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COSMIC BOMBARDMENT II.
INTERCEPTING THE BOMBLETS COST-EFFICIENTLY

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COSMIC BOMBARDMENT II. INTERCEPTING THE BOMBLETS COST-EFFICIENTLY*

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Introduction and Summary. Hyde[1] noted that the Earth is struck by sufficiently large asteroids to disrupt non-trivial fractions of the biosphere with non-negligible frequencies, even on human time-scales, and reviewed some of the most robust means which are even now technically feasible for deflecting or disassembling asteroids found to be on Earth collision trajectories.

This initial work was oriented primarily to coping with the hill- to mountain-scale asteroids which strike at intervals of millenia and may ruin the biosphere of a large fraction of a continent. The planetary biosphere-devastating asteroidal strikes which occur at intervals of tens of millions of years clearly aren't of human interest, as the *a priori* likelihood of one occurring in historical times are $<10^{-4}$.

In the present paper, we consider ways-and-means of dealing with Earth-strikes of micro-asteroids, bodies which are so small — and so numerous — that they strike the Earth every century to every year. These are time-scales so brief that they are of interest to contemporary human individuals and institutions. We are particularly concerned with not only the detection and disposal of cosmic objects which threaten to bombard the Earth, but with practical questions such as cost-to-benefit ratios and implementing means for planetary defenses which are at once near-term, robust and unquestionably acceptable.

In the sections which follow, we briefly review those aspects of the cosmic bombardment of the Earth which are of concern during the next several decades. We first take note of the frequency with which the Earth will be struck by asteroids of various sizes and note the corresponding physical damage levels. Then, we translate this into economic damage levels, so as to arrive at the denominator of the cost-benefit ratio of a shield against such bombardment. Next, we consider how such a shield might be realized, emphasizing minimization of its total operating cost (amortization plus

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* Research performed under the auspices of the USDoE under Contract W-7405-eng-48 with the University of California.

[1] Hyde, R., *Cosmic Bombardment*, Lawrence Livermore National Laboratory Report UCID 20062, March 19, 1984.

operation-and-maintenance) while providing the required reliability. Having developed a cost estimate, we then discuss the cost-benefit ratio of defending humans and their works on this planet from cosmic bombardment.

We conclude that defense against cosmic bombardment with asteroids is technically readily feasible (moreover without requiring nuclear explosives), that it is already cost-benefit-advantaged and that it will become sharply so in the coming quarter-century.

The Cosmic Bombardment Rate. The principal source of cosmic bombardment of the Earth is the set of Apollo asteroids, the ones whose orbits are Earth orbit-crossing. A variety of observations[2,3,4] indicate that there are about 800 Apollos in the 1 km diameter category. Wetherill's observations-based argument in favor of several hundred one-tonne-scale micro-asteroids striking the Earth annually implies that there are perhaps as many as 8×10^{10} objects of this size in Apollo-like orbits (given the generally agreed[2,3,4] lifetime of such objects against Earth collision of about 200 million years), and implies a power-law spectral index for the function of number of objects with diameters-greater-than-a-given-one versus diameter of -8/3, or 2.67 (since there are 8 orders of magnitude more Apollo asteroids of one-meter scale than there are of one-kilometer scale). Shoemaker, et al,[4] on the other hand, arguing from discovery rates of 1-10 km diameter Apollo asteroids as a function of their apparent optical brightnesses, indicate that the spectral index of the empirical power-law number-vs.-size function is 1.95 (at least in the 1-10 km diameter regime).

Now there is no first-principles reason to expect that this asteroid number-vs.-diameter function is a power-law one at all; it's merely conventional to do so, and doesn't conflict with the limited observational evidence. That this basic functional dependence is a power-law one over the three orders-of-magnitude in asteroid diameter between 1 km and 1 meter presently has rather limited support in observational data. The strongest single item in this respect is the observed size distribution of post-mare lunar craters,[3] which is congruent with a power-law distribution, moreover one with a spectral index of about 2.0. (Terrestrial evidence in this crater size — and thus asteroid diameter — range has been essentially totally obliterated by weathering.) Therefore, for present purposes, we'll quite conservatively assume that a power-law distribution with a spectral index of 2.00, normalized to 800 Apollo asteroids of diameter of at least 1 km. This key assumption will

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[2] Wetherill, G. *Apollo Objects*, Scientific American, 240, 54, March 1979.

[3] Shoemaker, E., *Astronomically Observable Crater-Forming Projectiles*, in *Impact and Explosion Cratering*, Roddy, D. et al, Eds., Pergamon Press, New York, 1977.

[4] Shoemaker, E. et al, *Asteroid and Comet Flux in the Neighborhood of the Earth*, preprint, 1988.

underestimate the number of meter-scale micro-asteroids by more than 20-fold, relative to the observational evidence cited by Wetherill.[2] (However, it does extend to 10 km diameter scales in a manner consistent with Earth-strikes of 10-15 km diameter asteroids being associated with planetary-scale extinctions every 50-100 million years.)

All of our quantitative economic conclusions depend linearly on the validity of this scaling relation; if there are actually ten times more (or less) small asteroids than this relation implies, then the actual economic implications of defending human civilization from asteroid strikes are an order-of-magnitude greater (or less) than what we derive in the following. Because our basic economic conclusions are reasonably robust as they stand, and are rapidly becoming more so, we don't feel much at risk in proceeding to develop the consequences of this particular scaling relation.

The rate at which Apollos of 0.1 km diameter will strike the Earth is roughly 10^{-3} per year.[5] Those of 1 km diameter will strike the Earth roughly every 100 millenia, while those of 10 meter diameter can be expected to impact our home planet every decade; 4 meter diameter micro-asteroids can be expected to hit about annually, if the empirical scaling relation noted above holds down to bodies of this scale.

The Devastation Of Cosmic Bombardment. Now the average density of Apollo asteroids can be taken to be roughly 3 grams[6] and the characteristic speed with which they impact the Earth is 25 km/second.[7] They therefore carry about 225 times the energy density of chemical high explosive on a volumetric basis, or about 80 times on a mass basis. A 100 meter diameter one — the size which can be expected to strike the Earth every thousand years — thus carries the kinetic energy-equivalent of about 110 megatons of standard high explosive, while a 10 meter diameter Apollo, massing about 1500 tons, carries 110 kilotons; a 4 meter boulder-sized one floats in with about 7 kilotons of motional energy.

As is well-known, small explosives create more areal devastation than do large ones — on a per-kilogram-of-explosive basis. Since space is three-dimensional, an explosion's blast-wave peak overpressure — which is generally the most damaging feature of large explosions, both to humans and to their works — drops below the (roughly equal) levels at which it is lethal to exposed humans and to most structures at a distance proportional to the cube

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[5] See, e.g., reference [3] and compare with the pertinent strike rates cited in reference [2].

[6] See, e.g., the discussions of references [2] and [3].

[7] See, e.g., the values cited in references [2] and [3], which seem more consistent with both orbital theory and observation than does the peculiarly low value cited in reference [4].

root of the explosion's energy release. Since the devastated area within this drop-off distance-from-explosion-center is proportional to the square of this distance, the area devastated by the blast-wave aspects of an explosion is proportional to the two-thirds power of the explosive energy release.

Blast-wave peak overpressures of 5 psi rather reliably destroy all but steel-reinforced structures, both residential and industrial, and generally compromise the human utilizability of even the latter.[8] Humans exposed to blast-waves are generally more robust than are structures, and may survive exposure to peak blast-wave pressures as high as 30 psi; however, the totality of indirect injury-engendering effects, such as physical displacement by blast-wave-driven winds, structure-reflected and -intensified blast-waves, and blast-wave-accelerated projectile injuries, suggest that 5 psi peak overpressures may be a practical level beyond which long-term human survival — particularly if exposed in-and-around structures — becomes problematical.[9] For present purposes, then, we take the 5 psi peak overpressure distance to define a circle-of-total-devastation; compensating for incomplete ruination inside it is our approximation that damage outside it is negligible.

These considerations lead to the conclusions that a 100 meter diameter mini-asteroidal strike at near sea level has a 5 psi blast-wave radius of 32 km, and a corresponding area-of-total-devastation of 3.2×10^{13} cm^2 — 320,000 hectares — while the corresponding values for 10 and 4 meter micro-asteroids are 3.2 km and 3.2×10^{11} cm^2 and 1.3 km and 5.2×10^{10} cm^2, respectively.[10]

Economic Lossage Of Cosmic Bombardment. It is now pertinent to attempt a quantitative material valuation of what asteroidal strikes can damage, in order to develop an estimate of the economic value of averting such strikes. We group things-at-risk from cosmic bombardment in two categories: people and their material creations.

The material value of human artifacts is relatively straightforward to determine. The depreciated capital plant of the United States has a current

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[8] Glasstone, S. and P. Dolan, *The Effects of Nuclear Weapons*, 3rd edition, USDoD/USERDA, 1977, Chapter 5.

[9] Glasstone, S. and P. Dolan, ibid, Chapter 12.

[10] Glasstone, S. and P. Dolan, ibid., Chapter 3 and *Nuclear Bomb Effects Computer*. We have taken the blast-wave's peak overpressure to be that of an explosive of equivalent yield, burst at an altitude which maximizes the overpressure at a distance; this is a seemingly quite reasonable approximation for the high-abundance micro-asteroids of greatest present interest, which will deposit much of their kinetic energy in the terrestrial troposphere as a streak of shock-heated air — rather than in the Earth's crust, as would asteroids having diameters of 0.1 km or more.

value of about \$30 trillion[11] or about 6 times the U.S. GNP. The American fraction of the planetary capital plant is variously estimated to be about 20%, so that the present value of all human artifacts is roughly \$150 trillion, or \$1.5 x 10^{14}.

The material value of the planetary population of humans is much less easily defined. As a necessarily crude approximation for present purposes, we take it to be of the order of what each person can or could earn during their lifetimes, under economic conditions prevailing at the present time. (This presumably reflects the present-day economic value to the race of saving human life from cosmic bombardment.) For the 0.6 billion people in the First World, we take a mean lifetime earning capacity of roughly \$$10^6$; for the 2 billion "middle class" humans presently living, we take an average lifetime earning capability of \$$10^5$, while the 2 billion "lower class" is taken to have a mean lifetime earning capacity of \$$10^4$. (These numbers, in their aggregate, fairly closely reflect current planetary economic demographic data.[12]) The material value of the present-day human race, reckoned purely in terms of (non-forward-discounted) lifetime earning capacity, thus is about \$8.2 x 10^{14}. Moreover, this estimate is congruent with the estimated (depreciated) value of \$1.5 x 10^{14} of the capital plant of the human race which was just developed above: experience and observation both suggest that the human world is re-built roughly two or three times during the working lifetime of a contemporary human, and the depreciated value of a capital plant whose components are continually being replaced is about half the plant's instantaneous replacement value.

We now make the key assumption that humans and their artifacts of all economic valuation levels are uniformly distributed over the planet's surface. This seemingly absurd approximation is manifestly valid, however, if we also make the astrophysically highly plausible assumption that asteroid strikes occur randomly over the entire surface of the Earth *and* if an actuarial approach — that of an insurance statistician — is taken to the economic risks of cosmic bombardment. Specifically, we limit ourselves hereafter to considering only asteroidal strikes which will occur not once but "many" times — perhaps dozens or hundreds of times — during the time interval presumed to be of interest to the human race. Exactly where each strike occurs — whether in mid-town Manhattan or in the Antarctic Ocean — then becomes of little interest, as we have restricted our interest to the statistical universe of many such strikes, all over our planet.

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[11] See, e.g., data presented in reference [11].

[12] *"The World In Figures: Editorial Information Compiled By The Economist,"* Boston: G. K. Hall & Co., 1988.

Within these limitations, then, we can speak of the value-at-risk of each unit area of the planet. It is simply the planetary surface area divided by the sum of the economic values of the planet's people and their artifacts. Since there are 5.1 x 10^{18} cm^2 of surface area on Earth and inasmuch as our estimate of the economic value of the human race and its possessions is \$9.7 x 10^{14}, we conclude that the *mean* value of defending any parcel of the present-day planetary surface from asteroidal strike is \$2 x $10^{-4}/cm^2$.

The mean value-at-risk from a 100 meter mini-asteroid strike is thus \$6.4 B, while that under-the-hammer of a 10 meter micro-asteroid is \$64 M; the 4 meter "lower-limit" body threatens an average of only \$10 M. (This lower limit on the size-of-asteroid of compelling interest arises naturally from the 10^3 gram/cm^2 areal density of the Earth's atmosphere, taken into basic shock hydrodynamic physics. If any projectile attempts hypersonic penetration of a effectively zero-strength fluid of equal areal density, it will lose of the order of [1/e] of its speed — or more than half its energy — in doing so. A 4 meter diameter micro-asteroid of density 3 grams/cm^3 has about the same body-averaged areal density as does the Earth's atmosphere penetrated head-on, and is thus the smallest body which will slow down relatively little in passing through the atmosphere and thus which will deposit most of its kinetic energy in the terrestrial biosphere.)

It is worth noting at this point that it is indeed the lower end of the asteroidal mass spectrum which is economically most significant. While the mass, and thus the kinetic energy, of smaller asteroids striking the Earth aggregates to less than that of the larger ones — given that the magnitude of the power-spectral index of the number-vs.-mass function is smaller than unity — it is the number times the two-thirds power of the mass which indexes the devastation-potential of each size category of asteroid. The power-spectral index of this function has a magnitude of 1.0 — half of that of the number-vs.-diameter function, indicating roughly equal significance of all portions of the asteroidal size range, as far as impact on human affairs is concerned.

In any case, it's the stuff between a truck and a house in scale which rains down on our fair planet at rates of dozens to hundreds of strikes per century. In contrast, only a half-dozen chucks of the size of a small city block have fallen from the sky since the end of the Stone Age — and all but one or two of these probably landed in the ocean.

We therefore conclude that the *present* economic value of shielding the Earth from cosmic bombardment is roughly \$60 M/year, with the threat consisting predominantly of the 4-20 meter diameter micro-asteroids. The smallest mass-octave of these has a damage-avoided value of about \$12 M annually, and the remaining more massive ones integrate to about four times this annual value.

Spotting And Intercepting The Bombardment-In-Flight. What's involved in spotting the incoming asteroids — those which will very soon strike the Earth — and then intercepting them, totally disassembling the smaller ones and deflecting the ones which can't be shattered?

Consider the technical challenge of seeing the smallest size of interest at great range. A 4 meter diameter micro-asteroid with an optical albedo of 0.16[13] scatters about 2.8 kW of sunlight into 2π steradians at the 1 A.U. distance of the Earth's orbit. Thus, a deep-space surveillance camera with 0.1 square-meter of effective aperture at a distance of a million km from such an optical target will see 5×10^{-17} W, or about 32 photons/second, scattered from it. With 10 second integration times attainable with focal surface-mounted, silicon-based astronomical-grade CCDs operating at $\leq$270 kelvins, signal-to-noise levels of several hundred can be attained when viewing such sun-illuminated targets — they could be initially detected at ranges approaching 10 million km! (Space surveillance cameras of such aperture and focal-surface detection characteristics with steradian fields-of-view and few hundred μradian raw resolutions across the fields-of-view are expected to go into regular operation in 1991.[14])

When moving at 25 km/second, these objects will traverse the million km to Earth in 4×10^4 seconds. If viewed by space-surveillance cameras in 100,000 km radius Earth orbits, their angular rates will be 250 μrad/sec just before impact, and a tenth of this when they are viewed at million-km range. (Over any 10 second integration time, from a million km on in, they will leave a telltale multi-resolution element streak in the focal surface CCD arrays of the deep-space surveillance cameras.) The combination of their secularly increasing brightness and their characteristic proper motion variation should robustly identify them to the computers associated with the deep-space surveillance cameras.

The question then arises as to how best to intercept them, to smash to harmless rubble the smaller ones and to deflect from collision with the continents the largest ones. Ground-based interceptors will obviously suffice to pulverize the micro-asteroids of $\leq$10 meters diameter, as the pulverization can be accomplished at virtually any altitude above the stratosphere (which will serve to slow and further pulverize the rubble, as long as it's composed of fragments less than a meter in largest dimension). Means of pulverization are discussed below. However, asteroids in the 10-100 meter diameter range

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[13] See, e.g., Delsemme, A. and Rud, D., *Albedos and Cross-sections for the Nuclei of Comets 1969IX, 1970II and 1971I*, Astron. & Astrophys., 28, 1, 1973, and references [1], [2], [3], and [4].

[14] Arno Ledebuhr and Nicholas Collela, LLNL, private communication.

can be reliably shattered into sufficiently small fragments only with very robust means, such as nuclear explosives.[1] Deploying these against mini-asteroids poses substantial challenges of both technical and political natures. We consider as an alternative the deflecting of the largest asteroids of concern from continental strike areas, and the pulverization of the smaller ones, using the same non-nuclear means.

Specifically, interposing a relatively very small mass of optimally selected composition and geometry between the asteroid and its continental strike area can be used to completely shatter the many-per-decade micro-asteroids, and to generate enough transverse impulse to deflect sufficiently even the once-every-few-century mini-asteroids. However, in order to accomplish the latter task reliably, the deflection must take place a significant distance from the Earth, in order to allow sufficient time for the applied transverse impulse to move the asteroid's strike zone from the central regions of the largest continent into the nearest ocean area of adequate depth and distance-from-shore.

The applied transverse impulse can be shown to be proportional to the mass which is optimally used to generate it (by hypervelocity collision-engendered blow-off of a selected side of the asteroid), so that the product of the deflecting mass employed and the distance from Earth at which the deflection is executed is (approximately) a constant, for any given asteroid. There is thus a substantial incentive to pre-deploy the intercepting mass a very substantial distance from the Earth; doing so can be done relatively leisurely, and thus probably more reliably and less expensively than deploying it when an asteroid is bearing down on a continental strike zone.

Now, if a dozen interceptor platforms are stationed in similar 100,000 km radius Earth orbits, the maximum distance which one of them will have to move in order to intercept the incoming micro-asteroid is about 50,000 km. Since it has 36,000 seconds in order to do so, it must have a mean speed of perhaps 1.5 km/second, after it's commanded to execute the interception. If it employs a standard long-service-life-in-space monopropellant system for this purpose, it will require about twice as much initial mass as the mass of the system which effects the interception, just by elementary rocket equation considerations (using a monopropellant I_{sp} of 250 seconds).

What, then, is the interception-package mass? Hyde[1] considered the use of nuclear explosives for disrupting or deflecting large asteroids. Such means would certainly be suitable for present purposes, and would involve package masses of at most 100 kg. While not dismissing this technology, we note that non-nuclear means apparently can be sufficiently robust for disposing of the threat posed by micro-asteroids.

In particular, since the kinetic energy density of the incoming asteroid is roughly two orders-of-magnitude greater than that of chemical bond energy densities in high explosives, converting one percent of the asteroid's kinetic energy into internal energy would suffice to vaporize it. Indeed, since we would be content to merely cut it into meter-sized chunks which won't survive high-speed passage through the Earth's atmosphere, it would suffice to input to it perhaps one percent of its vaporization energy, or 10^{-4} of its motional energy — if this could be done reasonably precisely, as hard-rock blasting is done in contemporary tunnelling and mining.

This same quantity of energy, employed to blow-off asteroidal material at its sound speed, can generate a transverse velocity component of at least 2% of the longitudinal one. At a range of 100,000 km from Earth, this velocity change will suffice to steer the asteroid into an adjacent ocean, even if its unperturbed trajectory would take it into central Asia.

A regular array — a two-dimensional lattice — of long rods oriented along the direction of the asteroid's travel would be ideal for either pulverizing smaller asteroids or deflecting larger ones. If composed of a dense, refractory material whose longitudinal areal density was comparable to that of the asteroid, such a bundle-of-rods would interpenetrate the asteroid, laying line-charges of super-high-explosive in a regular pattern throughout its volume. The effect could be very reliably expected to be comparable to that of the standard symmetric array of blasting holes which are emplaced in a hard-rock face being removed in tunnel or road construction: simultaneous shattering of the entire face into rubble. Such an array for asteroid-shattering might aptly consist of a lattice of tungsten rods, each of about 1 meter length and 1 cm diameter, with each rod lying parallel to its neighbors in square symmetry on 1 meter centers. In order to engage a 10 meter diameter micro-asteroid with some margin for positioning error, a 15 meter diameter array of about 200 such rods having a total mass of roughly 0.2 tonnes would be required. An additional 50 kg of positioning structure, together with 50 more kg of spacecraft and residual propulsion plant mass would imply an interception-package mass of about 0.3 tonne, so that the in-orbit interceptor spacecraft mass could be expected to be perhaps 0.6 tonne.

The interceptor spacecraft's operation would be notably straightforward---considerably more so than the task posed to space-based interceptor spacecraft of the Strategic Defense Initiative. (To paraphrase a hackneyed criticism of SDI, the asteroid wouldn't be trying to dodge the interceptor spacecraft.) After the incoming asteroid was detected with the space-surveillance camera system, the three spacecraft nearest to its collision trajectory with the Earth would be dispatched to independently intercept it — providing that its carefully computed Earth collision trajectory would bring it down on a continental area. During their 10 hour-duration interception runs, each of the three spacecraft would continually do proportional intercept navigation, with its sequence of angles-only observations of its target being supplemented by periodic coaching with respect to range by the triangulation-performing space-surveillance camera system.

When the interceptor-to-asteroid range decreased to a few hundred km in the final dozen seconds prior to collision, each interceptor would engage it with its own laser radar, in order to precisely determine range and thus time-to-collision. So doing would permit it to accurately position and orient itself prior to unfurling its tungsten rod-bearing umbrella to attain maximum penetration of the asteroid, i.e., to align precisely (to within 1%) the long axis of the rod bundle along the relative velocity vector. The luckiest interceptor would have the sky fall in on it in one piece; the two laggard ones would experience a sand-blasting the features of which would be quite literally out of this world.

Putting 12 such asteroid-intercepting spacecraft into high Earth orbit would require inserting about 5 times as much mass into low Earth orbit (LEO), i.e., roughly 40 tonnes, if reasonably high-performance upper stages are used. Contemporary large-lift launch costs are about $8 million/tonne, so that launch costs of $320 M are indicated. (To be sure, the Advanced Launch System scheduled for initial operation early next decade has quoted launch costs of $0.7 M/tonne into LEO, so that launching the entire asteroid interceptor constellation would cost only $30 M with ALS technology.) The per-interceptor spacecraft cost should be considerably less expensive than its present-day launch cost; each such unit would consist of a DoD-standard monopropellant propulsion unit and a means for deploying the lattice of penetrator rods, perhaps very similar to the unfolding-umbrella system used in the Homing Overlay Experiment. A unit cost of perhaps $5 M seems reasonable. The constellation would therefore have an in-orbit cost of $120-400 M, when spare spacecraft and non-recurring costs are included, depending on whether present-day or early-2000s launch costs are used.

Cost-Benefit Considerations. Cosmic bombardment — principally in the form of micro-asteroid strikes — has been estimated above to inflict a *time-averaged* damage rate of about $60 M/year on the human race, at current market values on people and property. Averting such damage could bear a one-time investment cost of perhaps $0.4 B, at the current cost-of-money to the Government and a 15-year amortization period.

It would appear that the current cost-to-benefit ratio of defending the human race and its activities from cosmic bombardment is currently between 0.3 and 1.0. This already-favorable range will decrease to even more attractive levels at rates of 4-6% annually, due to the concatenated effects of global population growth and per-capita income increase. Technological efficiency improvements in the areas of asteroid interceptor creation and emplacement of 5-10% per year can also reasonably be expected, decreasing costs proportionately. Thus, the already-attractive cost-benefit ratio of defense against asteroid strikes should improve by 10-15% annually, or 2.5-to-4 fold every decade, into the foreseeable future.

Conclusions. The Tunguska Event in central Siberia in 1908 put the human race on notice that a "rain of ruin from the skies" could happen in modern times, and that large-scale cratering of the Earth's surface by asteroids didn't go out with the dinosaurs. In spite of the fact that the several dozen megatons liberated in this Event exceeded by a large margin the total of all the explosive energy of all of mankind's wars, the implications of the Tunguska Event for the safety of large blocks of the human race has been almost — albeit not quite[15] — completely ignored by technical individuals and communities, as well as by the public-at-large and its governments.

Some of this *de facto* complacency is doubtless due to the ubiquitous human trait to discount or ignore that which is far away in space or in time, even though it may have been huge in scale. Much of it, however, may well arise from despair over doing anything effective about this threat, which many might see as the ultimate "act of God," in the face of which human agencies are completely powerless. We point out, in this paper for the second time, that defenses against asteroid strikes have become technically feasible during the past two decades. We have explained in the foregoing that such defenses are already cost-benefit-advantaged, and will become far more so during the coming quarter-century, as the value-at-risk rises sharply with growing per-capita wealth and burgeoning population and as the costs of defense against asteroidal strikes continue to diminish.

The foregoing indicates that erecting such defenses should be commenced at the earliest practicable date. The technical community should invite the attention of prudent, forward-looking political leaders to this threat and to the opportunity for enlightened leadership which,it poses. Even if one should choose to doubt that asteroid strikes will occur sufficiently frequently to be of significant human concern, it seems indefensibly risky to fail to immediately deploy the deep-space surveillance camera system sketched above, in order to quantify the asteroidal strike threat beyond dispute, and thus to define much more precisely the cost-benefit ratio of defending the human race from it.

It would speak poorly of the collective judgment of humankind if we didn't learn from a lesson so massive and so recent as that presented in the Tunguska Event.

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[15] Clarke, A., Rendevous With Rama, Ballantine, New York, 1975, Chapter 1.

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