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Countering Cosmic Collisions

Even relatively small space objects can cause damage to Earth

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Just over a hundred years ago, on June 30, 1908, at 7:14 a.m. central Siberian time, about 2,000 square kilometers of remote Siberian forest were flattened by a high-altitude explosion of a cosmic object. Although the extent of ground damage is profoundly clear, the exact size and type of this object remain a mystery to this day.

The object responsible for what became known as the Tunguska event is today thought to have been an asteroid or comet nucleus as small as 50 to 60 meters in diameter – minuscule compared to extinction-causing objects such as the hypothesized 11-km Chicxulub asteroid that doomed the dinosaurs 65 million years ago. Clearly, Tunguska-size events should not be dismissed out of hand: the fire and blast wave that flattened trees in a mostly uninhabited region of Siberia occurred at roughly the same latitude as St. Petersburg. But for a few degrees of planetary rotation corresponding to about three hours and 45 minutes, a large city could have been destroyed instead.

Tunguska was not a one-of-a-kind or even a once-in-a-century event. In 1972 an object about 80 meters in diameter entered the atmosphere over Utah and traveled 1,500 km through the U.S. and Canadian sky before harmlessly skipping back into



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Dr. James D. Walker (left) is an Institute scientist in the Computational Mechanics Section within the Mechanical and Materials Engineering Division. As part of his work in impact physics, he has engaged in research in wave propagation, plasticity, fracture and failure of metals, composites and ceramics. Typically, his work includes and combines large-scale numerical simulations, analytical techniques and experiments. Dr. Walter F. Huebner (center) is a technical adviser and retired Institute scientist in the Space Science and Engineering Division. He is internationally recognized in the fields of opacity and comet physics and chemistry. In comet research, Dr. Huebner developed computer models for the physics and chemistry of comet comae and nuclei. Dr. Wesley C. Patrick is vice president of the Geosciences and Engineering Division. He is experienced in rock mechanics, explosives engineering and program management of complex, highly visible, multidisciplinary projects. He is skilled in communicating complex technical and policy issues to government agencies, the general public and the technical community. In the background is a photograph of the site of the 1908 Tunguska event. Trees were felled radially outward below the center of the high-altitude explosion.

space. Smaller objects are known to have exploded over Brazil in 1930 and on two additional occasions in Russia near Vladivostok in 1947 and Vitim (Bodaybo) in 2002. As many as 136 high-altitude explosions involving objects of about a meter in diameter were detected between 1975 and 1992 (Zaitsev, 2006) and an even larger number when considering infra-

sound detections (ReVelle, 2008; ReVelle et al., 2008).

Cosmic objects close to the Earth's orbit are classified as near-Earth objects (NEOs). A subset of NEOs that might strike the Earth are called potentially hazardous objects (PHOs). Described here are the current knowledge about objects that might strike Earth and a plan to respond, proposed by a

Southwest Research Institute-Los Alamos National Laboratory (SwRI-LANL) team.

NASA's congressionally mandated sky survey

Mankind has been observing small objects in the solar system for millennia – primarily comets. With the invention of the telescope, more and more small bodies have been discovered, beginning with the asteroid Ceres by G. Piazzi in 1801.

SwRI and LANL have been actively involved in the study of small celestial bodies – comets and asteroids – for decades. This research considered the NEO and PHO risk and countermeasures even before NASA officially started investigating NEOs within its Planetary Astronomy program in 1997. Co-author Walter F. Huebner, while on leave from SwRI to NASA Headquarters, initiated the survey program gradually in 1994. Subsequently, SwRI staff members have been involved in missions such as Deep Space 2 to visit an asteroid, the Rosetta mission to visit a comet, and the Deep Impact mission to strike the nucleus of Comet Tempel 1 with an impactor. At NASA, the NEO survey has been expanded into a self-contained program.

The NASA Authorization Act of 2005 furthered its small-objects sky survey program with a congressionally mandated goal to identify, track and catalog 90 percent of NEOs larger than 140 meters by 2020. By March 2009, the original “Spaceguard Survey” for objects larger than 1 kilometer had found 6,108 near-Earth asteroids and 83 near-Earth comets, for a total of 6,191 NEOs. Of these, only 773 are believed to be larger than 1 kilometer, so 87 percent of the detected NEOs are smaller than the survey’s targeted objects. Similarly, objects smaller than 140 meters are likely to be found in a new survey focused on objects larger than 140 meters. More importantly, objects smaller than one hundred meters are of significant interest because they are thought to be up to 1,000 times more numerous than kilometer-size objects. Since smaller objects reflect less light they are generally fainter and thus harder to detect. Consequently, they will likely provide much shorter warning times between discovery and impact on Earth. Additionally, threats from long-period comet nuclei with orbital periods of hun-

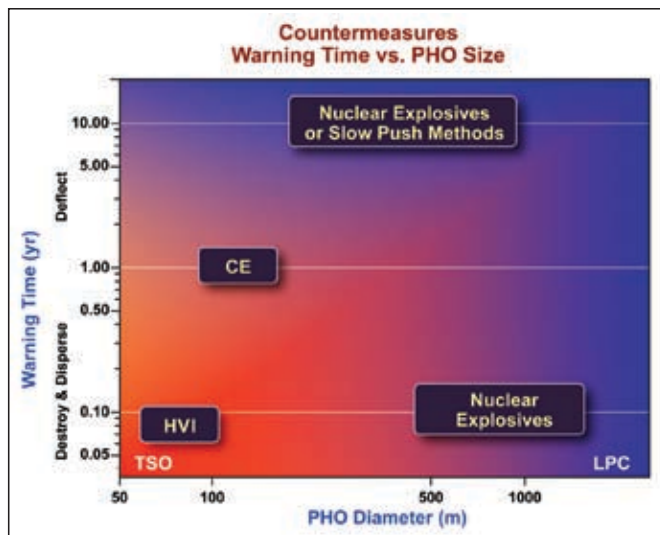
dreds to millions of years, although relatively rare, appear unexpectedly and provide little warning time because they transit very rapidly through the inner solar system. For example, the long-period Comet C/1983 H1 (IRAS-Araki-Alcock) was discovered in April of 1983, and passed within 0.03 astronomical unit (AU), or about 4.5 million kilometers, of Earth just two weeks later. Such comets come from the outer solar system at high speed and are not necessarily confined to the ecliptic plane. They can even be in a retrograde orbit that would combine the speed of the comet with the orbital speed of the Earth in a head-on collision.

Ideas for countermeasures

The 2005 NASA Authorization Act also directed NASA to provide a report to Congress on NEO survey techniques, costs, and mitigation options. SwRI provided information to NASA that was used in fulfilling this requirement in a 2007 NASA white paper to Congress. The white paper listed mitigation options to cause PHO deflection, including conventional explosives detonated at the target object’s surface or subsurface; nuclear explosives detonated at standoff distance, on the surface or beneath the surface; high-velocity kinetic impactors; and “slow push” methods. NASA assessed nuclear standoff explosions as 10 to 100 times more effective than non-nuclear alternatives in delivering the required energy. Surface or subsurface nuclear explosives may be more efficient, but they run the risk of fracturing an NEO into several large pieces, some of which may not be adequately deflected.

Non-nuclear kinetic impactors were rated as the most mature approach and one that could be used in some deflection or mitigation scenarios, such as when the NEO is a single, relatively small, solid body.

“Slow push” mitigation techniques were assessed as the most expensive option and the one with the lowest level of technical readiness. It would require a lead time of years or even decades to travel to and divert a threatening NEO. In the aggregate, NASA estimated that between 30 and 80 percent of PHOs are in orbits beyond the capability of current or planned launch sys-



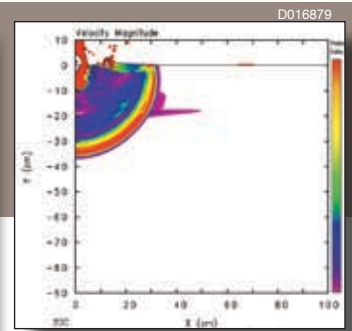
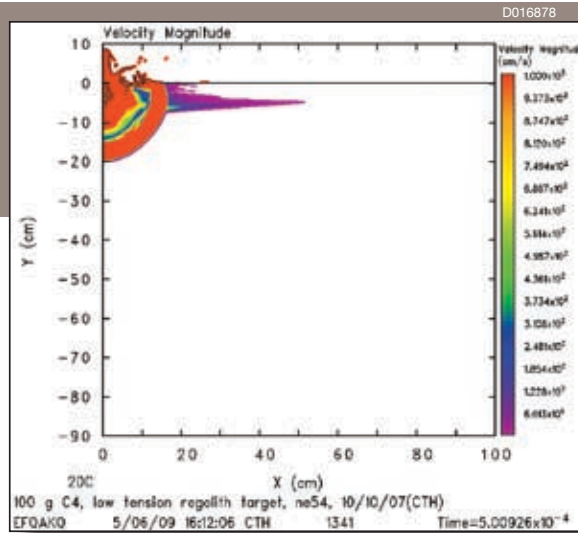
The available time to respond and the size of the potentially hazardous object (PHO) provide indications of possible mitigation strategies. In the lower left corner are Tunguska-size objects (TSO), which are relatively small and would likely have small warning times. These can be deflected or fragmented and dispersed with hypervelocity impactors (HVI) or conventional explosives (CE). In the lower right are long-period comets (LPC), which will have small warning times but potentially are much larger, leaving nuclear explosives as the only response. Moving toward the top are longer warning-time objects, which open up more possibilities for mitigation, including “slow-push” options. The red shading indicates the high abundance and short warning times one may expect for small PHOs.

tems for rendezvous or “slow push” mitigation. The NASA white paper did not address the much larger class of PHOs smaller than 140 meters in size, long-period comets or short warning-time objects, such as the Tunguska object.

Why small cosmic object strikes are a “unique” natural disaster

There are many other natural disasters competing for resources for early detection and mitigation. These include hurricanes, typhoons, tornadoes, earthquakes, tsunamis and volcanic eruptions. These other disasters occur much more frequently than impacts of cosmic objects with the Earth. However, frequency is only part of the risk-assessment equation. Not only the likelihood, but also the potential consequences of an event need to be considered, as well as our potential to counter the event. Each of these aspects argues in favor of pursuing countermeasures against PHOs. First, because the potential consequence of a PHO impact is so great, a risk assessment based solely on probability

Explosives loading an asteroid with a surface of low density, low sound-speed regolith like the dusty, sandy material seen on the surface of the Moon. Speed contours track the loading wave as it moves into the asteroid. These plots are at early time. The computations were used to determine the momentum transferred to the asteroid.



is not appropriate (Chapman and Mulligan, 2002). Second, preventing catastrophic loss from other natural events is based almost entirely on early detection and warning, followed by subsequent evacuation of the threatened area. Although detection systems for PHOs are in place and are being further improved to identify progressively smaller objects, warning systems are rudimentary and evacuation may not be possible because of uncertainty in the impact location and the potentially massive scale of the effects of an impact. Third, to date there are no known or likely countermeasures for other natural disasters, but it is within reach of technology to develop countermeasures against the collision of a cosmic object with Earth. The elements for such a system are already in hand. The technologies need only be tailored and deployed to meet the need. Designing and developing countermeasure systems could begin upon approval by the appropriate government agencies for the necessary funding.

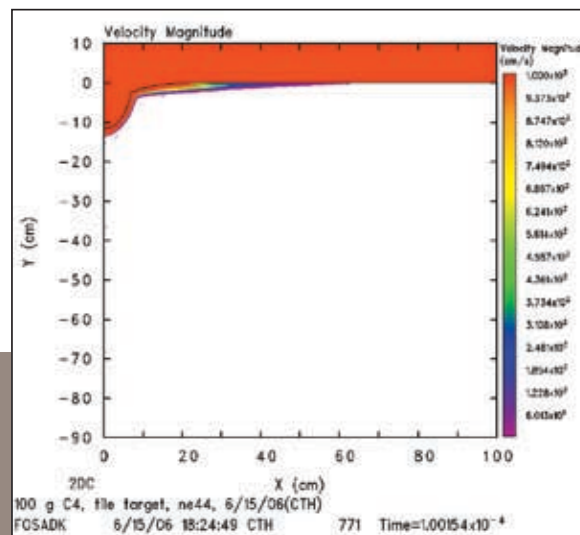
The SwRI-LANL countermeasure proposal

A joint team of scientists and engineers at Southwest Research Institute (SwRI) and Los Alamos National Laboratory (LANL) is proposing a comprehensive program for countermeasures to protect Earth against the subset of NEOs known as potentially hazardous objects (PHOs) from space. NEOs and PHOs are asteroids or comet nuclei whose orbits are close to that of Earth. An important part of the program is the ongoing surveys aimed at early detection of a PHO that approaches Earth's orbit within 0.05 AU, or about 4.7 million miles. However, just as in medicine, early detection is useful only if a cure is available. As discussed here, "early" may mean only a few weeks, or even days.

While holding to the intact deflection of a PHO as its highest priority, the SwRI-LANL team proposal recognizes that destruction of a PHO and dispersion of its pieces for small PHOs is an important mitigation strategy. Smaller objects are open to fragmentation and dispersion as a countermeasure. If an object were detected on a collision course with Earth with only

limited warning, deflecting the object by changing its orbit is beyond current technology, so destroying it and dispersing its fragments may be the only reasonable solution. Clearly, highly capable countermeasures will need to be at the ready to defend against objects with short warning times.

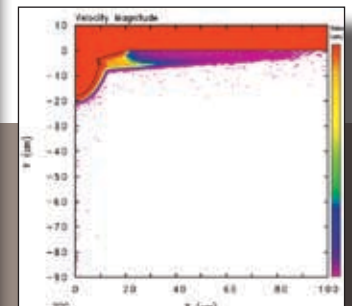
The team proposal includes studies of smaller, more frequently occurring objects, and countermeasures against long-period comets; enhancing the focus on short warning time; using non-nuclear methods, such as hypervelocity impactor devices and conventional explosives, whenever possible; and using nuclear munitions only when essential because of immediacy and magnitude; and stationing such devices on the ground rather than in space, for launch when needed. The above procedures for short warning times also work when time for reaction is long. They can also provide a back-up in case a "slow push" procedure fails.

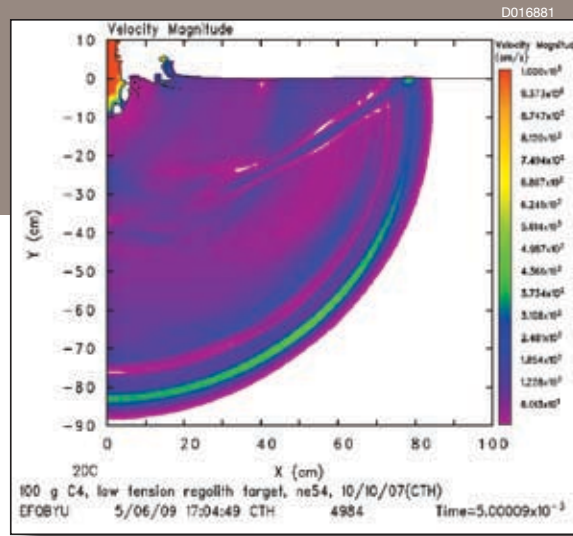
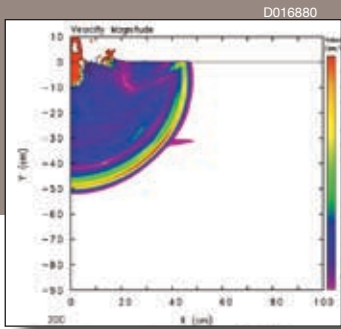


Ground-launched preventive measures are easier to maintain than space-based systems. They allow flexibility to use hyper-velocity impactors, conventional explosives, nuclear explosives or a combination of these. Launching from space might reduce the time for engaging a cosmic object, but maintenance and upgrades would require high-cost return visits, making it economically untenable. Ground-basing also avoids the political and diplomatic implications associated with weapons in space. Even so, the threat of an asteroid or comet nucleus collision with Earth transcends national boundaries, and the development and use of appropriate countermeasures will involve and encourage cooperation and coordination between governments and international scientific bodies.

Demonstrating it will work: Countermeasure modeling and experiments

Before countermeasures can be put in place, their capabilities, as well as the requirements posed by their target objects in space, must be assessed and proven using equipment that can approximate the extreme conditions of speed and force under which countermeasures approach and engage their target. This requires sophisticated computational models and experimental systems. This kind of information





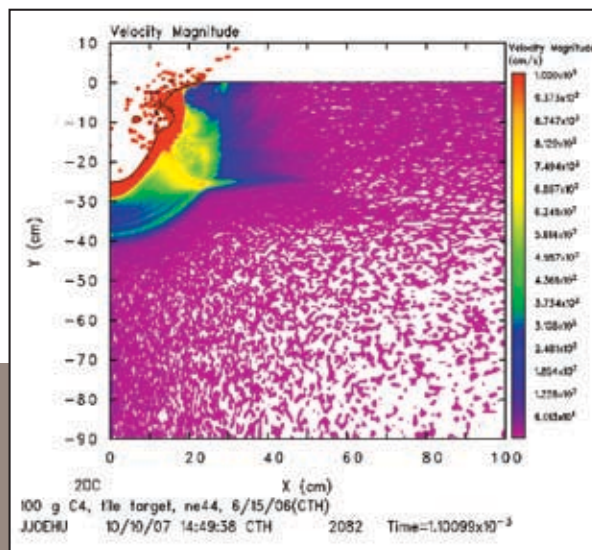
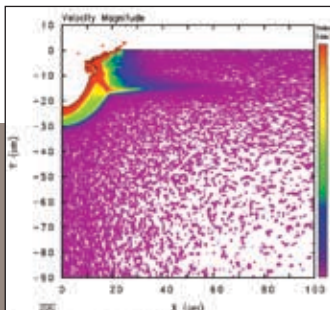
is what SwRI supplied to NASA as NASA prepared its white paper. For example, computer simulations were performed with explosives on different potential NEO object surfaces, ranging from rock to regoliths to ice to very low density silica materials (see figures). These detailed computations quantified the expected momentum transfer from conventional explosives and impacts that would occur given different potential PHOs. Over the years, SwRI and LANL have developed state-of-the-art computational tools that can be applied to model various forms of countermeasures. Relatively simple modeling might suffice for “slow push” techniques, but the requirements increase for impulsive techniques. For example, high-pressure and high-temperature material states and material strengths must be taken into account in the energy and momentum transfer calculations of deflection or disruption of an object by a kinetic impactor. When explosives are involved, detailed equations of state for the explosive product gases are needed.

Modeling explosive countermeasures requires consideration not only of the strength of materials but also of crater formation and shock propagation. Shock propagation can lead to a loss of momentum transfer through spalling of material off the opposite side of an object.

Nuclear explosive methods require the most compli-

cated modeling techniques: these models include radiation transfer, opacities, equations of state, and neutron absorption cross sections. Opacity plays an important role in energy deposition and subsequent ablation of the PHO’s surface materials, which is what leads to the momentum transfer.

Beyond computational modeling, SwRI also possesses a novel hyper-velocity test facility that can evaluate the effectiveness of kinetic impactors against various materials and structures. Speeds that are relevant for PHO deflection can be simulated using this facility. The NASA-funded inhibited shaped-charge launcher, which employs a vacuum flight and target chamber, was developed originally to assess the risks to the International Space Station from impacts by meteoroids and orbital debris. The facility launches a one-gram metal (such as aluminum) fragment into an evacuated chamber at speeds in excess of 11 km/sec (24,500 miles per hour). (See the cover story of the



September 1993 *Technology Today* for more details about the hypervelocity launcher.) Experiments with this system could be used to evaluate material response and the momentum transfer into various materials from hypervelocity impacts.

Conclusion

While the recommendations in the NASA white paper to Congress must be acted on in a timely manner, there is more that can and should be done to address PHOs, including accounting for smaller but more numerous — and therefore more frequently encountered — Tunguska-sized objects, short warning-time objects, and long-period comet nuclei. Otherwise, the next such object might emerge from the shadows of unwatched space to impact and affect a location less remote than a lonely stretch of Siberian forest. We have reached a unique time in our technology development when we have the ability to actually avert and prevent what would otherwise be reported by the news as a “natural disaster.” The SwRI-LANL team proposal is an important component in such a capability. ❖

Questions about this article?

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Loading a comet nucleus with a surface made of a distended silica material of low density, roughly one-fifth the density of ice. The comet nucleus images used SwRI-developed computational capabilities developed during the Columbia space shuttle accident investigation.