Assessing the Hazards of Space Hydrazine, and the Media Reportage of It
James Oberg // submitted to IEEE Spectrum magazine

Assessing technological risk is a thorny enough problem here on Earth, with vast experience and intuition about familiar uncertainties, factors, and processes. But transport the problem into the unearthly venue of outer space, where human experience is limited, and sound assessment becomes astronomically more challenging.

A spectacular case in point was last February's US missile launch to smash a derelict spy satellite before it could – potentially – splash a half ton of toxic hydrazine somewhere on Earth that would result in human injury or death. Hardly had this 'official explanation' been announced when a chorus of public criticisms denounced it as a phony 'cover story' meant to deflect attention for any number of more ominous motivations.

The launch of a Navy missile on February 20 achieved a head-on collision with the five-ton "USA-193" satellite and reduced it to impotent shrapnel, dispersing the contents of the vehicle's propellant tank harmlessly in space. To accomplish the intercept, the military teams had to reprogram the guidance system of an anti-missile missile designed for much slower and lower missiles, to design an intercept orbit that maximized the infra-red brightness of the target and provided a subsequent ground track that for several hours of debris 'rain down' was mostly above unpopulated areas, and to train its on-board computer to not only home in on the rapidly-approaching target outline but to shift position at the last possible millisecond to hit a 'sweet spot' behind which the fuel tank was installed. "We were operating on the margins of a system well engineered for a different job," a high official at the Pentagon's 'Missile Defense Agency' told IEEE, with a request his name not be used.

It was an amazing feat of space technology, but it has now been overshadowed by the controversy of its original purposes. In a contrary view that rapidly congealed into near-unanimity in news media in the United States and around the world, the mission was a long-planned 'space muscle flexing' demonstration to show off a space weapon that could discourage China and other countries from interfering with US military satellites, and the target satellite was just an opportunity for a clumsy cover story. In this view, there was no significant hazard from the hydrazine, and the government's claim that there was, and that it was the instigation of the intercept, was a deliberate deception.

The consensus of the roster of experts quoted in the national news media is clearly that the announced justification was bogus. For example, John Pike, director of the private 'GlobalSecurity.org', told reporters that "the claim there was a danger from the fuel is not the most preposterous thing the Pentagon has ever said -- but it seemed to be a bit of a stretch." Science commentator Noah Shachtman (in WIRED) approvingly quoted an unnamed 'space security expert' who told him: "The cynic in me says that the idea that this being done to protect the lives of humans is simply a feel-good cover story tossed to the media… Having the US government spend millions of dollars to destroy a billion-dollar failure to save zero lives is comedic gold." James Lewis, director of the technology and public policy program at the

private Center for Strategic and International Studies, told reporters: “The official explanation seems a bit thin… It was a surfeit of caution.”

But the actual space engineering issues seem to back up the original rationale, as described by NASA Administrator Michael Griffin (whose specialists performed independent hazard analysis which confirmed the results from Pentagon experts). “The analysis that we’ve done is as certain as any analysis of this type can be,” he told a press conference on February 14. “The hydrazine tank will survive intact … [because] the hydrazine in it is frozen solid. Not all of it will melt. So you will land on the ground with a tank full of slush hydrazine that would then later evaporate.”

To elaborate on this rationale’s role in the decision to smash the satellite, I talked with the top Pentagon space official and the leading NASA space debris specialist involved in the deliberation. General Kevin Chilton is the Commander in Chief of the US Strategic Command, the all-services group at Offutt AFB in Nebraska that controls US global strike assets. Nicholas L. Johnson has been NASA’s ‘space debris’ guru for many years, leading a team of experts at the Johnson Space Center in Houston. .

Chilton described to me how he was approached in a hallway at Cape Canaveral while attending a December 2007 military summit meeting on satellite launch costs. The head of the National Reconnaissance Office, Scott Large, wanted to discuss a problem satellite. “I’m worried about the reentry," Chilton recalls Large telling him. "My experts tell me it’s going to survive reentry.” Large said he was approaching the Missile Defense Agency commander, and not long afterwards, Chilton and his space staff were sucked into a Christmas holidays special study project. Within weeks, they were briefing the National Security Council, and then the President.

Their studies had indicated that action was advisable based on existing safety standards. Nicholas Johnson pointed out to me that there is already a long-standing risk level for satellite operations that provides a threshold beyond which hazard mitigation efforts are needed. The number is a 1:10,000 chance of human fatality.

In the past, heavy satellites with faltering control systems (such as the Compton Gamma Ray Observatory in early 2000) were deliberately deorbited over open ocean before control was lost and a random fall became inevitable. In the case of that satellite, NASA had estimated from the beginning that the chances of human casualties from a random fall was 1:1000, ten times greater than the threshold.

In fact, for most of the space age, almost all of the heaviest satellites (such as Soviet Salyut space stations, US military reconnaissance birds, Russian supply drones, and so forth) have used their rocket engines to terminate their flights safely, for this very reason. But the typical ‘expert quotation’ theme in the news media was that no mitigation efforts had ever been taken, or needed, in the past – all earlier falls had been random and uncontrolled. A good example is the quotation from Michael Krepon, co-founder of the ‘Henry L. Stimson Center’: “In the history of the space age, there has not been a single human being who has been harmed by man-made objects falling from space… [so] there has to be another reason behind this.” Actually, one could argue that the absence of previous casualties was in large part due to consistent mitigation strategies over the decades.

But how dangerous was USA-193? “Under various assumptions we got different probabilities of human risk from the uncontrolled entry of this satellite,” Johnson told me by telephone. “But they were all much riskier than the accepted standard.” In fact, it wasn’t until last July 20, with the premiere on the cable TV ‘Military Channel’ of a special program on the satellite intercept, that the actual values were released. General Henry (‘Trey’) Obering, head of the US missile defense effort, disclosed the quantitative results for the likelihood of human casualty: “It varied depending on which experts we talked to, but [we got] anywhere between 1 in 45 and 1 in 25 chance of that occurring.”

“Clearly nothing prior to USA-193 rose to that level,” Johnson had told me earlier. “The risk posed was much higher than any risk we’ve ever seen.”

Chilton confirmed that it was the specific contents of this satellite that elevated the hazards far above the mitigation requirement threshold. “If it had just been hardware we would never consider these extraordinary measures,” he told me. The presence of the toxic chemical, in a tank completely full because the payload had failed immediately after launch, was the unusual driving factor. Johnson concurred: “The odds of injuring MANY people was much higher then we’d seen in the past,” he had explained. “It was no longer just physical trauma injury.”

A graphic illustration of this ‘nightmare scenario’ occurred on October 15, 2004 when an off-course Chinese spy satellite’s film canister smashed through the roof of a four-story apartment building in Penglai (southwest Sichuan). Photographs through the smashed roof of the refrigerator-sized capsule sitting among splintered bricks and wood showed what MIGHT have happened if it had been carrying toxic chemicals – dozens of people might have been poisoned, many fatally. And in terms of probabilities, this was one of only several hundred uncontrolled landings of similarly-sized space vehicles.

But could the hydrazine actually reach the surface in sufficient concentration to hurt anyone, as NASA’s classified studies indicated? Here, too, in the press the expert consensus was clear and consistent. The tank would be consumed by the heat of atmospheric entry and disintegrate high above Earth. For example, Jeffrey Kluger, TIME magazine’s science correspondent, wrote (Feb 20): “The tank… is unlikely to make it through the heat and aerodynamic violence of the plunge that awaits it, meaning it will spill its contents high in the atmosphere,” and concluded, “The hydrazine argument is suspect”.

However, this rosy scenario rests on technical misconceptions. There is a widespread notion, for example, that meteorites falling to Earth arrive red-hot, sometimes releasing super-heated fumes or setting brush fires, as a result of the tremendous heating during passage through the atmosphere. However, this is an untrue myth, however well-established it may be in Hollywood thrillers and in folklore.

Actually, the opposite is true. Small meteorites actually fall to the ground COLD, and under humid conditions can even briefly form frost on their surfaces. True, a thin outer layer is briefly exposed to very hot air, but for most of the descent that air is

thinner than the purest vacuum inside thermal-shielding thermos bottles. Compared to the original sub-freezing temperatures in the object's interior, any regions of hot skin quickly equilibriate to the original cold-soak levels. One example cited in Brian Mason's Meteorites (John Wiley and Sons, 1962) is the Colby meteorite, which fell in 1917, and when excavated from a small crater a few minutes after it fell was observed to have frost on it, despite its falling on a hot July afternoon in Wisconsin.

Nicholas Johnson explained to me the factors used by his team to calculate the likely thermal history of the hydrazine in the satellite's tank. The satellite's owners, who had all the technical specifications, had calculated that it would be frozen (just as the water tanks of the USSR's derelict Salyut-7 space station froze in 1985), and substantially below zero (C). Heat transport into the structure would be absorbed by the thermal inertia of the ice, or if it reached sufficient levels, by the heat of fusion of the chemical itself as it partially melted. "Hydrazine requires a tremendous amount of energy to go from solid to liquid," he points out.

NASA's detailed computations of the tank's survivability were described in a paper by NASA contractor experts Robert Kelley and William Rochelle in Houston. Their results were summarized at the end of the paper: "Under the initial conditions and modeling techniques described above, it was found that the N2H4 located inside of the titanium tank does not reach its melting temperature… The N2H4 would have needed to absorb 43.15 MJ of energy to reach 275 K [its melting point – JEO] from the start temperature of 214 K. It only absorbed 29.34 MJ, or about 68% of that."

As for outside experts who reach different conclusions, Johnson was skeptical. "They simply don't have the expertise to do the analysis, it's just not easy," he pointed out. There are complex thermodynamic processes at work: "Most important is re-radiation – a lot of the heat doesn't go into the object," he explained.

Real independent experts who have actually done the thermal calculations confirm Johnson's conclusion. For example, Andrew Higgins is an associate professor of mechanical engineering at McGill University in Montreal, Canada with MS and PhD degrees in Aeronautics and Astronautics from the University of Washington, Seattle. He is a researcher on the dynamics of explosions and detonations, hypersonic reacting flows, and simulating hypervelocity impacts in the laboratory. Responding to what he saw as widespread media misreporting of the basic physics of the controversy, he performed specific research and published the results on the Internet. His conclusion: claims that the tank would be destroyed were "written in apparent ignorance of well-established heat transfer relations for spacecraft reentry. Simple estimates of the total heat transfer to the tank upon reentry, available in any number of aerospace textbooks, show that the heating of the tank would probably not have been sufficient to melt the hydrazine entirely, much less vaporize or ignite it."

Nor would the tank disintegrate from other forces. Johnson added that the deceleration forces – perhaps 8 to 10 G's – were well within the structural strength of the tank to endure. As to the observation that the hydrazine 'exploded' when the tank was actually hit – possibly indicating it would have done the same during the descent -- Johnson was equally dismissive. USA-193 disintegrated due to the immense physical shock of the missile impact, and the scattered hydrazine decomposed at

that point, once it had been strewn into empty space. The chemical energy of any hypothetical tank explosion was miniscule compared to the kinetic energy imparted by the collision.

In terms of the ultimate decision driver, Chilton and Johnson both referred to what they called the 'regret factor' – the issue of what might follow a decision to do nothing that led to a human tragedy. "At the end of the day," Chilton told me, "how could we look somebody in the eye, who had relatives killed or injured, how could we have that conversation?" Chilton attended the White House briefings where President Bush was given the options and the odds, and he remembers Bush's specific directive that if something could be done to mitigate the risk to human life, it needed to be done.

At the meeting, Chilton also raised other threats. "There's a risk that people will SAY it's an ASAT test," he recalls pointing out. The missile defense people actually argued AGAINST the effort, Chilton told me, seeing it as a diversion of time and resources from their existing research and testing activities; Johnson recalled that diplomatic experts advised there would be bad publicity over the event, based on assumed 'hidden motives'. But as Chilton remembered it, Bush responded, "I don't care what people will say, we're doing it for the right reason, and it's transparent."

If amateur experts were quick to express skepticism, real experts knew better. Anatoliy Perminov, a former Russian general once in charge of his country's military space program and now the head of the civilian 'Russian Space Agency', told Russian reporters on February 16: "In the given situation – if the satellite is indeed out of control – destroying it is the inevitable and right thing to do, I think." [Moscow VESTI TV, in Russian, Feb 16] Perminov was in a position to understand the risks and the options, and the US decision seemed proper to him – although his statements were never quoted anywhere in the Western press (that I could find).

But the White House assumption of transparency of motives, it seems, has almost universally run afoul of the murkiness of domestic and international politics. By and large, the media has portrayed the project as aggressive and militaristic, an excuse to threaten China, a back door gimmick to test 'space weapons'. As a result, a well-defined and thoroughly-researched technological hazard assessment – one that it may be hoped should not ever be needed again, but could well be – has wound up buried in obscurity and obfuscation. This is not an encouraging starting point for the next time such analysis might be invoked.