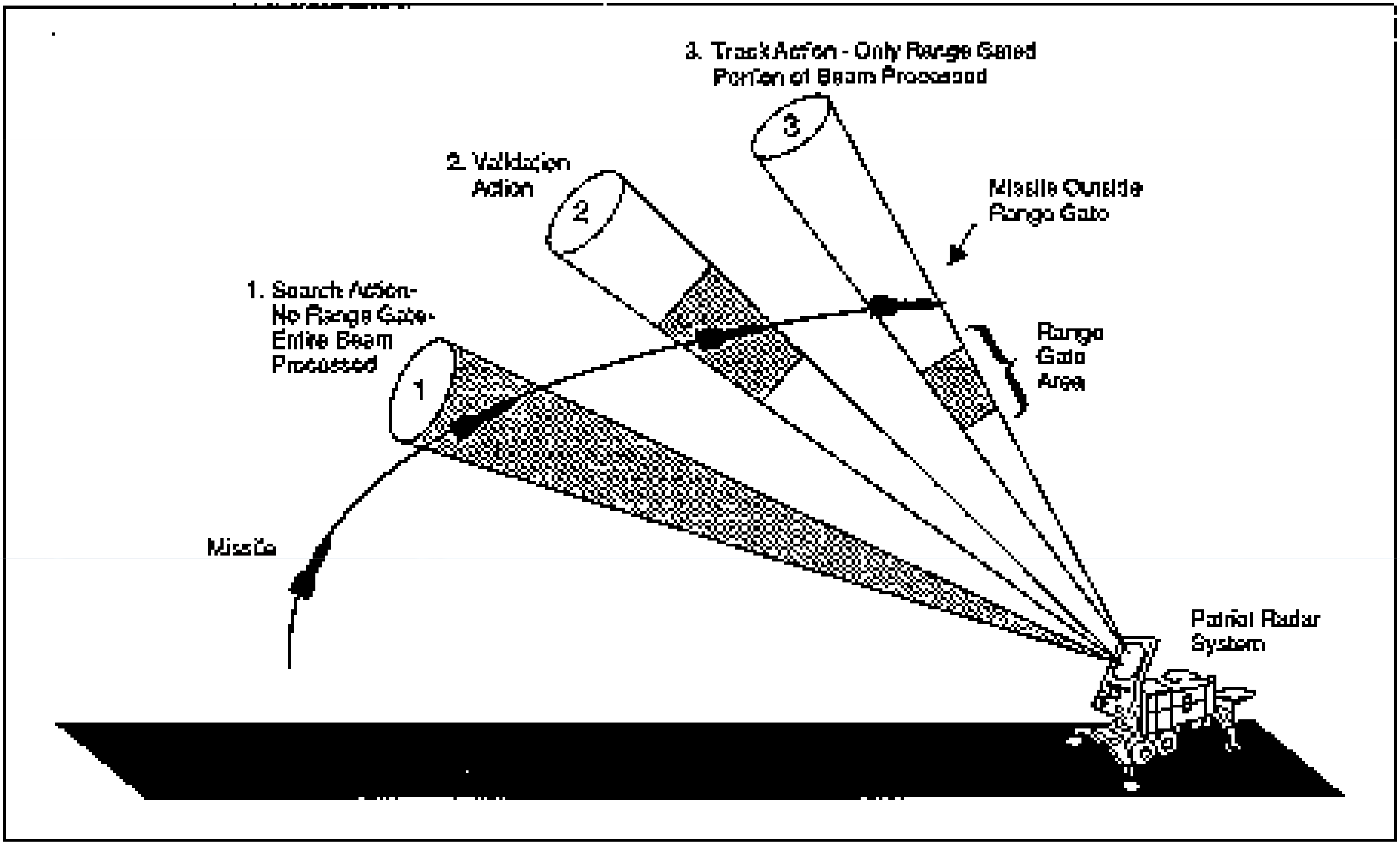

Image source: [1]

Code Quality Failure

- Tracking should have depended on elapsed, not absolute time; errors should have cancelled out
- A subroutine which returned a number with 48-bit precision was defined to cope with faster missiles, but was not called in all necessary places [6]
- As a result, errors failed to cancel and inaccuracy crept in

Testing Recommendations

- Safety critical code should be subject to heavy scrutiny and reviews, with test cases to ensure numerical accuracy at every essential step
- Program was written in assembly language, which may have presented maintenance and testing difficulties
- Code fifteen years old; lack of understanding, comments, documentation?
- Shouldn’t code safety critical functions at a low level; should abstract away from the hardware as much as possible for safety and testability [7]

Operating Constraints

- Battery intended to run for a few hours per use
  - Poor or non-existent risk analysis?
  - Hangover from old constraints
  - Should start afresh with safety critical systems
    - Registers with 8 more bits give 256 times the accuracy!
- “Very long run times could cause a shift in the range gate, resulting in the target being offset” [1]
  - Supply operators with rich analysis of constraints and limitations to minimise margin of error
- Rebooting to reset state
  - Downtime produces a 90 second window of vulnerability; power cycling should be a last resort

Safety By Diversity

- Essential for safety critical systems
- Several instances of single points of failure
  - No early warning from observation system in Narrungar, Australia [8]; though expensive to maintain, should other such systems be available? [9]
  - Other battery was broken - two batteries with a “run for three hours at a time” constraint is a lethal combination - three hour repair window!
  - Updated software arrived the next day [10]; should delivery have been expedited? Perhaps have software engineers on site?

Patriot Accuracy

… or inaccuracy?

Accuracy Claims

- George Bush Snr claimed 97% success:
  - “Patriot is 41 for 42: 42 Scuds engaged, 41 intercepted!” [11]
- U.S. Army claimed initial success rate of 80% in Saudi Arabia and 50% in Israel
  - Later scaled back to 70% and 40%
- 1992: Postol and Pedatzur testify that according to their studies, success rate closer to 10% and perhaps even 0% [3]

What is a 'Successful Launch'?

- Standard practice: fire four Patriots at each incoming Scud
  - 25% accuracy should result in around 100% success rate
- What is a 'kill'?
  - Hitting the warhead?
  - Hitting the missile?
  - Deflecting the missile?

Observed Misses

- Postol (1992) documented misses observed through press footage
- Patriots often missed target by >100m
  - Range gate errors?
  - Late launches – ‘early warning’ failure?
- Patriots dove into the ground
  - Rocket motor failures?
- Scud breakup caused incorrect targeting
  - Hull debris targeted rather than the warhead

Possible Reasons for Inaccuracy

- Errors in prediction and tracking: holdovers from the retrofit to track TBMs?
- Missile failures: inadequate field testing?
- Targeting the wrong part of the missile:
  - Iraqi redesigns caused Scuds to be faster but more prone to breakup [11]
  - Software needed faster response to changing operational parameters (or more adaptability)

Project Management Faults

Customer Focus

- System designed without contemplating stakeholders – operators/soldiers!
  - Should ensure that a customer (or proxy) with field experience is available
  - User acceptance tests verified by customer
- Retrofitted to run in unfamiliar context
  - Simulations or mockup exercises with potential operators

External Pressures

- Taxpayers money – project managers may have prioritised dollar over human cost
  - “Value of human life” perhaps had an impact; dire history, e.g. the Ford Pinto [12]
  - “We can just patch this old system up” attitude
- Rushed rollout – pressure from customer to deliver software
  - Requirements non-negotiable – testing suffers

Safety First

- Project management's top priority should have been maximising safety
  - Testing should extend beyond 'normal operational parameters' and be supported by software
  - Definition of abilities and limitations must be clear and explicit
  - No 'single points of failure' can be tolerated
  - Critical vulnerabilities must be identified and fixed as quickly as possible
  - Instead of delivering faulty software on time, fully operational software later could have given the best outcome

Outcome – PAC redesign

- PAC-3 (current version) designed ‘from scratch’
  - Learning from Desert Storm mistakes
  - Much higher success rate in Iraqi Freedom: 9/9 kills (8 confirmed, 1 probable) [5]
- MEADS (next version) learning from Iraqi Freedom mistakes
  - IFF improvements to reduce ‘Friendly Fire’ incidents

References

1. Anon. (1992). *GAO/IMTEC-92-26 Patriot Missile Software Problem.* Available: http://www.fas.org/spp/starwars/gao/im92026.htm. Last accessed 03 November 2008.
2. Shelley Toich. (1998). *The Patriot Missile Failure in Dhahran: Is Software to Blame?.* Available: http://shelley.toich.net/projects/CS201/patriot.html. Last accessed 16 November 2008.
3. Theodore A. Postol. (1992). *Optical Evidence Indicating Patriot High Miss Rates During the Gulf War.* Available: http://www.fas.org/spp/starwars/congress/1992_h/h920407p.htm. Last accessed 16 November 2008.

References

4. Redstone Garrison. (1995). *PATRIOT History.* Available: http://www.redstone.army.mil/history/systems/PATRIOT.html. Last accessed 07 December 2008.
5. DSB Task Force. (2005). *Patriot System Performance Report* Summary. http://www.acq.osd.mil/dsb/reports/2005-01-Patriot_Report_Summary.pdf. Last accessed 07 December 2008.
6. Robert Skeel. (1992). *Roundoff Error and the Patriot Missile.* Available: http://www.mc.edu/campus/users/travis/syllabi/381/patriot.htm. Last accessed 16 November 2008.

References

7. Andrew McGettrick. (2003). *Programming Languages and High Integrity Systems.* Available: http://local.cis.strath.ac.uk/teaching/ug/classes/52.422/programming_languages_slides.pdf. Last accessed 07 December 2008.
8. Cameron Stewart. (1999). *US Aussie spy base revelations: Nurrungar played fateful role in Desert Storm tragedy.* Available: http://www.hartford-hwp.com/archives/24/167.html. Last accessed 16 November 2008.
9. Robert Garran. (1999). *US Aussie spy base revelations: ASIO was in on it, says top analyst.* Available: http://www.hartford-hwp.com/archives/24/167.html. Last accessed 16 November 2008.

References

10. Eric Schmitt. (1991). *US Details Flaw in Patriot Missile.* Available: http://query.nytimes.com/gst/fullpage.html?res=9D0CEED7163AF935A35755C0A967958260. Last accessed 07 December 2008.
11. William Safire. (1991). *The Great Scud-Patriot Mystery.* Available: http://query.nytimes.com/gst/fullpage.html?res=9D0CE0DF1431F934A35750C0A967958260. Last accessed 07 December 2008.
12. Matthew T. Lee. (1998). *The Ford Pinto Case and the Development of Auto Safety Regulations, 1893-1978.* Available: http://www.h-net.org/~business/bhcweb/publications/BEHprint/v027n2/p0390-p0401.pdf. Last accessed 09 December 2008.