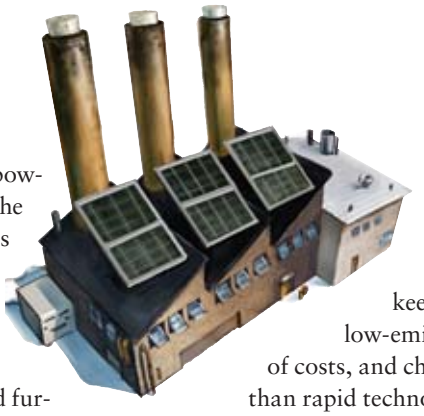

tion of carbon dioxide from coal-burning power plants. With a clean power grid, most of the other emissions can also be controlled. In less than a decade, plug-in hybrid automobiles recharged on the grid will probably get 100 miles per gallon. Clean electricity could produce hydrogen for fuel-cell-powered vehicles and replace on-site boilers and furnaces for residential heating. The major industrial emitters could be required (or induced through taxation for tradable permits) to capture their CO_2 emissions or to convert part of their processes to run on power cells and clean electricity.

Carbon capture and sequestration at coal-fired power plants might raise costs for electricity as little as one to three cents per kilowatt-hour, according to a special report of the Intergovernmental Panel on Climate Change. The mass conversion of the U.S. to solar power might involve an incremental cost of roughly four cents per kilowatt-hour, with overall electricity costs on the order of eight to nine cents per kilowatt-hour. These incremental costs imply far less than 1 percent of the world's annual income to convert to a clean power grid. The costs in the other sectors will also be small. The fuel savings of low-emissions cars could easily pay for batteries or fuel cells. Residential heating by electricity (or cogenerated heat) rather than by home boilers will generally yield a net savings, especially when combined with improved insulation.

The Bali negotiations will succeed if the world keeps its eye on supporting the speedy adoption of low-emissions technologies. Issues of blame, allocation of costs, and choice of control mechanisms are less important than rapid technological development and deployment, backed by a control mechanism chosen by each country.

If the less polluting technologies pan out at low cost, as seems possible, the rich countries will be able to afford to clean up their own energy systems while also bearing part of the costs to enable the poor to make the needed conversions. Climate control is not a morality play. It is mainly a practical and solvable technological challenge, which, if met correctly, can be combined with the needs and aspirations for a growing global economy. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

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MATT COLLINS

Forum

NASA's Flimsy Argument for Nuclear Weapons

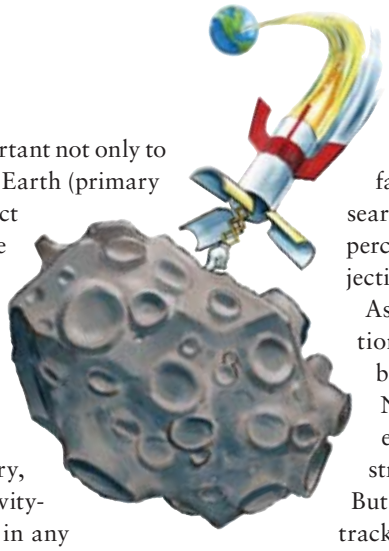
Nukes will not be needed to guard against dangers from space

BY THOMAS GRAHAM, JR., AND RUSSELL L. SCHWEICKART

On January 4, 2007, the *Wall Street Journal* published an op-ed entitled "A World Free of Nuclear Weapons," written by an impressive array of statesmen: former secretary of state George Shultz, former secretary of defense William Perry, former secretary of state Henry Kissinger and former senator Sam Nunn of Georgia. In the article the authors worried that the likelihood of international terrorists acquiring nuclear weapons is increasing. They asserted that "unless urgent new actions are taken, the U.S. soon will be compelled to enter a new nuclear era that will be more precarious, psychologically disorienting and economically even more costly than was Cold War deterrence." Invoking President Ronald Reagan's call in the 1980s for the abolition of all nuclear weapons, they endorsed "setting the goal of a world free of nuclear weapons and working energetically on the actions required to reach that goal."

Recently, however, a counterargument has been advanced—by NASA. In 2005 Congress ordered the space agency to analyze the alternatives that it could employ to divert a near-Earth object (NEO)—an asteroid or comet—if one was found to be on a collision course with our planet. Last March, NASA submitted a report entitled "Near-Earth Object Survey and Deflection Analysis of Alternatives," having first coordinated its response with the White House, the Department of Defense and the Department of Energy. In its report NASA chose to analyze only the highly improbable threat posed by large NEOs, which very rarely strike Earth, in lieu of the more realistic danger of a collision with one of the cohort of smaller NEOs, which are far more numerous. What is more, the report emphasized the effectiveness of nuclear explosions in providing the force to deflect an NEO from a collision course, but it completely neglected the need for precision in such a procedure.

COURTESY OF THOMAS GRAHAM, JR. (*top*); COURTESY OF RUSSELL L. SCHWEICKART (*bottom*)



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This analysis is seriously flawed. It is important not only to deflect an NEO from a collision course with Earth (primary deflection) but also to avoid knocking the object into a potential return orbit that would cause it to come back a few years later (secondary deflection). Nuclear explosions are not controllable in this way. But a nonnuclear kinetic impact—that is, simply smashing a spacecraft into an NEO—can provide the primary deflection for the vast majority of objects, and a precise secondary deflection, if necessary, could be performed by an accompanying gravity-tractor spacecraft, which would be needed in any event to observe the NEO deflection and its aftermath [see "Gravitational Tractor for Towing Asteroids," by Edward T. Lu and Stanley G. Love, in *Nature;* November 10, 2005].

Nuclear explosives would be needed only for deflecting the largest NEOs, which are the least common and most easily detectable objects. Scientists are not concerned about a collision with an extremely large NEO—say, 10 kilometers in diameter—because all these objects have been discovered and none currently threatens Earth. Big things are easy for astronomers to find; the smaller objects are what we have to worry about. Of the estimated 4,000 NEOs with diameters of 400 meters or more—which includes all objects that might conceivably require nuclear explosives to divert them—researchers have so far identified about 1,500. And if NASA meets the search goals mandated by Congress, it will locate 98 percent of these objects and calculate 100-year projections of their orbits by 2020.

As NASA continues to find big NEOs, the calculations of risk change accordingly. A decade ago, before astronomers began to systematically locate NEOs larger than 400 meters in diameter, they estimated that we faced a statistical risk of being struck by such an object once every 100,000 years. But now that researchers have identified and are tracking about 37 percent of these NEOs, the frequency of being hit by one of the remaining large objects has dropped to once in 160,000 years. Unless NASA finds a large NEO on an immediate collision course by 2020 (a *very* unlikely event), the frequency of a collision with one of the 80 still undiscovered objects (2 percent of 4,000) will drop to once every five million years.

Thus, the probability that nuclear explosives might be needed to deflect an NEO is extremely small. And even this minuscule probability will diminish to the vanishing point as researchers improve nonnuclear interception technologies. After 2020 the need to keep nuclear devices on standby to defend against an NEO virtually disappears. As a result, the decision to move toward the

worldwide elimination of nuclear weapons can be made strictly on the basis of human threats to global security. Extraterrestrial dangers need not be considered. ■

Thomas Graham, Jr., served as special representative of the president for arms control in the 1990s and now chairs Thorium Power Ltd., which develops proliferation-resistant reactor fuel. Russell L. Schweickart, a former astronaut who flew on Apollo 9, *heads the B612 Foundation, which champions the testing of spacecraft designs that can deflect NEOs.*

Skeptic

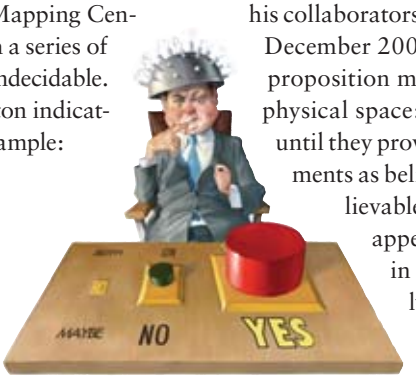
Adam's Maxim and Spinoza's Conjecture

Belief, disbelief and uncertainty generate different neural pathways in the brain

BY MICHAEL SHERMER

During an early episode of the über-pyrotechnic television series *MythBusters,* Adam Savage was busted by the camera crew for misremembering his predictions of the probability of an axle being ripped out of a car, à la *American Graffiti.* When confronted with the unmistakable video evidence of his error, Adam sardonically rejoined: "I reject your reality and substitute my own."

Skepticism is the fine art and technical science of understanding why rejecting everyone else's reality and substituting your own almost always results in a failed belief system. Where in the brain do such belief processes unfold? To find out, neuroscientists Sam Harris, Sameer A. Sheth and Mark S. Cohen employed functional magnetic resonance imaging to scan the brains of 14 adults at the University of California, Los Angeles, Brain Mapping Center. The researchers presented the subjects with a series of statements designed to be plainly true, false or undecidable. In response, the volunteers were to press a button indicating their belief, disbelief or uncertainty. For example:



Mathematical:
(2 + 6) + 8 = 16.
62 can be evenly divided by 9.
$1.2^{57} = 32608.5153$.

Factual:
Most people have 10 fingers and 10 toes.
Eagles are common pets.
The Dow Jones Industrial Average rose 1.2% last Tuesday.

Ethical:
It is bad to take pleasure at another's suffering.
Children should have no rights until they can vote.
It is better to lie to a child than to an adult.

The findings were revealing. First, there were significant reaction time differences in evaluating statements; responses to belief statements were significantly shorter than responses to both disbelief and uncertainty statements (but no difference was detected between disbelief and uncertainty statements). Second, contrasting belief and disbelief in the brain scans yielded a spike in neural activity in the ventromedial prefrontal cortex, associated with decision making and learning in the context of rewards. Third, contrasting disbelief and belief showed increased brain response in the left inferior frontal gyrus, the anterior insula and the dorsal anterior cingulate, all associated with responses to negative stimuli, pain perception and disgust. Finally, contrasting uncertainty with both belief and disbelief revealed elevated neural action in the anterior cingulate cortex, a region associated with conflict resolution.

What do these results tell us? "Several psychological studies appear to support [17th-century Dutch philosopher Benedict] Spinoza's conjecture that the mere comprehension of a statement entails the tacit acceptance of its being true, whereas disbelief requires a subsequent process of rejection," report Harris and his collaborators on the study in their paper, published in the December 2007 *Annals of Neurology.* "Understanding a proposition may be analogous to perceiving an object in physical space: We seem to accept appearances as reality until they prove otherwise." So subjects assessed true statements as believable faster than they judged them as unbelievable or undecidable. Further, because the brain appears to process false or uncertain statements in regions linked to pain and disgust, especially in judging tastes and odors, this study gives new meaning to a claim passing the "taste test" or the "smell test."

As for the neural correlates of belief and skepticism, the ventromedial prefrontal cortex is instrumental in linking higher-order cognitive factual evaluations with lower-order emotional response associations, and it does so in evaluating all types of claims. Thus, the assessment of the ethical statements showed a similar pattern of neural activation, as did the evaluation of the mathematical and factual statements. People with damage in this area have a difficult time feeling an emotional difference between good and bad decisions, and they are susceptible to confabulation—mixing true and false memories and conflating reality with fantasy.

This research supports Spinoza's conjecture that most people

PHOTOGRAPH BY BRAD SWONETZ; ILLUSTRATION BY MATT COLLINS