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THE HARD RAIN: IMPACTS, EVENTS AND CANADIAN SECURITY

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Canada

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By Major J. Schamehorn

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ABSTRACT

This paper argues that there is an extant risk to Canada from impact events, that is to say meteors and debris from space, causing fatalities, destroying infrastructure and / or adversely affecting the environment within Canadian sovereign territory. It illustrates recent UN and International protocols in addressing the impact threat and highlights the absence of plans to address this issue in Canadian public security, emergency management, defence or scientific agencies. The paper posits it is possible to provide a holistic approach to the impact threat within the principles of Canada's Space Policy Framework and National Security Program integrating Canadian industry, academia, government and military with relatively little effort. The research goes on to define extant measures being take to address impact events globally and to propose how Canada could act in concert with its NORAD and USSTRATCOM, United Nations NEO initiatives such as the Space Mission Planning Advisory Group (SMPAG) and bilateral CSA/NASA space missions like OSIRIS-Rex and throughout the growing space industry to address the risk from an impact event. Such activity would not only deal with a significantly under appreciated risk to national security, but with a view to stimulating Canadian space sector expansion in line with the Minister of Industry's recently released Space Policy Framework and consistent with the National Security Program.

Figure 1.1: Meteor photographed over Chelyabinsk Russia 15 February 2013. This event released approximately 500 kilotons of explosive force and caused an estimated 1,200 injuries from debris caused by the sonic impact of the descent(Photo credit: Reuters News Agency).[1]

CHAPTER 1 THE SKY REALLY IS FALLING

"But bombs *are* unbelievable until they actually fall."

- Patrick White, *Riders in the Chariot*.

> " "Now those skilled in war must know where and when a battle will be fought. They measure the roads and fix the date. They divide the army and march in separate columns. Those who are distant start first, those who are near by, later. Thus the meeting of troops from distances a thousand *li* takes place at the same time."
>
> Tu Yu (732-812 CE) on *Sun Tzu's The Art of War*

Introduction

There are literally more than 10,000 objects in the space around Earth which could bring destruction upon us. Some could alter the course of our nations, others the course of all humanity. Though we have long watched objects fall from the sky, only twice in the whole of mankind's recorded history have we identified, predicted and

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[1] Reuters News Agency, "Meteorite explodes over Russia, more than 1,000 injured ", 15 February 2013, http://www.reuters.com/article/2013/02/15/us-russia-meteorite-idUSBRE91E05Z20130215

observed an impact event. In neither case did we have any more than 21 hours notice. In Chelyabinsk, Russia, on 15 February 2013 they had none. As Tu Yu points out, if we are to be successful in this most important of battles, our planning must be precise.

Each and every day, this planet is struck by asteroids of varying size, anywhere between 20 to 300 tonnes of extraterrestrial material per day ranging from dust particles through to car sized masses of iron, stone and ice. Some research predicts a multi-kiloton impact (think Hiroshima, Japan 1945) annually, with a regionally destructive megaton impact event (think Tunguska, Siberia 1908) as frequently as once per century.[2] Because of the severity of such an impact when it occurs, Canadians have less chance of being killed by a tornado, than of being killed in the course of a meteor impact.

Anyone who has seen a meteor's fiery descent through the sky, often at night and more dramatically in daylight, has witnessed the effect of Earth being struck by the material from space. Occasionally, such as recently occurred in the Russian city of Chelyabinsk, a meteor or "bolide" will make it all the way to the surface causing damage and injury.[3] Very occasionally, on the time scales which challenge the human capacity to reasonably assess, these objects have reshaped continents, ended species and very possibly formed the moon orbiting above us. In 1980, Luis Alvarez proposed a theory in which the impact of an asteroid between 10 to 15 kilometres in length set in motion the

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[2]SpaceRef."Satellite Study Establishes Frequency of Megaton-Sized Asteroid Impacts." Last modified 20 November 2002, http://www.spaceref.com/news/viewpr.html?pid=9865

[3] B612 Foundation. "FAQ on the Chelyabinsk Asteroid Impact" Last updated 18 February 2013. http://sentinelmission.org/news/faq-on-the-chelyabinsk-asteroid-impact/.

end of the reign of dinosaurs 65 million years ago (the Cretaceous-Paleogene or K-Pg).[4] This is the Impact Event, the release of energy from an extra-terrestrial object's collision with the Earth, be it in the atmosphere above or the water and land below.

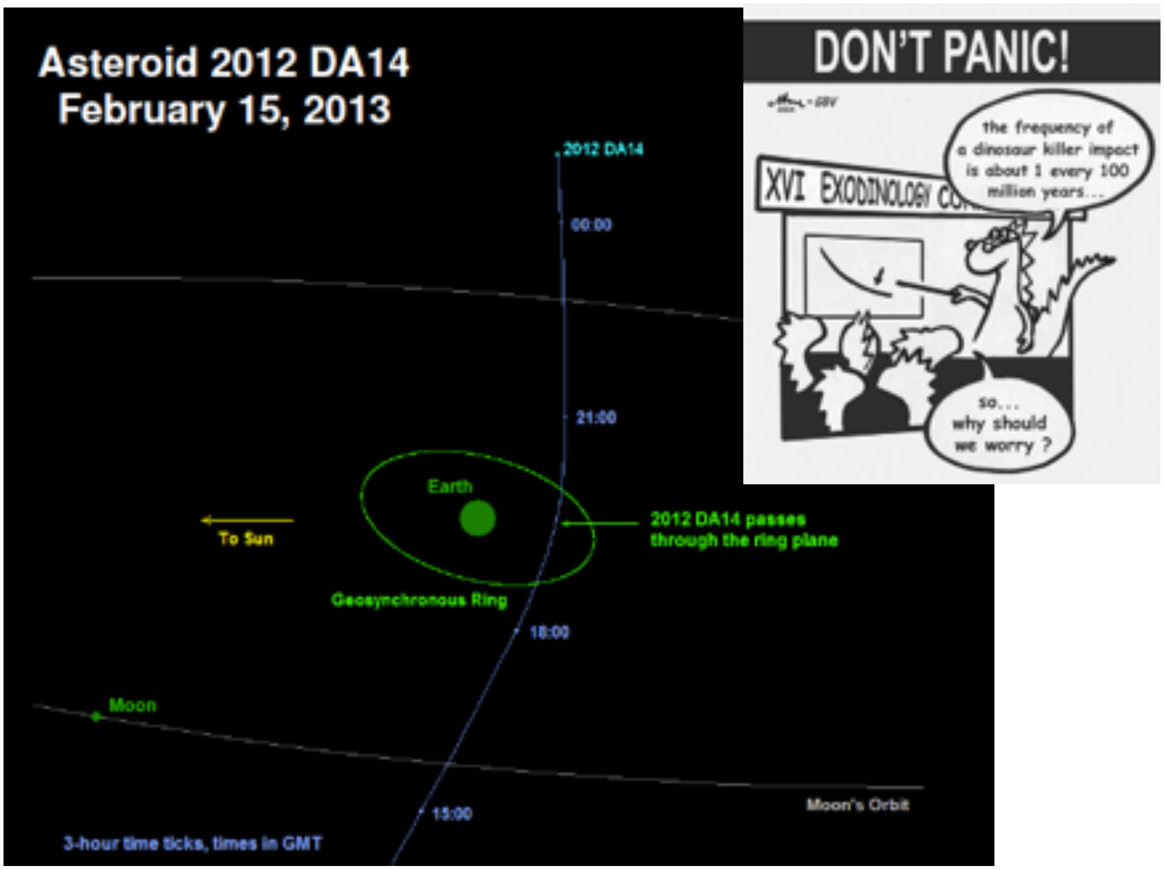

Figure 1.2: Although an easy speaking point when discussing the NEO threat, the Mass Extinction scenario poses a lesser concern than a sub-global event. This is due to a greater population of smaller diameter NEOs and the difficulty of detecting a NEO of this size. with sufficient time to deflect or deter the impact. No more eloquent demonstration of this could be made than the passage of the 45 metre Asteroid 2012 DA14 within 27,000 km of the Earth's surface (as predicted) on the same day as the unpredicted 17-20 metre Chelyabinsk meteor. Figure Credits: Ettore Perozzi(Inset) & Don Yeomans.

To date, we neither know the location of all of these threatening Near Earth Objects (NEOs), nor have we arrived at a conclusive means of dealing with the NEO impact event scenario.[5] Figure 1.3 gives a reasonably clear status of our situational

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[4] Alvarez, LW, Alvarez W, Asaro, F and Michel, HV (1980). "Extraterrestrial cause for the Cretaceous-Tertiary extinction". *Science* 208 (4448): 1095-1108.

[5] Hans J. Haubold, Steve Nadis. *Astrobiology & Outreach* 2014 Ed 2.2 "Near-Earth Objects – The United Nations International Conference:Twenty Years Later." Last accessed 22 June 2014, 1.

awareness of the estimated 10,000 plus NEO population at this time, and the significant work to be done to catalogue them.

Since the mid to late 1800's the destruction wrought by meteor impacts has been documented in science, popularized in cinema, invigorated by recent understanding of the Near Earth Object (NEO) population, and sensationalized by media reports whenever a meteor impact or close approach occurs. It has only been since the late 1980's and early 1990's that serious consideration and focus have taken shape regarding impact events. Impact events are not a new issue; they have occurred with frequency in the past and will continue to do so in the future. In the Planetary and Space Science Centre (PASSC) data base maintained by the University of New Brunswick is the evidence of numerous impacts of varying size and severity over the Earth's history.[6] Canada, or at least Canada as it is defined now, has seen more than its share of such impacts over the Earth's long history. Metal, stone and ice are not the only concern, however.

Satellites and space debris, our legacy of early and continued efforts to utilize space bows to the inexorable pull of gravity and return the planet from which they came. When returning or "de-orbiting", these man-made objects, rocket boosters, satellites, and other objects can disperse debris over exceptionally wide areas. These objects can present a danger to life and the environment as was the case with COSMOS 954 in January 1978 which covered 124,000 square kilometres of Canada's North.[7] Such debris

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[6] Planetary and Space Science Centre, University of New Brunswick. "Earth Impact Database - North America", last accessed 07 January 2014, www.passc.net/EarthImpactDatabase/NorthAmerica.html

[7] Health Canada, "The Cosmos 954 Accident " Last modified 24 June 2008, http://www.hc-sc.gc.ca/hc-ps/ed-ud/fedplan/cosmos_954-eng.php

is actively catalogued and tracked as a threat to active spacecraft by organizations like US Strategic Command and Canada's Director General-Space.

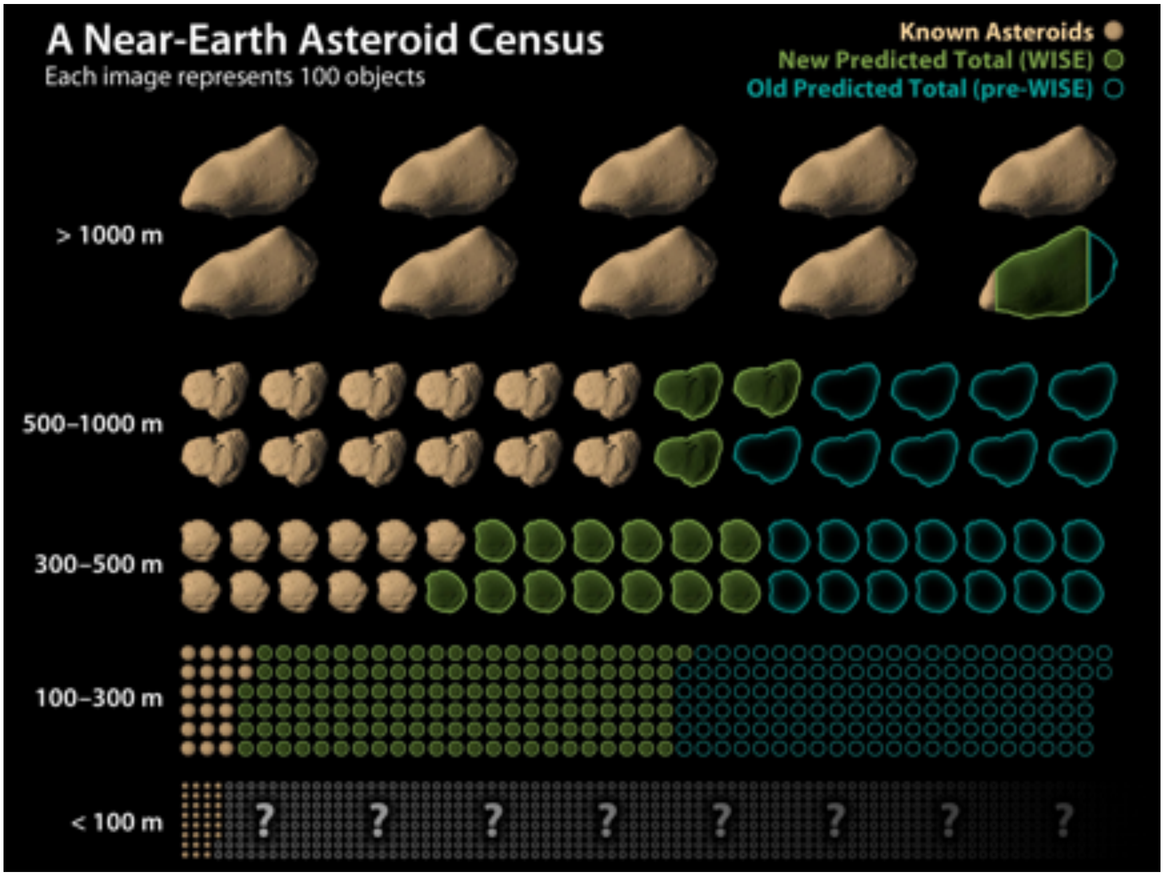

Figure 1.2: An infogram providing a snapshot of NASA efforts to detect and track the estimated 10,000 plus Near Earth Object (NEO) population posing a risk to Earth. WISE was a space based infrared telescope deployed in a low earth orbit on a polar orientation that ran in 2010-2011 and helped define the NEO population. Note that the Cheylabinsk meteor was approximately 17 metres in diameter and well below the threshold of this diagram. Figure Credits: NASA

Today, the possibility of the same fate, the proverbial "falling of the sky", overtaking humanity is a nascent field which is largely among academia. Indeed, an entire vernacular has been created to translate academic interest in NEO into something more easily grasped by political leadership and the general public, should the need arise. Success in addressing impact events hinges upon foreknowledge of a collision with sufficient time to deal with truly massive volumes of metal, stone and ice. Mankind, through a variety of largely ground based observatories, watches the sky and catalogues threats, while a few key individuals ponder methods to deal with threats when they are found (if they can be found in time). The rest of us, barring spectacular media images briefly making headlines, ignore a threat which could be as likely to befall any one of us as dying in an aircraft accident. Perhaps this is because of the magnitude of the problem, much like climate change, makes the scope of a response seem impractical at all but the international level. As Ingrid Stephanovic observed: "…values and basic philosophical considerations *about truth and about reality* influence human capacity for risk assessment in multiple ways."[8] (italics added by author)

Goals of this research.

This project seeks to establish four elements in support of the requirement to establish a holistic impact event protocol predicated upon counter munitions protocols in Canada:

a. To what degree does Canada face impact event peril from near earth objects rated as threats to the nation within a regional, national or global context (and / or de-orbiting space debris)?

b. What extant Whole of Government measures are in place to deal with such space based impact threats at this time?

c. Is there a gap in extant security, emergency management and defence policy and the space based impact threat to Canada?

d. Are other nations positioned to deal with impact events and what could be learned from their examples?

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[8] Ingrid Leman Stepanovich, "The Contribution of Philosophy to Hazard Assessment and Decision Making",

Thesis Statement

The threat of an impact event requires a more proactive and integrated response from Canada than we are currently making. Canada can address impact events with minor reinterpretations and the inherent flexibility of recently introduced government space, security and emergency management and defence policies, particularly *Canada's Space Policy Framework.* In doing so, the government can advance Canada's space capability, strengthen international collaboration, and secure our nation.

Summary

This paper will examine the challenges of a statistically infrequent event ranging in consequence from the locally significant to the globally catastrophic. It will be demonstrated that there is both a risk to Canada substantive enough to be deemed a threat, a gap in extant government policy towards addressing the impact events. It will conclude by illustrating how principles of Canada's Space Policy Framework can be used to address impact events and meet the obligations inherent in the National Security Policy o the safety and security of the Canadian people.

CHAPTER 2 THE THREAT: A RAIN OF METAL, STONE AND ICE

Introduction

In 2002, the Canadian space science leadership of Dr. Peter Brown invigorated NEO discussions. Dr. Brown, Canada Research Chair in Meteor Science and Director of the Centre for Planetary Science and Exploration (CPSX) at the University of Western Ontario led a team which discovered nearly 300 impact events around the globe over an eight and a half year period that began a redefinition of the frequency of NEO impact events and their risk to the Earth.[9] The team included four co-authors including Brigadier General Simon Worden, formerly of the United States Air Force (USAF) Space Command (Both Brown and Worden would play major roles in Canada's NEOSSat program).[10] The team analyzed data from the US Department of Defence and Energy satellites which detected optical flashes indicative of high energy release by satellites originally intended to detect nuclear detonations for treaty monitoring. Dr. Brown's team repurposed the data to discover impacts of objects between one to ten (1 to 10) metres in size, currently below the routine threshold of current optical observation. Their research observations indicated that at least once a year one of those impacts released the equivalent of five kilotons of energy when it impacts.[11]

Our Solar system is a tumultuous neighbourhood filled with a myriad of other occupants, all moving at great velocity and upon their own courses. The great majority of

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9 SpaceRef."Satellite Study Establishes Frequency …" http://www.spaceref.com/news/viewpr.html?pid=9865

10 Near Earth Space Surveillance. "NESS Project Team Members." Last accessed 15 July 2014, http://neossat.ca/?page_id=162.

11 Spaceref. "Satellite Study…".

these bodies arose in the creation of the system itself over 4.5 Billion years ago. These majestic comets, tumbling asteroids, moons and planetary rings follow paths which are, for the most part, far removed from the Earth's. But for the slenderest of chances objects will remain in their own orbits never approaching the Earth's orbital plane, much less the the current and exact location of the Earth. None the less, one need only observed the scarred and worn face of our own moon or media clips from Chelyabinsk to see that it does happen. Near Earth Objects, or NEOs as they are frequently referred to, do not shy away from Earth. More than 10,000 of these NEOs are the ones posing the great peril to this world, and there is the distinct possibility that less than 1% of the most threatening objects remain largely undiscovered to this day.[12] Mankind's deeper understanding of impact event's role in altering the planet's ecosystem, as well as our growing technological capacity to perceive near-earth-objects, has has vividly challenged humanity's myopic position towards this threat.

In this chapter I will illustrate the current state of our understanding of the impact threat. I will provide an overview of the types of NEO which may affect the Earth, and in particular Canada. Essential to this is the understanding of the role of "time and space" as it pertains to these objects, namely the correlation of detection time for determining the various decisive points in reacting to the situation. Rounding out the chapter will be an examination of the contemporary scales being used to communicate risk levels of impactors of all types among the NEO community. A detailed discussion of effects will

[12] Andy Turnage. Thomas D. Jones. "Vital Next Steps in a Global Response to the Asteroid Threat." 17 January 2014. Last accessed 06 August 2014, http://www.space-explorers.org/committees/NEO/2013/ASE_NEO_Defense.pdf.

not be provided, as the local and regional effects (meteors of 100 to 1000 metres in size) equal the energy release of nuclear weapons in the kiloton and megaton range. A comparative equivalence will be considered using this analogous language of explosive force equivalence, kiloton and megaton but this should not imply to the reader any commensurate radiation hazard.

A Brief Nomenclature

As the distances , forces and speeds involved in this discussion are large I will default to some of the scientific terminology, when necessary, to convey their magnitude. Readers should be familiar with the following measurements in reading this chapter:

- Earth Radii (R_E). 6,378 km as expressed as a single unit of measure. Distance from the centre of the Earth's core to the surface (mean distance) as a unit of measure. Two Earth Radii (2 $R_{E)}$ is the zone containing all manned spaceflight activity and the bulk of military, communications and Earth's observation satellites but our full zone of activity extends out to 6 R_E in geo-synchronous orbits.
- Astronomical Unit (AU). The distance between the Earth and the Sun as defined as a unit of measure. One AU is equal to 151,800,000,000 kilometres or 1.518 x 10^8 km. Thus Mercury has a distance from the Sun of 0.39 AU, while Jupiter orbits at 5.21 AU, and Pluto a distant 39.5 AU.
- Low Earth Orbit (LEO). An altitude band for satellites between 100-1000km above the Earth's surface. Objects are affected by atmospheric drag at or below 400 km and will eventually "de-orbit". LEO is well within the 2 R_E zone. The International Space Station and manned missions all occur in this altitude band.

- Mid Earth Orbit (MEO). 5,000-10,000 km above the Earth, and demarcates the outer limit of the 2 Earth Radii zone.
- Geosynchronous Orbit (GEO). An altitude of 36,000 km (5.6-6 R_E) in which satellites remain in a stable position rotating with the earth over on location around the equator. Asteroids have been observed to pass with this zone.

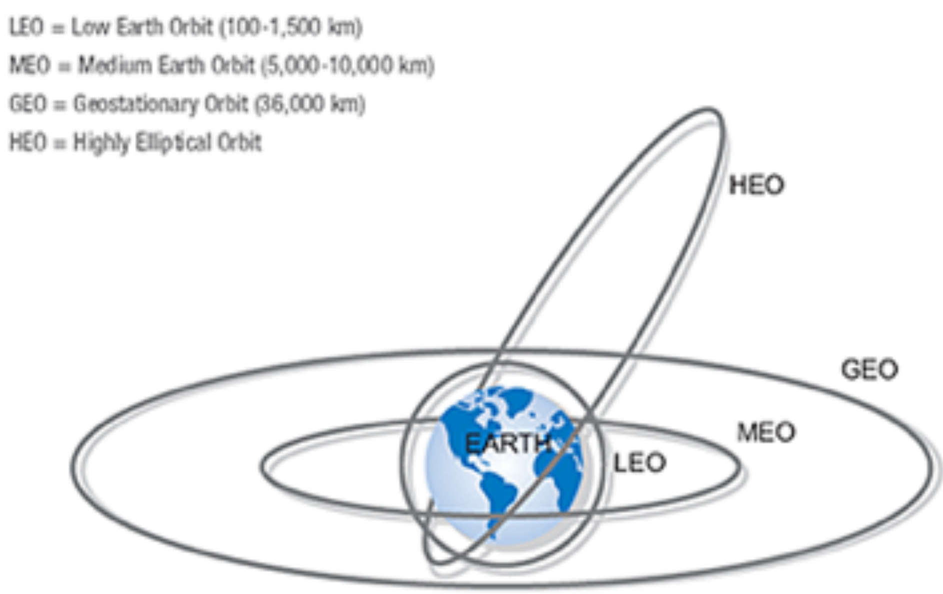

Figure 2.1: Illustration of the relationship between the various satellite orbits. Note that the LEO orbits shown here illustrate circumpolar orientation and are just one of a myriad of orbits which are flown at this level. LEO would be more accurately illustrated as a sphere around the global. Also illustrative is the Highly Elliptical Orbit (HEO), that is. not on any fixed orbital distance from the Earth.(Diagram Credits to quarkology.com)

- Kiloton / Megaton(kt / mt). Normally used to describe the energy release of nuclear weapons, a kiloton (kt) is often used to describe the explosive force equivalent of the detonation of 1,000 lbs of Tri Nitro Toluene (TNT). It is one third of the explosive force released in the explosion of the *Mont-Blanc* in which devastated Halifax harbour in December 1917. A 1000 fold increase is a Megaton, which has been estimated as a third of all explosives used in World War 2, including the nuclear weapons dropped on Japan.

- Metres / Second Velocity is frequently referred to in terms of meters moved per second, or m/s. A jogger runs at 1.7 m/s, a car in town moves at 16.7 m/s, sound at sea level travels at 331 m/s, 5.56mm bullet at 975 m/s and the fastest plane so far built flies at 981 m/s. Asteroid impacts will often be expressed in terms of Kilometres / second, a 1000 fold increase in magnitude.

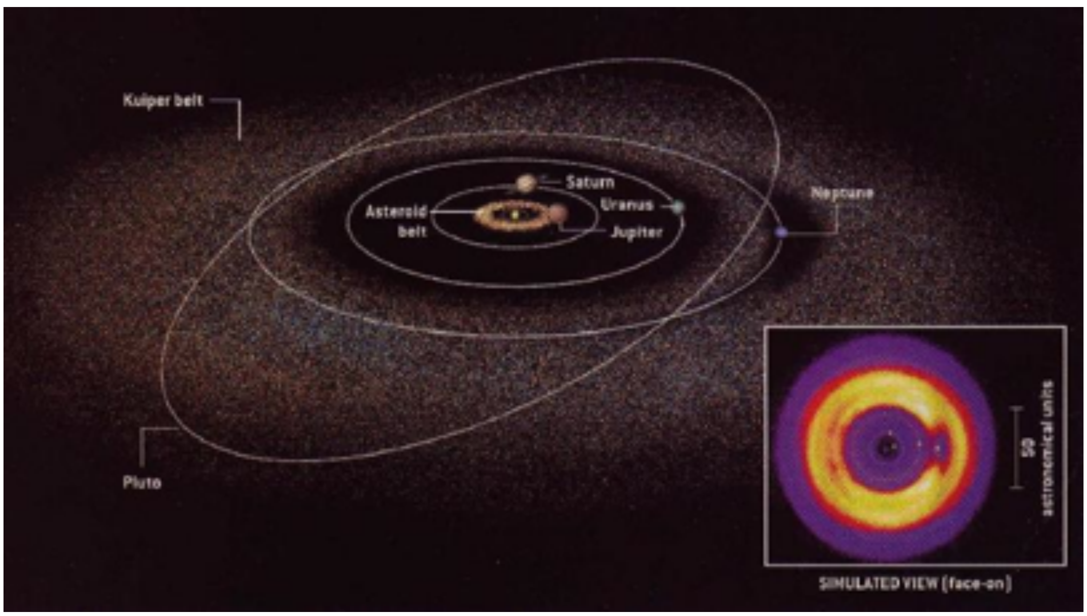

Figure 2.2: The Solar system illustrating the location of minor planets, planetoids and cometary debris fields. Though normally confined to within the identified zones, gravitational disturbance frequently moves material Sunward, and into possible collision with Earth. (Figure Credit: Prof. Sam Wormley)

Metal and Stone: The Asteroids.

Until an object enters the Earth’s atmosphere, it is member of a diverse family of objects which are generally found at great distances from the Earth. This family is made up of material in various states based upon its region of origin in the solar system. The comets are the outermost of these elements, coalescing around the entire solar system and upon the plane of the ecliptic where the bulk of planetary orbits lie and will be address in more detail later. Inside of cometary halo lie the rocky and metallic remains of minor planets and planetoids commonly referred to asteroids. Asteroids are generally located between the orbits of Mars and Jupiter and thought to be the remains of a large rocky planet similar to those of the inner solar realm. This theorized planet may have been torn apart by tidal forces, or failed to coalesce in the orbit now occupied by the asteroid belt.[13] These objects range from tiny particles to the size of a small moons 1000 kilometres in diameter. Asteroids generally, but not exclusively, form a band roughly 80,000,000 km thick following circular, coplanar orbits to the sun.[14] Asteroids are classified as in one of three groups:

- Main Belt. Those minor planetoids and planetesimals residing within the orbits of Jupiter and Mars, and under the gravitational influence of the Sun. They do not pose a collision threat to Earth unless a gravitational influence is applied upon them, changing their normal path;
- Trojan. Those asteroids held within the gravitational influence of a planetary body and the Sun which remain in positions relative to the planetary body in two of five possible "Lagrange" points called "L4" and "L5". Jupiter, Neptune, Earth and Mars all possess Trojan asteroids of varying size.[15] They do not pose a collision threat due to their stability in the associated planetary orbit unless disturbed; and

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[13] Larousse. *Dictionary of Science and Technology*. Ed. Prof Peter Walker (Edinburgh: Larousse, 1995),65.

[14] NASA, *Solar System: Asteroids*. Last updated 13 May 2014, http://solarsystem.nasa.gov/planets/profile.cfm?Object=Asteroids&Display=OverviewLong.

[15] Ibid.

- Near Earth Asteroids (NEA). This category of asteroids encompasses those following paths which approach or intersect the various planetary orbits of the inner solar system and, in particular, that of the Earth. Any asteroid calculated to pass within 45 million kilometres of Earth falls into this category of which more than 10,000 are currently known. It should be noted that there is no ongoing observation of the Inner Solar system for NEO / NEA. According to some sources, less than 1% of this inner system population has been observed.[16] NASA discovery rates of this type of asteroid are described by size in Table 2.1:

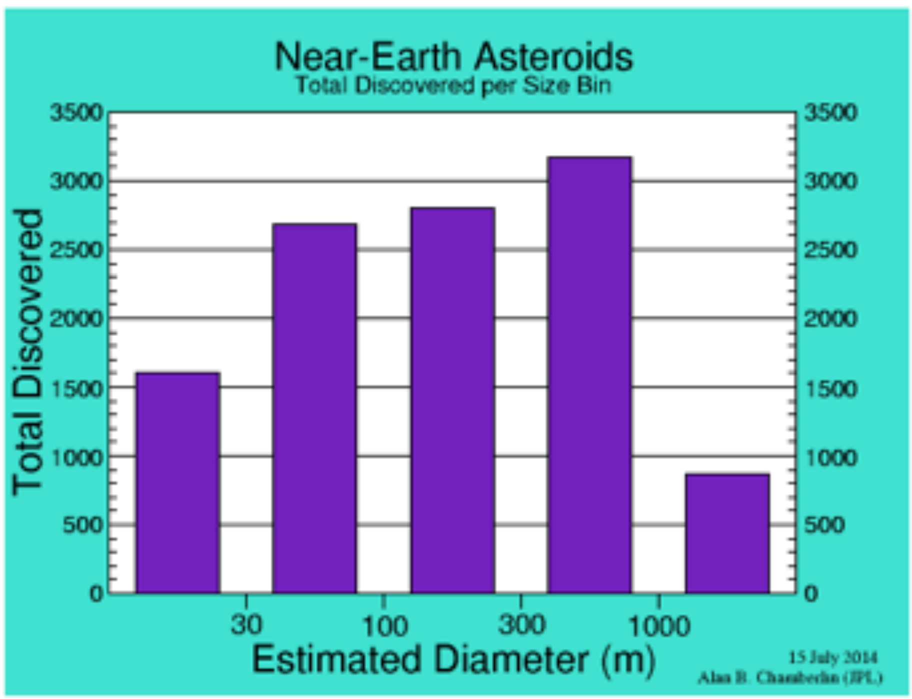

Table 2.1: NASA detected NEA over the course of observations since 1995 as classified by size. NASA purports this to represent 90% of the 1 km population as directed under the Brown Bill of 2005. The second half of the mandate, to catalogue objects down to 140 metres in diameter, has been much more difficult to achieve as illustrated by the lower number of observed small objects. (Table Credits: NASA NEO Program Office.)

There are four principal types of these NEA: Apollo, Aten, Amor and Inner Earth Objects (IEOs). The orbits by which they are distinguished are represented in Figure 2.3.

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[16] Turnage. Jones. 1.

Apollo or Aten asteroids, which fall directly across the Earth's orbit, are further defined as "Earth Crossers".[17] The NEO Dynamic System (NEODyS) is reporting 11,195 bodies as of June 2014, and this number changes constantly with new observation and reporting.[18] Of the millions of asteroids in our system we have currently detected and assessed there are some 1497 asteroids that are currently classified as potentially hazardous asteroids (PHAs).[19] Of these, 514 are of concern within 100 years at time of this writing.

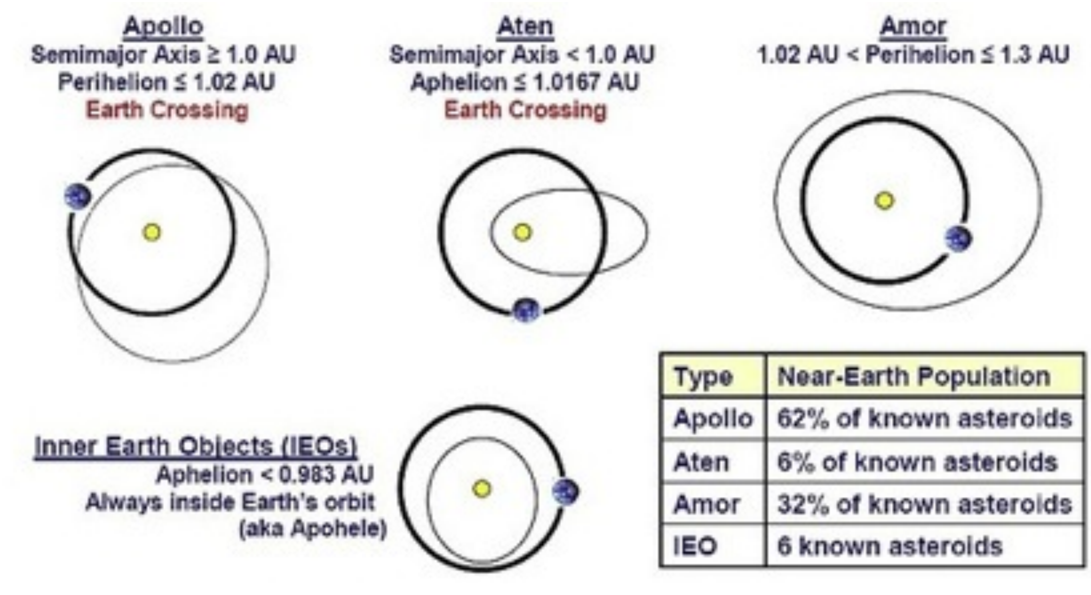

Figure 2.3: Near Earth Asteroid orbit differentiation. Note that only Apollo and Aten actually cross the Earth's orbit and represent the principal population for generating Potentially Hazardous Asteroids (PHAs) accounting or 68% of known NEA. (Diagram Credits to NASA NEO Program.)

A Special Note on Sunward Orbits: Both Apollo at Aten orbits represent a specific and highly worrying vulnerability in our current observational capability. As can be seen in

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17 William J. Kaufman. *Universe, 2nd Edition.* (New York: W.H. Freeman and Company, 1988), 327.

18 University of Pisa. *Near Earth Orbit Dynamic System-2(NEODys-2).* Accessed 24 June 2014, http://newton.dm.unipi.it/neodys/index.php?pc=1.0.

19 National Aeronautics and Space Administration (NASA). *Near Earth Object (NEO) Program - Risk Table.* Last updated 02 August 2014. http://neo.jpl.nasa.gov/risk/.

Figure 2.3 both orbits possess periods when the object could be approaching the Earth from the direction of the Sun. Under such conditions where the NEO is Sunward our ground based daytime observation the detection of a NEO is currently impossible because a small object will neither outshine the sun (visually or in infrared), nor casting a silhouette.

Ice of all sorts: Comets and Cometary Debris

Asteroids do not represent the full array of bodies within the solar system. As illustrated in Figure 2.2, at a distance of 50 Astronomical Units (AU), or 50 times the distance of the Earth to the Sun, is a ring of lighter cometary water ice bodies comprising the Kuiper Belt, a belt of comet generating ice arrayed in a larger deeper formation the the Asteroid Belt of the inner solar system.[20] Beyond this, to distances nearly half the way to the nearest star (some $1x10^5$ AU) lies the Oort Cloud, a spherical body of cometary nuclei and other primordial debris which, if disturbed by gravitational influence, can begin the long journey sunward, and across the Earth's orbit.[21] When they do so they leave behind them a trail of debris in their wake so dense that when the Earth passes through them they create "meteor showers" such as the Leonids or Persieds.[22] These are annual occurrences with varying intensity which have affected humanity in the past and serve as an elegant reminder of the NEO threat.[23]

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[20] Mark Bailey, Victor Clube and William Napier. *The Origin of Comets*. (Toronto: Pergammon Press, 1990), 204.

[21] Ibid, 179.

[22] Kaufmann, 337.

[23] Bailey et al, 76 & 83.

Galactic Debris: Gravel on the Galactic Road

The final element in this potential projectile catalogue is extra-solar debris, galactic debris strewn across the solar system's path as it makes is slow progression around the core of the Milky Way. This circuit takes a staggering 200 million years to complete and, like a "merry go round", is in synchronization with the five other arms of the Milky Way galaxy.[24] In the same way that comets leave a trail of debris in their wake, the Sun, with its clutch of planets in tow, drifts through clouds of debris in the wake of the passage of the Cygnus and Perseus arms which lie directly ahead of us. Some scientists have theorized a connection, currently under debate, between mass extinctions recorded in the geological record and this 200 million year orbital period qualifying this type of debris for consideration in the NEO catalog.

Historical Impact Data

Having identified a host of naturally occurring bodies on a collision course with the Earth to worry about in the future, let us also look into the past for proof that the Earth, and the geographical region of Canada, has been struck by these objects in the past. As noted in the introduction, the Planetary and Space Science Centre (PASSC) established by the University of New Brunswick maintains the Earth Impact Database (EID) online for use by researchers world wide. Of the 184 confirmed impact sites in the database 31 of these (16.8%) lay within the boundaries of Canada.[25]

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[24] Kaufmann, 491.

[25] PASSC "Earth Impact Database - North America" Accessed 24 June 2014 , http://www.passc.net/EarthImpactDatabase/NorthAmerica.html.

The PASSC database is not a complete inventory of impact events in Canada, merely an inventory of discovered crater effects from impacts. Approximately 70% of the Earth is covered by water and impacts in this location have left little or no trace unless, like Chicxulub, they are of enormous and geography re-defining proportions. Spaceguard Australia's Michael Paine added further detail to the lack of cratering in his simulation study of asteroid impacts in 2002. Although his work is predicated on a simulation over a one million year period and not historical evidence, his analysis indicated that the vast majority of impacts were either into water, over water, or, like Tunguska, well above the surface of the earth. A mere 8% of the impacts (265 of the 3326 fatality events) left craters.[26] Having established the precedence of impact events, let us now look at the outcome of an impact so as to underscore the need to prevent them in the future.

Impact Assessment

So far we have established the origins of near earth objects (NEOs) and their historic precedent to strike the Earth. Some further explanation is required to render the subject in context with other risks to humans and in a measure of comparison for decision makers and resource allocators. Table 2.2 was utilized to orient participants in the USAF natural impact hazard (asteroid strike) Interagency Deliberate Planning Exercise in December of 2008 and acts as a good tool for context of the NEO impact issue.

In a sad sense we are all very familiar with the degree of destruction which is possible by larger meteor strikes by virtue of the spectre of nuclear weapons today. The

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[26] Michael Paine. *Simulation of Asteroid/Comet Impacts with Earth* "Simulation 1046 One million years looking at worst event each century" 06 Jan 2000 Last accessed 07 August 2014, http://users.tpg.com.au/users/tps-seti/sta1046.htm.

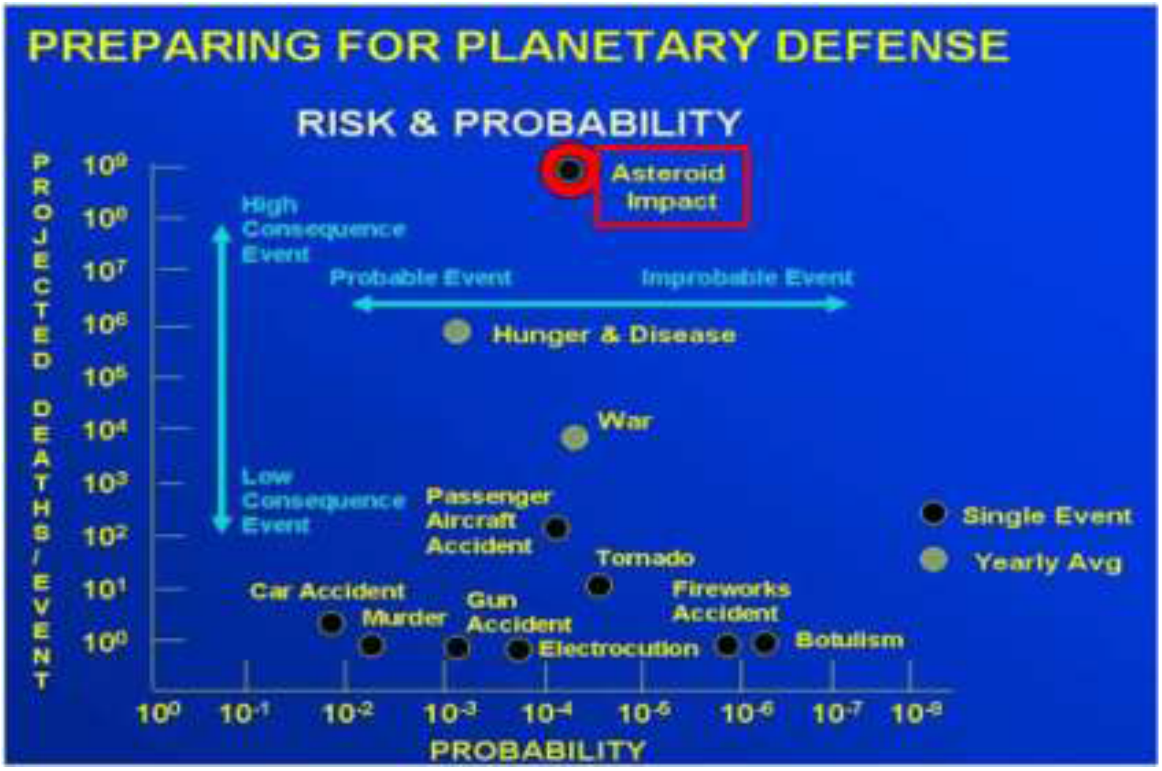

Figure 2.4: USAF briefing slide on illustrating the 1:20,000 risk to an individual (Morrison et al, 1994) within the context of other hazards. It uses a combination of single event individual hazards and two yearly averages events against the generally accept risk of fatality in an impact scenario. Recall that the magnitude, not the frequency, is the key factor in elevating risk to individuals by impact event. (Figure credit: USAF)

energy release of these weapons is on a comparable scale with the smaller meteors, for example, the approximately 17-20 metre Chelyabinsk meteor released between 440 to 500 kilotons of energy.[27] The 1994 study of impact hazards by Morrison, Chapman and Slovic defined a value of 3 x 10^5 megatons as the transition point to a global event likely to kill 25% or more of the world's population from a combination of impact and second / third order environmental effects.[28] Morrison et al went on to provide a categorization standard in wide use among the NEO community to classify the size of impactor and its

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[27] Haubald. Nadis. 2.

[28] David Morrison. Clark R. Chapman, Paul Slovic. "The Impact Hazard" In *Hazards due to Comets and Asteroids.* Edited by Tom Gehrels. Tuscon: University of Arizona Press, 1994. http://www.boulder.swri.edu/clark/mcshaz.pdf.

impact type / location with respect to the local, regional or global influence of the impact event (Table 2.3).[29] Note that Table 2.3 reflects the 'equivalent annual average deaths", a comparative "constant casualty rate" which combines the frequency / probability of the event to allow comparison. As such, in the parlance of the military planning process, although the Mass Extinction is clearly the Most Dangerous, it is threshold Global catastrophes that present the Most Likely threat. Plans to deal with them must be balanced accordingly.

Type of Impact Event	Torino Scale Equivalent	Energy (Megatons[MT])	Impactor Diameter	World Deaths / Year
High atmosphere break up	8	< 10	< 50 m	< 1
Tunguska-Like Event	8	10 - 2 x 10	50 m - 300 m	55
Sub-Global Land Impact	9	2 x 10	300 m - 2 km	30
Sub-Global Ocean Impact	9	2 x 10	300 m - 2 km	300 (?)
Threshold Global catastrophes	10	10	1 km - 2 km	3000
Mass Extinction	10	>10	> 4 km	< 300

Table 2.3:Comparative illustration of Fatality Rates as a function of Impact Energy with an equivalent Torino Scale rating.

Throughout this paper, the impactor diameters provided by Morrison et al will be used to reflect NEO impactor categories.[30] The magnitude of these impact events make them far from a regional, even a national concern. To understand the concerns of scale, local,

[29] Ibid, Table II.

[30] Ibid.

regional, national and global it would serve us well to examine some historic precedents from which our current understanding of impact events is derived. Let us begin with the smallest, and work our way up.

Each day material from space makes its way into the Earth's atmosphere settling in most cases as dust upon our planet. Anywhere from five to 300 tonnes of meteoric flux is estimated to enter the Earth's atmosphere daily.[31] This material makes up the vast majority of observed meteors as the larger pieces, still only as large as pebbles, react to the friction of passage into the atmosphere in dazzling releases of energy. They pose no risk to the planet and are actually an important source of new material to the Earth. In general observation that objects strike the Earth of less than two to three centimetres tend to be consumed prior to impact[32].That is not to say remnants of larger meteors are not reduced to the centimetre size or smaller before impacting as the debris around Chelyabinsk illustrates.

Local event damage, for example a single building or less than 10 people, would involve a meteor from 50 cm up to several metres depending upon composition. Moving up to a regional perspective, the Planetary Sciences Institute describes the 1908 impact event in Tunguska, Siberia as devastating approximately 2,000 square kilometres of forest after an aerial detonation of a stony meteorite (see Figure 2.4).[33] The meteor has been estimated at 50 metres in size, half the length of a football field, and entered the

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[31] Royal Astronomical Society. Science Daily. "Measuring the Cosmic Dust swept up by Earth". Last updated 29 March 2012, http://www.sciencedaily.com/releases/2012/03/120329225140.htm.

[32] Peter A. Nelson. Tulane University. "Meteorites, Impacts and Mass Extinction" Last updated 12 July 2012, http://www.tulane.edu/~sanelson/Natural_Disasters/impacts.htm.

[33] Ibid.

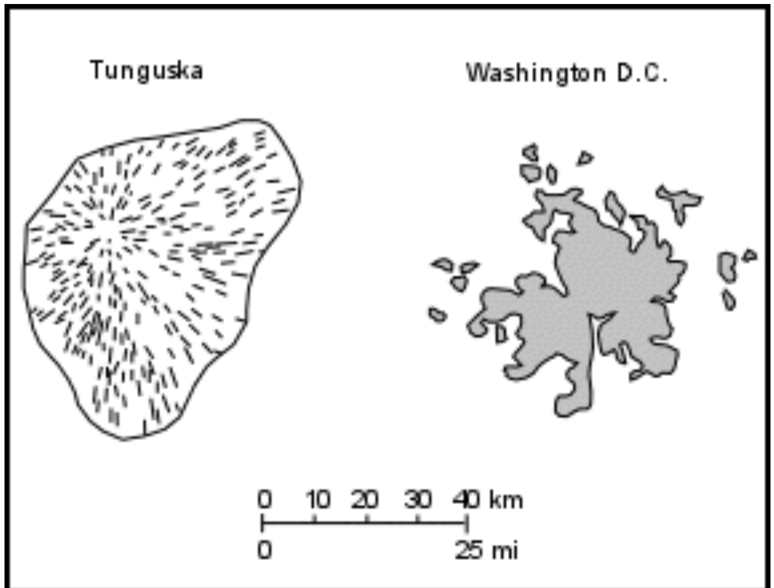

Figure 2.4: Comparison of area effected by the 1908 Tunguska meteor airburst with Washington D.C. based on best estimates. (Figure credits: Prof Stephen A. Nelson)

atmosphere at between 12 to 20 kilometres / second. The resulting heating of the rocky meteor caused it to explosively shatter at an altitude of some five to six kilometres.[34] This is the same mechanism of destruction illustrated by the recent Chelyabinsk meteor, although some larger fragments of the meteor did impact the ground (predominantly in a lake).[35] 1200 people injured in the event, mostly from glass shattering by the shockwave after they were drawn to see what was happening, which is highly synonymous with a nuclear detonation.[36] The key lesson's from this event is that rocks can airburst, and airbursts are as destructive in many ways as those that impact ground or water as are nuclear blasts.

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[34] Planetary Sciences Institute, "1908 Siberian Explosion: Reconstructing an Asteroid Impact from Eyewitness Accounts" Last Accessed 15 June 2014. http://www.psi.edu/epo/siberia/siberia.html.

[35] B612 Foundation. "FAQ on the Chelyabinsk Asteroid Impact" Last updated 18 February 2013. http://sentinelmission.org/news/faq-on-the-chelyabinsk-asteroid-impact/.

[36] Reuters. "Meteor explodes …

Tunguska's equivalent, albeit with a nickel-iron meteorite whose structure and nature prevented it shattering above ground, left its mark in the form of the Barringer Crater near Winslow, Arizona. The crater may as much as 50,000 years old but retains a width of 1.2 km and depth of 200 meters from the impact of a 50 metre nickel-iron meteor.[37] It struck the ground at 11 km/s and created a blast equivalent to a 20 mT. As can easily be imagined, the resulting shock wave, debris field and dust cloud had measurable global environmental effects, and substantial regional ones. Both craters, the Pingaluit in Northern Quebec and Barringer in Arizona, exhibit the signs of an equivalent nickel-iron impactor. In conjunction with global iridium siderophile measurements, both craters are indicative of the prevalence of nickel-iron meteor events in Earth's history.

The classic example of a globally influential impact event is the Alvarez "K-T Killer" confirmed by an evidentiary panel in 2010.[38] The 160 km wide crater is located near Chicxulub, Mexico and is the result of the impact of a 15 km long asteroid so massive it was effectively still outside the atmosphere even as it penetrated the ocean floor at a speed of twenty times that of a bullet.[39] The outcome was horrendous, the ensuing global winter from the ejecta, the hemispherical tsunami zone, the continental concussion wave and fire storm, and resulting mass extinctions. What is crucial to take away from this event is that it the 15 kilometre diameter asteroid that visited such devastation upon our world is beyond our current capability to deter in any way.

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[37] Kaufmann, 328.

[38] National Geographic Society. "Asteroid terminated Dinosaur era in a matter of days." Last updated 4 March 2010 . http://newswatch.nationalgeographic.com/2010/03/04/asteroid_terminated_dinosaur_era_in_days/.

[39] Ibid.

The damage a particular impactor could cause can be quantified through a number of highly accurate simulations, the most often referenced being the Earth Impact Effects Program.[40] This web based simulator allows the input of a range of detailed observational data as well as less refined planning figures, to calculate local, regional, national or global environmental effects for an impact event. Ranging from first order effects like crater size and ejecta thickness at a distance from the impact, through seismic and tsunami secondary effects to include alterations in planetary orbit, the simulator has become an essential tool in quantifying the hazard posed by NEO. What is consistently remarkable in working with the tool is how small the objects can be while still creating significant regional damage upon impact. Equally chilling is how large bodies can extinguish most part, if not all, life on Earth as we know it today. Given the need to find a means of taking action against a potential hazard, and the time it would take to implement such action, the old adage "To be fore warned is to be fore armed" takes on a new significance with respect to the NEO hazard. It becomes a matter of time and space.

Time & Space Issues

There is arguably no dimension more central to the NEO issue than time. The frequency of the threat, the observation period required to determine a trajectory, the reaction time necessary to avert collision are but a few of the implications of time, and by inference, space, due to the need to physically interact with a potential impactor should the threat be sufficient to merit further reconnaissance. Table 2.4 illustrates one model of

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[40] Gareth S. Collins, H. Jay Melosh, and Robert A. Marcus. "Earth Impact Effects Program: A Web-based computer program for calculating the regional and environmental consequences of impact on Earth". *Meteorites & Planetary Science 40*, Nr 6, 817-8140 (2005) http://meteorics.org.

impact event frequency germane to this discussion. The impact frequencies depicted in Table 2.4 are by no means definitive. Our holistic appreciation of the frequency of impact events is a combination of geological evidence of past events, simulations of future impacts and augmentation by new discoveries across the realms of astronomy, geology, mathematics and increasingly in the historical narrative. What can be taken from the data in Table 2.4 is that impact events *do* happen, and more cross disciplinary research is required to resolve the frequency.

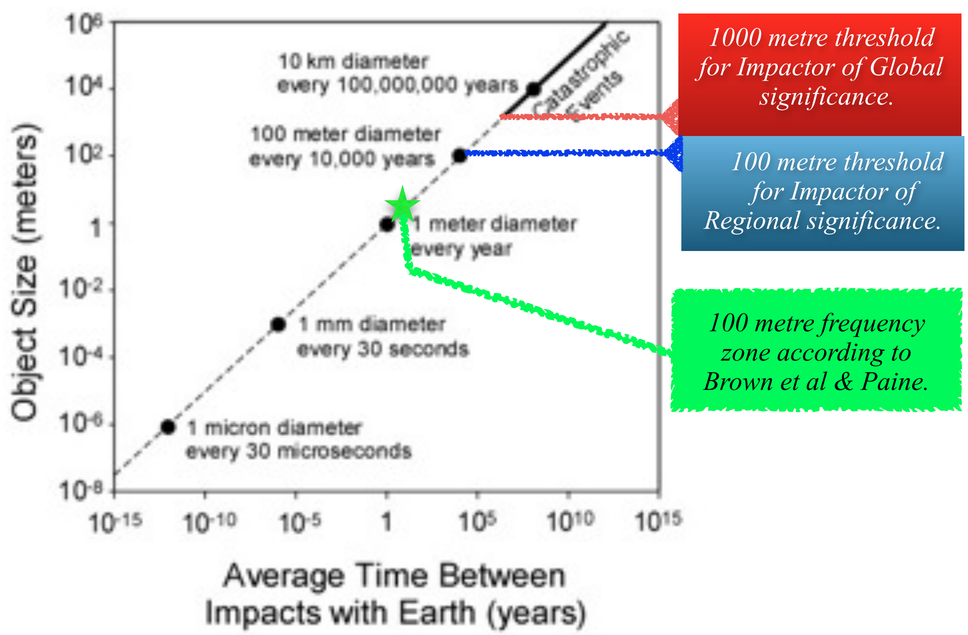

Table 2.4 Correlation of Impact Events by size as a function of time based on pre-2002 research. This data is an initial tool to quantify potential risk based upon last know occurrence. The 2002 work of Dr. Peter Brown and his team are currently redefining activity rates in the one to 100 metre zone (indicated by the Blue Rectangle) to as high as every 400 years vs. 10,000. The simulations of Spaceguard Australia's Michael Paine also call for a higher frequency of 100 metre impacts at 1 every 382 years with a 1km + event every 1382 years (Yellow).(Author's amendments).(Table credits to Prof. Stephen A. Nelson)

A fire in the sky over the Nubian desert of Sudan on 07 October 2008 marked the first time in humanity's long history of watching the sky that a predicted impact event occurred.[41] Asteroid 2008 TC3 as only detected 20.5 hours prior to its impact, a marvel considering it was only two to five metres in diameter and travelling at 12.4 kilometres per second relative to the earth. Its impact was a shallow passage through the sky resulting in the release of 1 kt of energy, well above the ground. Since that time only one other predicted impact has come to pass, 2014AA, also detected 20 hours before impact on 02 January 2014.[42] As promising as these detections and predictions are, the planning horizon remains far too short to deal with larger objects.

In 2016 the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) will be launched by NASA for a rendezvous in 2018 with the asteroid 101955 Bennu (aka 1999 RQ36). What is particularly interesting about this mission is that the 483 metre Bennu is assessed as having a 1:18000 chance of impacting Earth in 164 years from now in 2180.[43] What is important to note is that a great deal of the information necessary to deal with a likely impactor, composition, mass, gravitational peculiarities and even confirmation of the dimensions, must be gained by physical visitation of the object. Finding NEO with enough lead time to design and dispatch a reconnaissance mission, much less craft and execute a remedial solution, is central to the NEO issue. Another crucial time element is the size of the potential impactor.

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[41] National Aeronautics and Space Administration. NEO Program. "Asteroid 2008 TC3 Strikes Earth: Predictions and Observations Agree". Last updated 21 July 2014, http://neo.jpl.nasa.gov/news/2008tc3.html.

[42] NASA. NEO Program. "First Discovered Asteroid of 2014 Collides with the Earth" Last updated 08 May 2014, http://neo.jpl.nasa.gov/news/news182a.html.

[43] NASA, NEO Program JPL Small body database browser. "101955 Bennu (1999 RQ36)". http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=bennu;orb=0;cov=0;log=0;cad=0#orb.

The most likely means of dealing with a potential impactor is to deflect it from its course of collision with the Earth. The early work on theories for how this would be achieved all agree on one point-the earlier deflection is started, the less deflective force will be required. Thus, a massive impactor, particularly those at high relative velocities, would require deflection efforts to begin as soon as possible, perhaps decades in advance, if the impactor is of significant mass.[44] This is one of the major reasons that impact hazard scales consider a window of a century to develop a threat set.[45]

The key is time: time to plan; time to design and build; and time to travel (and sometimes return) over the vast distances of our solar space. This time can only be obtained thorough observation and cataloguing of NEO, together with a program of ongoing vigilance at the maximum distance possible, a military precept understood since the time of Sun Tzu.

Impact Risk Quantification Systems

Table 2.4 illustrates the observational precept that larger impact events occur with lower frequency, and smaller impactors occur with greater frequency. This is drawn from a combination of geological records, anthropological & historical record and extant observation today. On the lower left side of the graph are the micrometeoroids which comprise the meteoric flux continually cascading over the planet, in the middle to upper right of the graph are the bolides and fireballs such as Chelyabinsk, Pingaluit & Barringer. To the far right quadrant is the domain of the Chicxulub-like events.[46] There are two

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[44] J.S. Belton., " " in *Mitigation of Hazardous Asteroids and Comets*, ed.

[45]Ibid, .

[46] Nelson, Ibid.

accepted NEO hazard scales, the first being the Torino Impact Hazard Scale for use as a means of communicating the NEO threat to decision makers and the public at large. The second is the Palermo Technical Impact Hazard Scale, intended for professional prioritization of effort in the evaluation and definition of evaluation of NEOs.

The Torino Impact Hazard Scale

In 1999 at the annual meeting of the International Astronomical Union (IAU) Professor Robert Binzel first proposed the idea of a commonly accepted scale to categorize and quantify the degree of threat a particular NEO would possess. As the conference was held in Turin, Italy, the resulting scale was labelled the Torino Scale. At its heart was the concept of providing a medium to focus non-professionals, political decision makers and the public on a NEO of particular threat. The scale's simple 1to 10 ranking amalgamated the impact energy and probability of impact within 100 years, into a threat category, number ranking, and brief descriptor as illustrated in Table 2.5 (credits to NASAhttp://neo.jpl.nasa.gov/images/torino_scale.jpg).[47] There are five self-explanatory hazard categories and associated colour code: No Hazard (White)/Rank 0; Normal (Green)/Rank 1; Meriting Attention by Astronomers (Yellow)/Ranks 2-4; Threatening(Orange)/Ranks 5-7; and Certain Collision (Red)/Ranks 8-10. To date the highest ranking awarded has been 4 which has since been downgraded to a 0.

The Torino scale was amended in 2004 after concern that its terminology was somewhat inflammatory, in categories Two to Four, the descriptor was changed from "meriting concern" to "meriting concern from astronomers". This change more clearly

[47] National Aeronautics and Space Administration (NASA). NEO Program Office. "The Torino NEO Hazard Scale" Last updated 08 June 2014 , http://neo.jpl.nasa.gov/news/news046.html..

communicates when an object requires more observers to refine observations from a multitude of locations without causing public alarm until the object has been properly defined.[48] A perfect example of this took place in December 2004 when asteroid 2004 MN4 (now named 99942 Apophis, see Figure 2.5) was classified as a Torino Category 4 by the NASA NEO Program Office.

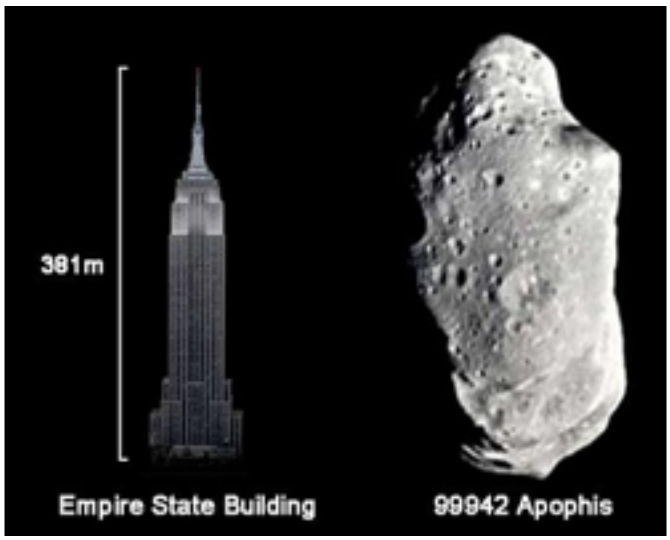

Figure 2.5: Comparative size of the asteroid Apophis based upon its initial estimates of 400 metres at the time of its Torino Cat 4 designation. Subsequent observation refined it to 330 metres. (Image Credit-Mark Brewer)

Apophis (see Figure 2.5) was originally estimated to be some 400 metres in size with a 1:37 chance of striking Earth on 12 April 2029. The resulting additional observation by astronomers, sensitized to the threat by the NASA's Cat 4 Torino designation, refined the orbital trajectory estimates. By 2006 Apophis had already been downgraded to a 1, and by 2013 it was categorized as a 0 based upon extensive observation over a nine year period, but it will remain among the closest approaches of an

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[48] Elizabeth A. Thomson. Michigan Institute of Technology (MIT) News. "Revised asteroid scale aids understanding of impact risk." Last updated 12 April 2005, http://newsoffice.mit.edu/2005/torino.

THE TORINO SCALE

Assessing Asteroid/Comet Impact Predictions

No Hazard	0	The likelihood of collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bolides that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal	1	A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0.
Meriting Attention by Astronomers	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0.
	3	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
	4	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
Threatening	5	A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A close encounter by a large object posing a serious, but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.
	7	A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur.
Certain Collisions	8	A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years.
	9	A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.
	10	A collision is certain, capable of causing a global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

Table 2.1: The revised Torino Scale based upon Binzel's proposal in 1999. The major modification was to draw additional astronomers to provide observational data on NEO classed as 2, 3 or 4 versus raising public concern prematurely. (Table Credit to NASA NEO Program Office.)

asteroid to that point (within 2 R_E, and below many satellites in LEO).[49] While categorized as 0 on the Torino Scale for public consumption, 99942 Apophis (2004MN4) still retained a Palermo rating of -3.19 for professional astronomers responsible for monitoring it,[50] Which brings us neatly to discussions of the Palermo scale.

The Palermo Technical Hazard Impact Scale

The Palermo scale was introduced in September 2001 at the Mount Palermo observatory by a team of five astronomers, all key figures in the NEO field and founding members of Spaceguard Foundation. The team proposed a more advanced NEO categorization system with a view to providing risk posed by a particular *potential* impact event in both absolute and relative terms as a function of background activity. That is how much more of a threat the object presented than the norm. It does not supplement the Torino scale, but rather compliments it with a level of professional assessment for prioritization of scarce astronomical & astrophysical observational and analytical resources.[51]

The Palermo scale is logarithmic, and any positive value (i.e. greater than 0) is cause for concern and is equivalent to Torino ranks 5+, indicating greater risk than the background / normal possibility of collision. Palermo values in the range of -3 to -5 are of

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[49] Mark Brewer. MSB1959's Blog. "Apophis 99942-Asteroid that does come close" Last accessed 26 June 2014, http://msb1959.wordpress.com/2011/05/19/apophis-99942-asteroid-that-does-come-close/.

[50] National Aeronautics and Space Administration (NASA). NEO Program Office. "99942 Apophis (2004MN4) Impact Risk Summary" Last updated 08 June 2014 http://neo.jpl.nasa.gov/risk/a99942.html.

[51] Steven R. Chesley (JPL), Paul W. Chodas (JPL), Andrea Milani (Univ. Pisa), Giovanni B. Valsecchi (IASF-CNR) and Donald K. Yeomans (JPL) *Icarus* **159**, 423-432 (2002) Last Accessed 24 Jun2 2014,http://neo.jpl.nasa.gov/risk/doc/palermo.pdf.

interest to professionals in the observational field (ie: Torino ranks 2 to 4).[52] A detailed understanding of the scale is more than is required for this research, but is easily extrapolated from the entries in the SENTRY automatic impact risk list.[53]

Summary

It is demonstrable that the Earth has suffered from impact events ranging from the routine flux, adding material to the Earth daily, up to and including massive blows that have reshaped the form and life upon the planet and perhaps even forming the moon above. An impactor's possible severity is predicated upon a number of variables, but principally its composition, mass, velocity, and angle of attack. Energy release in the kiloton range is not unusual, but frequently dispersed at very high altitudes. NEO size is a common classification threshold for severity, with objects one kilometre or greater (1 km +) representing a global concern (ie: K-T Killer, Chicxulub range threats). Objects ranging from 140 to 1700 metres in size are a Regional/Sub-Global threat influencing as much as a continent or hemisphere (Tunguska, Barringer); and objects from 10 to 139 metres or of local concern (such as Pingaluit, Chelyabinsk).

Our current efforts to catalogue the 10,000 plus NEO population is based on a limited number of largely ground based observational tools predominantly in the Northern Hemisphere. Humanity's capacity to search out NEOs is therefore limited to larger bodies with higher albedo reflectivity. This further limits our NEO search programs to looking away from the sun, missing any approaches from the inner domains of the solar system.

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52 Ibid, 431.

53 Unites States Government. National Aeronautics and Space Administration. NEO Program Office. "Sentry Impact Risk List." Last accessd 08 August 2014, http://neo.jpl.nasa.gov/risk/.

Perhaps as few as 1% of the potentially hazardous NEOs have been catalogued at this point, but the NASA NEO Program maintains that it has catalogued 90% of the NEO population of one kilometre or greater in size despite observational limitations.

Impact event frequency remains a hotly debated issue, but the most recent tools for observing impacts have drastically reduced estimates to as low as one 100 metre impactor (ie: a Regional / Global level threat twice the severity of Tunguska, Barringer or Pingaluit) once in every 380 to 1400 years. At least one five kiloton impact was detected per year during the Brown et al review of optical flashes recorded by US government satellites over an eight year study.

Finally, in line with other forms of natural threat such as the Richter scale for seismic activity and the Beaufort scale for weather, the Torino and Palermo impact hazard scales have been established to quantify and categorize the threat a particular NEO poses to Earth. The Torino scale is a public communications tool ranging from 0 to 10 where serious concern is not generally merited below rank 8+. The Palermo scale, for use by specialists in the NEO field, is logarithmic in nature and more precisely describes the risk a NEO poses against background activity to aid in prioritization, observation and effort. Only positive values are of significant concern with the vast majority of NEO residing at -3 or lower on the Palermo scale.

CHAPTER 3 DEFINING THE TARGET

Introduction

This chapter will look at Canada to illustrate a historic precedence for impact events and analysis for emergency management concerns in NEO impact event scenarios. This analysis will include a brief review of elements such as human settlement, critical infrastructure and key terrain to define regional points of vulnerability for hazard to space impact. It will serve to provide a baseline for discussion only, and frame the deeper consideration necessary at the national level of emergency response planning.

The context will be within the local, regional and global impact hazard scales defined in the previous chapter. This method will permit an assessment of Canada and identify the specific areas where the nation would be most adversely influenced by the range of effects of a space impact event. In a sense, it will define the "area of interest" for Canadian initiatives to address the threat of a space impact event.

Historic Precedence

As we saw in the last chapter, the Planetary and Space Science Centre (PASSC) of the University of New Brunswick maintains the Earth Impact Database (EID) which provided physical evidence of earth impact events, beyond the scarred face of the moon overhead. Of the 184 confirmed impact sites in the database an extraordinary 31 of these (16.8%) lay within the boundaries of Canada as illustrated in Figure 3.1.[54]

[54] PASSC "Earth Impact Database - North America" Accessed 24 June 2014 , http://www.passc.net/EarthImpactDatabase/NorthAmerica.html.

Following on with Paine's 8% physical cratering limit, it can be extrapolated that the overall number of impact events is somewhere closer to 387 when airbursts and water impacts are included.

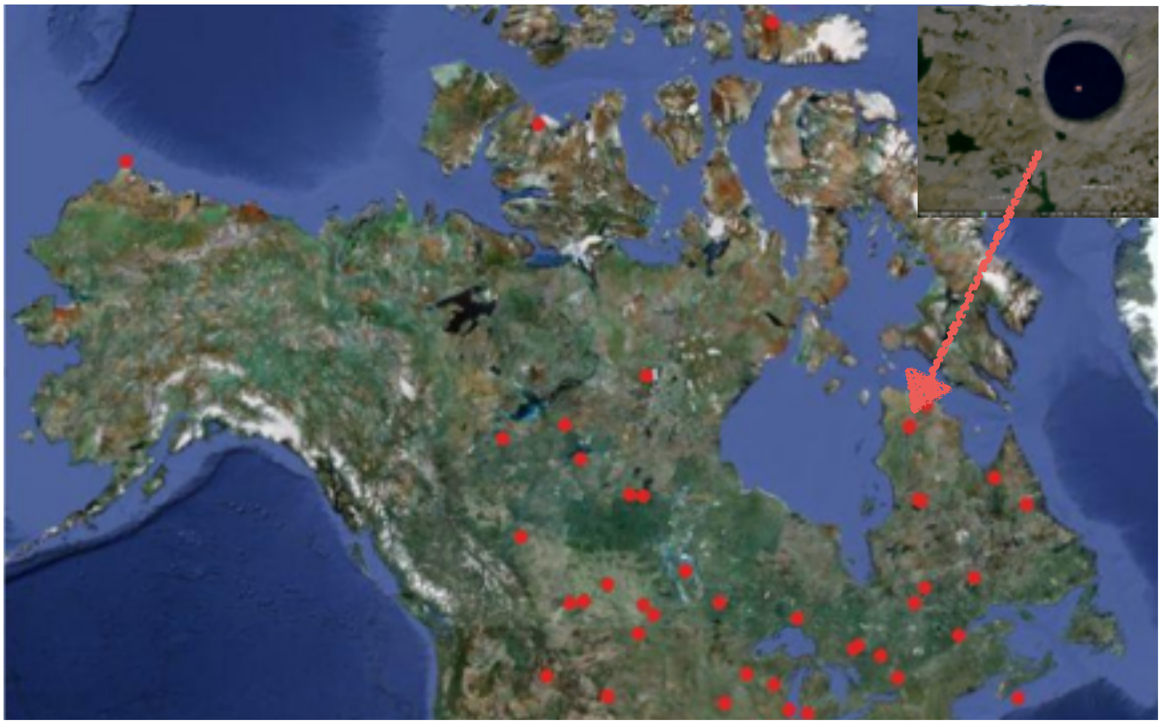

Figure 3.1: Graphic extract of historical impact events in Canada from the Planetary and Space Sciences Centre's (PASSC) Earth Impact Database. The inset image is of the Pingaluit Crater in Nunavik, one of the best preserved,and least known impact sites in the world. (Figure Credits: PASSC and Google Earth (Pingaluit Insert)).

Canada as an Entity.

Our nation covers some 9,984,670 square kilometres with some 202,080 kilometres of coastline. In the summary points on the nation, Canada is summed up as:

> [The] second-largest country in world (after Russia) and largest in the Americas; strategic location between Russia and US via north polar route; approximately 90% of the population is concentrated within 160 km (100 mi) of the US border; Canada has more fresh water than any other country and almost 9% of Canadian territory is water; Canada has at least 2 million and possibly over 3

Figure 3.1: Canadian population distribution in 2006 with key terrain groupings for the purpose of prioritizing National Emergency Response System on the creation of impact event response plans. Map credit: Natural Resources Canada.(Atlas of Canada, 6th Ed), www.atlas.gc.ca

> million lakes - that is more than all other countries combined.[55]

I have chosen to define a number of zones which would be of priority concern for emergency response planning. While I consider a detailed analysis outside the scope of this paper, these zones serve as a preliminary definition in setting the conditions consideration by public safety officials.

With respect to the location of our population, Canadians mostly inhabit a zone of roughly one million square kilometres (1,026,560 km) in the Southernmost regions of the nation (barring a pronounced North-South corridor in Alberta). This distribution has been more accurately illustrated by Natural Resources Canada based upon the 2006 census in figure 3.2.[56] These zones which are closely correlated with Canada's major urban

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55 United States Government, Central Intelligence Agency. *The World Factbook*, "Canada" last updated 23 June 2014,https://www.cia.gov/library/publications/the-world-factbook/geos/ca.html

56 Government of Canada, Natural Resources, "The Canadian Atlas" last updated [accessed] 08 July 2014,http://atlas.nrcan.gc.ca/site/english/maps/population.html

centres in which 80.7% of Canadians live, are in order of population: Toronto, Montreal, Vancouver, Calgary, Ottawa and Edmonton.[57] For the purposes of this study these population centres are grouped into four major and one minor locality referred to as Zones A-C,D1 & D2.

Zone A - Beginning at Windsor and enclosing the Toronto, Ottawa, Montreal corridor with an extension to city of Quebec this area represents the highest density of population and critical infrastructure in the country. Approximately 13,308,000 (37.3%) Canadian's live in this geologically stable region which is exposed to some danger of a water impact from Lake Ontario in its Southernmost zone. It encompasses the jurisdiction of two provinces, Ontario and Quebec, which would require an additional element of emergency planning coordination.

Zone B - Calgary and Edmonton Corridor. Also geologically stable, Zone B represents the increased population density of Alberta at some 2,654,400 (7.4%) of Canadians. The zone itself does not require provincial de-confliction. Power generation and critical infrastructure are fairly dispersed as well. Second and third order effects of an impact in the resource zones of the province should be considered within the national response strategy but would not impact immediate disaster response efforts.

Zone C - Winnipeg and South Central Manitoba. Home to only 771,400 (2.2%) of Canadians, this zone has been identified because of the second order effects of a severe local impact or regional / sub-global on national land lines of communication. It contains a Provincial governance node as well as the bulk of the provincial population. Although a

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[57] Ibid.

similar argument could be made for the Rogers Pass in the Rocky Mountains, there is no commensurate first order loss of life associated with that location.

Zone D 1-Vancouver, the Southern BC mainland and Victoria and Zone D2 - the Halifax area, its major shipping port and critical infrastructure and the Atlantic Provinces. These two coastal zones are both provincial governance nodes as well as sea-lines of communication hubs. D1 is substantially more populated with 2,800,600 Canadians (7.9%) and geologically unstable. Plans for NEO impact response in D1 would closely mirror the significant planning made to respond to seismic disaster and could be a valuable jumping-off point of the NEO Impact response contingency. D2 is home to approximately 681,500 Canadians (1.9%), but an impact event could influence three provincial capitals in this one region. Both D1 & D2 are vulnerable to tsunami effects of an impact well beyond Canadian jurisdiction.

Canada within a Global Context

Given our population’s proximity to the United States, consideration must be given to an impact event straddling the border and requiring a coordinated response by both nations. Should the impact be sub-global in nature, the assistance of both nation’s may be crucial in the initial response regardless of whether the first order effects are confined to the sovereign territory of either nation. Public Safety Canada and the US Federal Emergency Management Agency (FEMA) should collaborate on the emergency response.

Canada is a global citizen, and should also be prepared to consider the displaced persons and, on a longer scale, refugees that might arise from a sub-global event. Deeper considerations of this issue are reserved for study at a later date, but would likely be a point of discussion in UN considerations of the NEO impact risk such as the International Disaster Planning Advisory Group (IDPAG).

Summary

Canada contains physical evidence of at least 31 impact events, which is likely representative of at least 387 such events in the past. Canada contains a disproportionate amount of ground impact events at nearly 17% of global physical evidence. Despite the vast size of the nation there are generally five zones of immediate concern for emergency response planning, planning which could be closely modelled upon large scale seismic emergency response. Only Zone D1 & D2 require integration of tsunami influence from an impact beyond sovereign territory. Federally led discussions on interprovincial and international response is essential given the proximity of all zones to the international border. Second and third order concerns regarding displacement of persons, influence upon key resource sectors, effect on global weather to food supplies or weakened military posture all require consideration outside the scope of this paper. None the less, these issues are necessary to the national representation likely to be called for in attending UN discussions on the NEO issue

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CHAPTER 4 INTERNATIONAL NEO POLICY AND INITIATIVES

Introduction

As we have seen, mankind writ large and Canada in particular, shares the concern of impact events. It is demonstrable that even a 50 to 100 metre NEO could produce effects of grave concern with respect to a humanitarian disaster and the economic effects of the aftermath of such a sub-global impact.[58] Despite the long history of acquaintance with the experience, NEOs have only recently begun to receive attention, funding and some degree of reaction by national governments. This chapter will review the relatively few organizations around the planet that are focussed, wholly or in part, on the NEO issue.

Although the United Nations has provided a framework to address the issue and act as the coordinating agency, much work remains to be done in providing a practical apparatus to the many elements necessary in an impact event scenario. NEO impact efforts continue to be largely led by academics with tenuous funding support. These efforts have only achieved centralization with regards to data collaboration vital to the detection and classification process. Outside of these academic efforts there has been little or no engagement by government or their associated militaries to date. At the same time, there is extensive governance and policy on the man-made objects in and around Earth as well as academic, civil and military organizations involved in satellites through all stages of their life cycle. Much of this satellite command and control (C2) architecture could be leveraged in addressing the NEO issue if there was government will to do so. Canada

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[58] Morrison et al.

already has several means by which a "whole of government" influence could be applied to the NEO / space debris impact issue should it choose to do so.

This chapter will quantify the major players in the NEO impact threat with particular attention to identifying the role Canada. Of particular importance will be the inherent responsibility to act in Canada's *National Security Policy* and *National Emergency Response System* frameworks, and how this may be accomplished within the *Canada's Space Policy Framework*. This chapter will pursue a "top down" approach in defining the agencies and offices involved, beginning with the United Nations.

The United Nations and NEOs

The United Nations is involved in space activities through its Committee on the Peaceful Use of Outer Space (COPOUS) which oversees the international treaties and agreements governing all aspects of the international community in space. Under this mandate the COPOUS established the Office of Outer Space Uses (UNOOSA), its subcommittees and working groups. Through the COPUOS the UN deals with the administration of treaties and matters relating to activity in space governed by these groups. In 2001, as a result of recommendations from the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), and culminating progress on the NEO threat ongoing since 1995, Action Team 14 (AT 14) was established.[59] Action Team 14 represents the UN's most directly focussed element with regard to the NEO impact event scenario. Its mandate, as elaborated in a press release following the February 2013 Chelyabinsk incident, is cited below:

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[59]Haubold, Nadis. *Astrobiology & Outreach* 2014 Ed 2.2 "Near-Earth Objects …

a. Review the content, structure and organization of ongoing efforts in the field of near-Earth objects (NEOs);

b. Identify any gaps in the ongoing work where additional coordination is required and/or where other countries or organizations could make contributions; and

c. Propose steps for the improvement of international coordination in collaboration with specialized bodies.[60]

AT 14 presented their final report to the 50th session of the Scientific Technical Subcommittee (STSC) in February 2013.[61] The STSC oversees the various action teams assigned by COPUOS and recommends them for passage to the General assembly via COPUOS. Outcomes from the work of AT 14 include the proposal of a NEO monitoring and resolution process integrating a steering committee for the extant (and evolving) NEO sensor network, two advisory groups which would work through UNOOSA and an Ad Hoc advisory group to provide a cohesive response in the event a credible (Torino 8+) impact threat. Figure 4.1 illustrates the UN response protocol, accepted by the 68th session of the UN General Assembly on 13 December 2013.[62]

The International Asteroid Warning Network (IAWN) proposed by Action Team 14 is largely based upon the American NASA NEO survey program mandated by

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[60] United Nations Office for Outer Space Affairs. "Press Handout: Recommendations of the Action Team on Near-Earth Objects for an international response to the near-Earth object impact threat." 20 February 2013, last accessed 01 August 2014,http://www.oosa.unvienna.org/pdf/misc/2013/at-14/at14-handoutE.pdf.

[61] Sergio Camacho. "Report of the Action Team on NEOs: Recommendations for an International Response to a NEO Threat.", 13 February 2013. Last accessed 08 August 2014. http://www.oosa.unvienna.org/pdf/pres/stsc2013/2013neo-01E.pdf.

[62] Haubold, Nadis. *Astrobiology & Outreach* 2014 Ed 2.2 "Near-Earth Objects …3.

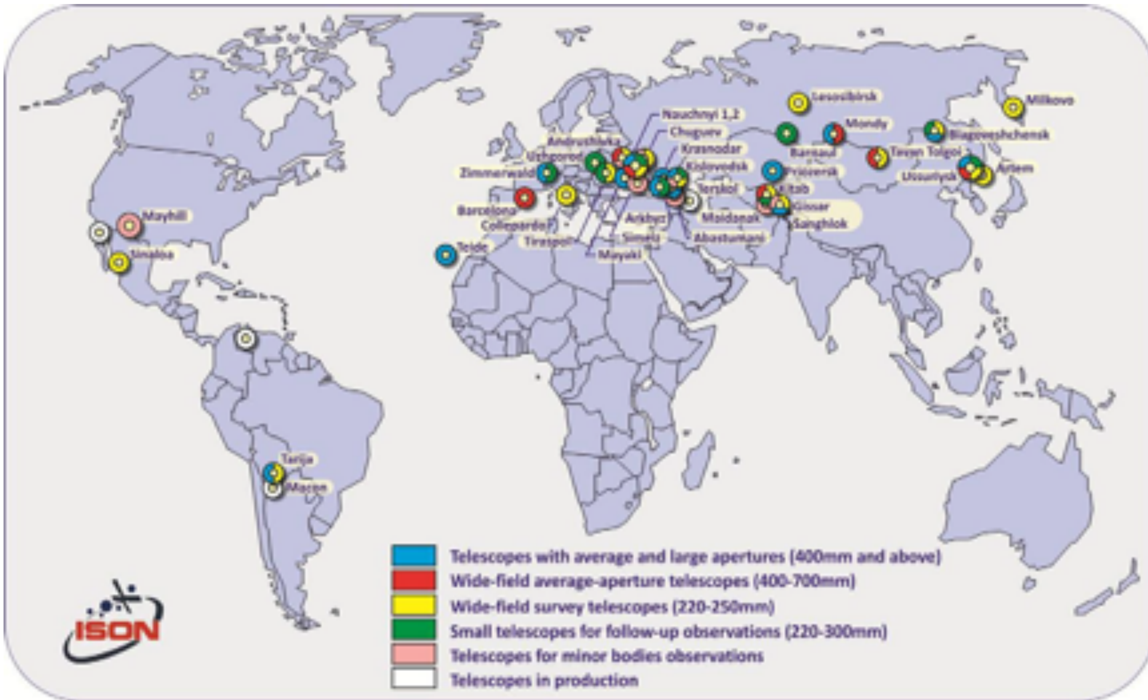

Figure 4.2: The International Scientific Optical Network (ISON) which links a total of 50 telescopes in 32 facilities across 13 countries. The network aids in observation scheduling and coordination as well as support maintenance in addition to its space debris and NEO reporting tasks. Figure Credit: Russian Academy of Sciences Keldysh Institute of Applied Mathematics.

Congress in 2005 and will be addressed in greater detail later in this paper. Under the UN plan a Steering Committee would be formed to work with the extant networks of sensors and specialists already engaged in the NEO issue. This would integrate groups such as the IAU Minor Planet Centre (MPC) and Europe's Near Earth Asteroid Search Observatories (EUNEASO) and a number of other non-governmental initiatives such as Spaceguard. This informal community and the crucial internet based reporting architecture of SENTRY and NEODyS, makes up the IAWN which reports annually to COPUOS (via the Steering Committee). An excellent example of one such network of extant observatories is the NEO equivalent of the UN's support of the IAU's International

Scientific Optical Network (ISON) which, among its many endeavours, monitors orbital debris and NEO threats(Figure 4.2).[63]

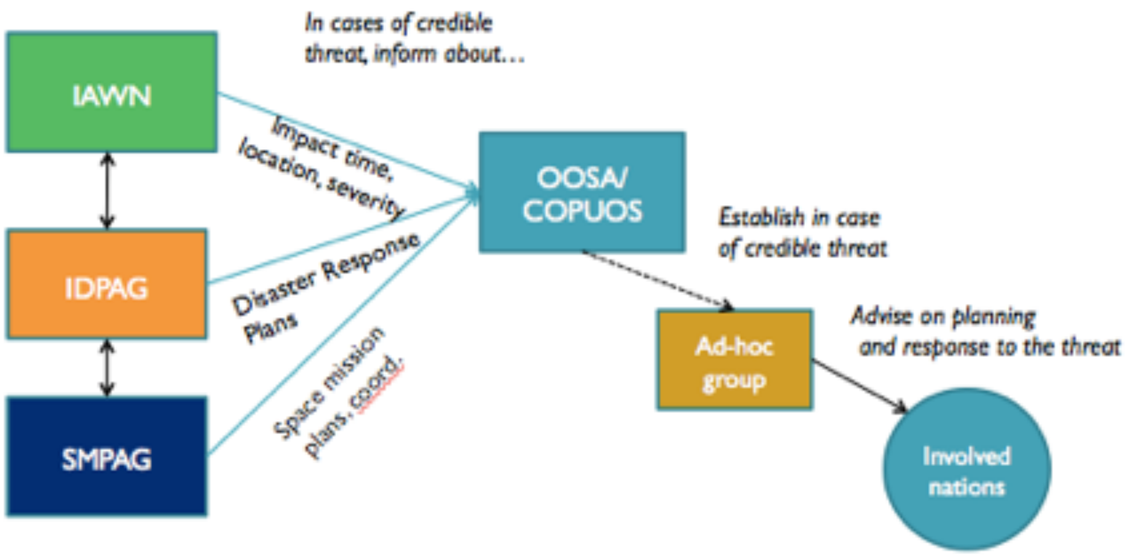

Figure 4.1: UN NEO Protocol as proposed by Action Team 14 and accepted by the UN General Assembly 13 December 2013 The protocol integrates the extant individuals, organizations and agencies of the International Asteroid Warning Network (IAWN), and two recently formed advisory groups. The International Disaster Planning Advisory Group (IDPAG) and the Space Missions Planning Advisory Group (SMPAG). In the event of a credible threat (Torino scale 8+) the Office of Outer Space Affairs would coordinate the inputs of these three elements and constitute an Ad-Hoc Group for the specific threat. This Group would then coordinate with the contributing nations, much like a UN Peacekeeping mission, in defining, organizing, supporting and executing a solution to a credible NEO threat.(Figure Credit: UN OOSA)

The Space Mission Planning Advisory Groups (SMPAG pronounced "Same Page") first met in February of 2014 with a member of the Canadian Space Agency (CSA) among the attendees.[64] Although in its early stages, this group's role is to provide an international venue for the collective and collaborative efforts on space missions meant to assist in the definition, understanding and influencing NEOs. Outputs from this advisory group would be defining and disseminating standardized reference mission

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[56] United Nations. Office of Outer Space Affairs. "Russian Academy of Sciences Briefing - Results of GEO and HEO monitoring by ISON Network in 2012". Last updated 22 February 2014, http://www.oosa.unvienna.org/pdf/pres/stsc2013/tech-07E.pdf.

[64] European Space Agency. "SMPAG: Summary of First Meeting." Last updated 14 February 2014, http://blogs.esa.int/rocketscience/2014/02/12/smpag-summary-of-the-first-meeting/.

profiles, procedures and timelines for the full range of NEO related space missions. This would ultimately include the mediative efforts such as deflection activities, but would certainly address the design of a spacecraft type for NEO reconnaissance research and definition. While there have historically been a number of unilateral, bi-lateral and increasingly multilateral space efforts carried out by the three principal launching agencies of the world the SMPAG is a heartening first step to the kind of international collaboration and centralized coordination necessary to deal with the impact event threat. The third tier of the UN NEO agencies relates to the response to an impact event which cannot be avoided.

The International Disaster Planning Advisory Group (IDPAG) is similar to the IAWN in that it has been created via the representation of extant disaster management and emergency response organizations at the national and non-governmental organization level such as the UN Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), Office for the Coordination of Humanitarian Affairs (OCHA) and the office of Disaster Risk Reduction (UN-ISDR).[65] Although the OOSA literature describes the IDPAG as being initiated by the IAWN, its purvue of planning and exercising responses to anticipated and unanticipated impacts of localized, regional and global natures would seem to require a standing committee.

These newly created entities represent the UN’s contribution to the coordination of humanity's response to a credible NEO threat. With the completion of its work, AT 14 hands over the portfolio to the NEO Working Group, itself an adjunct of the STSC. The

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[65] OOSA. Action Team 14 Recommendations NEO for an International response…,2

NEO Working Group is to ensure the actions necessary to provide a baseline and framework to support and sustain the IAWN, SMPAG and IDPAG. Integration and participation of non-governmental organizations (NGOs) within the all groups, particularly the IAWN and IDPAG, was emphasized.[66] This plan remains in its earliest stages at the time of this writing, the IDPAG not even having been convened and both the IAWN and SMPAG still fully defining their terms of reference. In addition to this, none of the work of these groups is likely to funded by the UN, costs being born by the representing / participating nations and supporting national agencies on a rotational hosting basis.[67]

As noted, the UN efforts are in their infancy. Much work remains to be done across a range of issues, not the least of which is the assignment of decision making authorities in an organization dominated by consensus. It is somewhat akin to organizing a Fire Department in a village made of wood, but without agreeing on who can decide how the fire will be fought and when. Although the process for response to a credible NEO threat appears a straight forward concept as outlined in Figure 5.1 this can only be so if it remains unfettered of of the complex administrative process of day to day UN activity.

International Agencies / Non-Governmental Organizations

The NEO issue has long had champions outside of governments and official agencies. This began in the late 1980's as the Alvarez theory gained acceptance and

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[66] Comacha, 5.

[67] Comacha, 12.

public awareness was drawn to the academic discourse on the role of impact events in the geological and biological record. It was also heightened by a growing understanding of the micro-meteoroid threat to spacecraft as the human presence in orbit began a period of dramatic expansion in LEO and GEO zones. The various Planetary Societies of nations, together with associations like the International Astronomical Union (IAU) began to form their own sub committees and working groups to champion the issue. In many ways these organizations are to be credited for the advance of the NEO threat onto the UN stage. What follows is a brief explanation of some of the key players in the issue, and their role in further NEO impact event developments.

International Astronomical Union (IAU) & The Spaceguard Foundation

The Spaceguard Foundation was established on 27 March 1996 from roots in the International Astronomical Union (IAU),. The members were from among the academics associated with IAU Commission 20, "Positions and Motions of Asteroids, Comets and Satellites".[68] The intent of the organization was to enhance the international constituency of research into the NEO field following the establishment of NASA's NEO Discovery and Interception working groups. Spaceguard incorporated an excellent mix of US and international members, many already among the NASA teams. The foundation includes many of the seminal members of the NEO community such as Binzel, Gehrel and both

[68] Spaceguard Foundation. "A Brief History of the Spaceguard Foundation" Last updated 08 January 1999,http://spaceguard.iasf-roma.inaf.it/SGF/history.html.

Shoemakers of Comet Shoemaker-Levy fame.[69] It has since expanded to include a number of new national representatives, with two Canadian names among them.[70]

The Spaceguard Foundation established a protocol for the coordinated detection of NEOs among the world's ground based observatories as well as the "Central Node", the IAU Minor Planet Centre (MPC), for the collection and correlation of observation data. Together they form the Spaceguard Survey, and represent the origins of humanity's attempt to come to grips with the threat of an impact event. The MPC continues to vet any contributed observations submitted to it in accordance with long established protocols.[71] Since the Brown Bill was passed NASA has funded MPC operations in a series of five year grants. The work of the Spaceguard Foundation was the genesis of NASA's SENTRY automated NEO Risk list and the ESA's NEO Dynamic System (NEO DyS) which are both fed data from the MPC in addition NEO observations generated by their own programs. The the contributions of the MPC, and their many other activities the IAU and Spaceguard will remain an active and crucial voice in the work of the UN's IAWN and SMPAG in the future.

Association of Space Explorers

This non-profit organization consists exclusively of persons who have completed at least one orbit around the Earth. There are a total of 395 members from 35 countries,

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69 Spaceguard Foundation. "Members of the Spaceguard Foundation". Last updated 17 May 2002, http://spaceguard.iasf-roma.inaf.it/SGF/members.html.

70 David D. Balam. " David D. Balam (Spaceguard/CBAT Observer, telescope operator)." Last accessed 30 July 2014, http://astrowww.phys.uvic.ca/~balam/.

71 Minor Planet Centre, "NEO Page", Last accessed 22 August 2014, http://www.minorplanetcenter.net/iau/NEO/TheNEOPage.html.

all former astronauts or cosmonauts.[72] The Association of Space Explorers (ASE), through the work of its NEO Working group and several key members, has been an active and vocal advocate for UN leadership in addressing the NEO threat.[73] Following the acceptance of the AT 14's recommendations by the UN General Assembly, the ASE released a call for additional measures from the international community to support the nascent UN NEO Threat framework. In their open letter the ASE called upon the UN member nations to maintain the momentum by five further actions:

1. The UN delegations should brief their respective national policy makers on the asteroid hazard and the General Assembly actions taken to prevent a NEO impact.

2. All national policy makers (not just those of the space-faring nations) should specifically address impact hazards in their disaster response plans and budgets.

3. To create clear accountability, national governments should explicitly assign lead responsibility for asteroid hazard response to their space or disaster response agency, as appropriate.

4. To find the approximately one million NEOs capable of threatening Earth, policy makers should commit the modest funds necessary to support the launch by 2020 of a space-based search telescope.

5. Anticipating these search results, policy makers should direct their space agencies to launch within ten years an international deflection demonstration, to alter the path of a small near-Earth asteroid.[74]

The ASE, along with Spaceguard, will likely remain a key player in the fight to counter the NEO threat given the high profile of its membership and its access to key leadership

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[72] Association of Space Explorers. "Homepage", Last accessed 05 July 2014, http://www.space-explorers.org.

[73] Turnage. Jones, 3.

[74] Ibid.

across member states and the United Nations. Not the least of the ASE connections is that of ASE members and veteran US astronauts Rusty Schwiekert and Ed Lu and their work with the B612 Foundations Sentinel space telescope initiative.

B612 Foundation

The B612 foundation takes its name from the designation of the tiny moon from the children's story "The Little Prince". The foundation was formed to further the aim of a privately funded deep space initiative called Sentinel which would be used to create "the first comprehensive, dynamic map of our inner solar system".[75] The Sentinel is an infrared space telescope designed to orbit the sun 40 million kilometres deeper in the inner system in an orbit similar to Venus. For the duration of its six and a half year mission it would be able to scan the entirety of the solar system every 26 days using proven components from the Kepler and Spitzer space telescopes.[76] Sentinel would be much better placed and equipped than any current observatory to identifying and tracking asteroids, particularly those approaching from the inner solar system which are currently not observed by any element of the Spaceguard Survey. Built by Ball Aerospace and with many of the same teams and components proven in earlier, and highly successful NASA missions, the project is specifically oriented to address the observation limitations of the current contributing stations to the NEODyS and SENTRY impact risk lists (via the

[75] Sentinel Mission."B612 Foundation Announces First Privately Funded Deep Space Mission." Last updated 28 June 2012. Last accessed 14 July 2014, http://sentinelmission.org/newsroom/press-releases/b612-foundation-announces-first-privately-funded-deep-space-mission/.

[76] B612 Foundation. "Sentinel Mission Data Sheet." Last accessed 08 July 2014, http://sentinelmission.org/wp-content/uploads/2013/02/D2071_Sentinel-DataSt_313_4-2013.pdf.

Minor Planet Centre). It will also provide a wealth of data to applicable NEO monitoring agencies and a wide range of users in the space community.[77]

The mission is slated for launch in 2017-2018 and will return its data via the NASA Deep Space Network, also used for spacecraft navigation and tracking transmissions.[78] In responding to public inquiries following the Chelyabinsk incident B612 CEO Ed Lu stated:

> It [the Sentinel satellite] will find 90 percent of asteroids larger than 140 meters (about 1000 times more massive than Chelyabinsk) [sic] and about half of those larger than Tunguska (30 times more massive than Chelyabinsk) [sic] in the first 6.5 years of operation. It will find some, but not the majority of the much smaller Chelyabinsk sized asteroids.[79]

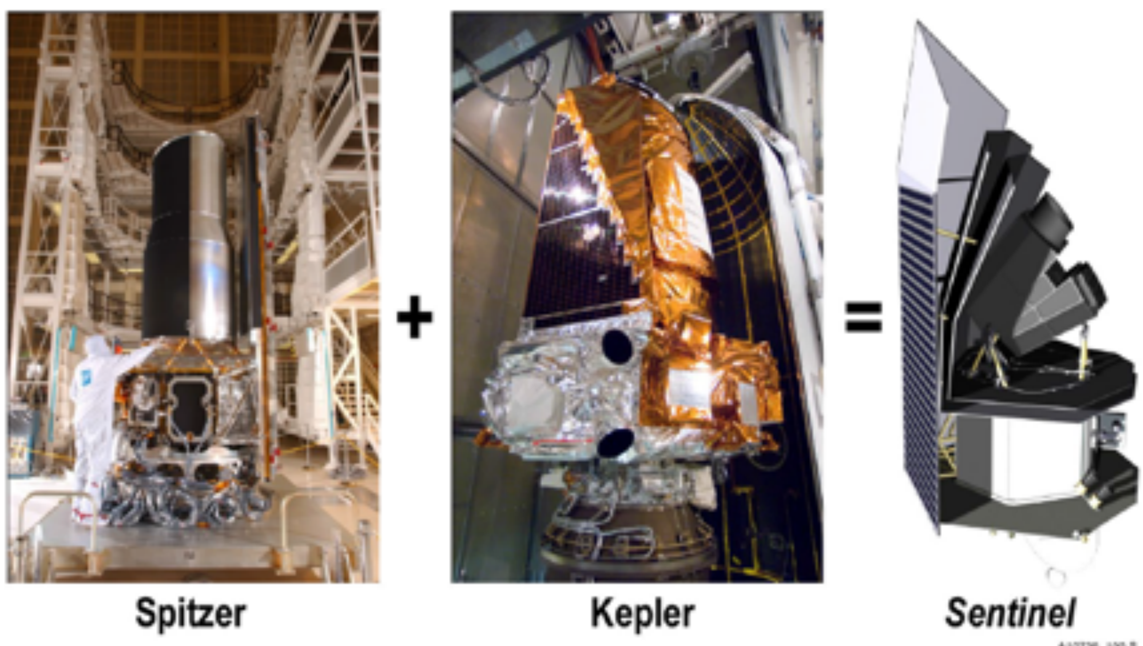

Figure 4.3: Combination of Spitzer and Kepler space telescopes proven components for the Sentinel NEO detection observer and mapper. Scheduled to launch in 2017-2018 Sentinel will operate for 6.5 years and provide accurate detection and orbit determination for the bulk of 50 metre objects in the solar system. The B612 Foundation's Sentinel is unique in that it will be the first privately funded space venture beyond the Earth-Moon system. (Figure Credits: B612 Foundation)

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77 Ibid.

78 Sentinel Mission. "B612 Foundation…".

79 B612 Foundation. "FAQ on the Cheylabinsk…".

The Sentinel observational data will first pass to the Laboratory for Space Physics (Colorado, USA) prior to international distribution via NASA's Minor Planet Centre (Massachusetts, USA) for all manner of scientific, educational and space advancement initiatives. Sentinel will provide a key tool in the NEO detection arsenal if it can overcome its need for donor contributions to meet the cost of this expensive but necessary endeavour.

American NEO Initiatives and Responsible Agencies

The United States, the world's preeminent space faring nation, is the only country in the world which has government engagement in the NEO threat. NASA has been working the detection and cataloging of the NEO populations since the mid 1990s with its Discovery and Interception working groups. In 2005 these activities became an assigned task when Congress introduced the George E. Brown Jr. NEO Survey Act in 2005 directing:

> The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration in science and engineering systems be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects impacting the Earth.[80]

The bill was signed into law on December 30, 2005 by President Bush and set a precedent in national governance official recognition of the NEO issue.[81] Aside from NASA, the US

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[80] United States Government. *H.R. 1022 (109th): George E. Brown, Jr. Near-Earth Object Survey Act.*Last accessed 08 August 2014, http://www.gpo.gov/fdsys/pkg/BILLS-109hr1022rh/pdf/BILLS-109hr1022rh.pdf.

[81] United States Government. *Govtrack Summary* "H.R. 1022 (109th): George E. Brown, Jr. Near-Earth Object Survey Act*"*.Last accessed 08 August 2014,https://www.govtrack.us/congress/bills/109/hr1022.

Department of Defence via its Strategic Command (USSTRATCOM), maintains a mandate with regard to the impact event threat.

National Aeronautics and Space Administration (NASA)

Funding from the Brown Bill allowed NASA to continue and expand the networks of terrestrial based optical search programs through sponsorship of a range of programs among the academic community. The element of NASA principally charged with the NEO issue is the NEO Program Office, which is staffed by a number of the same personalities central to the early inception of the NEO movement in the late 1980's and 90's such as Dr. Don Yeomans, Tom Gehrel and others. NASA's self imposed mandate in 1998 was to detect 90% of NEO's of one kilometre or larger in diameter. In 2005, under the Brown Bill, this was expanded to include objects down to 140 metres in diameter within a specific timeline.[82] Current detection rates, including several closed projects and missions, is encapsulated in Tables 4.1.

As noted earlier, NASA continues to struggle with the challenge of the smaller objects because of the limitations of its terrestrial observations comprised of:

- The Catalina Sky Survey (CSS) (Tucson Arizona);
- the LINEAR project (Socorro New Mexico);
- Pans-STARRS1 (Maui, Hawaii); and
- Spacewatch (follow-up only) (Tucson Arizona).

The only space based observation in this survey took place in 2010 with the NEO-WISE program utilizing a infrared space telescope in a LEO Polar orbit. NEO-WISE provided

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[82] NASA. "Introduction: Near Earth Object Search Program" Last updated 12 August 2014, http://neo.jpl.nasa.gov/programs/intro.html.

significant contribution to the program, but ended after 10 months when its coolant was exhausted and funding not renewed.[83] NASA has no plans for a replacement at this time, thus the intervention by B612 and the ASE for the Sentinel program. NASA's NEO Program Office and subsidization of the IAU Minor Planet Centre are key elements in the NEO solution space and remain dependent on US government funding to continue. It should be said that the US is bearing a significant element of the costs in what a global concern. Given the time & space issues involved in the NEO threat detection and resolution, possibly running into the decades, a means of conserving the necessary resources for these NASA initiatives from something other than the highly volatile funding environment of the US government may be necessary.

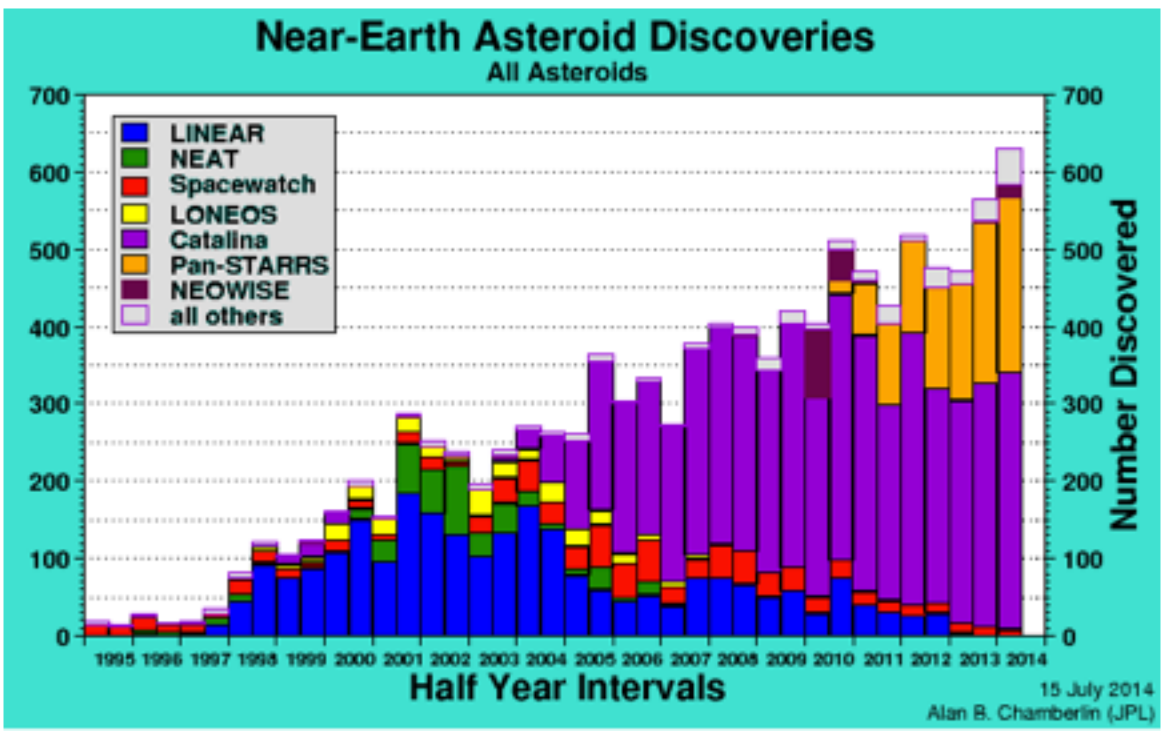

Table 4.1: NASA NEA discovery rates from the time of the Discovery WG through to the present day configuration as the NEO Program Office. Note that LONEOS, NEAT and NEOWISE are no longer operational in 2014. (Table Credits: NASA NEO Program Office)

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83 Ibid.

Much of the remainder of US interest in space is focussed on the various satellite operating zones in and around Earth. This is a common feature among all space faring nations given the great utility of spaced based sensors and the danger to them from a range of environmental and debris hazards. A bewildering array of US government agencies utilize space based sensors for an equally diverse set of missions. Chief among these agencies is the Department of Defense, and within it, the US Strategic Command (USSTRATCOM).

It is the task of the US Strategic Command to act as the monitoring agency for the US government on what is in the space surrounding earth from the point of view of spacecraft and space debris. Specifically, USSTRATCOM, through the Joint Forces Component Comand-Space (JFCC-Space) exercises the function of "Space Control" via execution of the following missions:

- surveillance of space;
- protection of US and friendly space systems;
- prevention of an adversary's ability to use space systems and services for purposes hostile to US national security interests; and
- direct support to battle management, command, control, communications, and intelligence.[84]

The space control mission is conducted by USSTRATCOM's Joint Functional Component Command for Space (JFCC Space), and most pertinently to this research, falls under the

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84 United States Government. "USSTRATCOM: Space Control and Space Surveillance." Last updated January 2014, http://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance/.

command and control construct referred to as the Joint Space Operations Centre, or JSpOC.[85] In a very real sense the JSpOC acts as a sort of "Space Traffic Control" on steroids, having the capacity through its space sensor network (SSN, see Figure 4.4) to detect orbiting spacecraft, debris and other objects, and having a limited defensive / offensive capability to deal with them. The JSpOC leverages a range of phased array and conventional radars, electro-optical and space based sensors to catalogue and track all resident debris objects and spacecraft orbiting the earth which could influence US and allied space missions.[86] The JSpOC computes orbits and determines possible collisions, and shares unclassified versions of this information for the public and other interested parties. Canada, through its NORAD relationship and the recent reorganizations in the Department of National Defence (DND) is also privy to this information on the classified level. This space surveillance capability has been recently augmented by two space based sensors which will significantly enhance the level of fidelity in trajectory calculations.[87]

The Geo-Synchronous Space Situational Awareness Program, or GSSAP, consists of a pair of specialized satellites designed to provide continual observation of the resident debris object population. The system possesses considerable manoeuvre capability and is intended for the GEO altitude band. In conjunction with the GSSAP, but on a separate task, is the Automated Navigation and Guidance Experiment for Local Space or ANGELS research satellite from the US Air Force. This spacecraft is an attempt

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85 Ibid.

86 Ibid.

87 United States Air Force. "Geo-synchronous Space Situational Awareness Program Factsheet". Updated 25 July 2014, http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=21389.

to provide a level of automation to the observation and control of orbital traffic and has been compared to a "…space based neighbourhood watch."[88] ANGELS allows the JSPoC to control the observation based prediction, and if not avert an incident, at least warn all parties of collision or de-orbit scenarios (Figure 4.5).

Figure 4.5: The American Joint Force Component Commmand-Space's dedicated surveillance network for monitoring orbital content and activity from LEO to GEO. This system has recently been augmented by the Geosynchronous Space Situational Awarness Program (GSSAP) allowing NEO detection and tracking as well. (Figure credit:USSTRATCOM)

Increasingly, the JSpOC has begun to include the NEO threat in its area of interest for the purpose of full space domain awareness. Many, if not all, of the sensors comprising the SSN have some utility in detecting the closer, smaller NEO that have proven such a difficult challenge to the Spaceguard and NEO Discovery surveys. Although JSpOC may not have time to deflect or deter such a NEO, it may provide the

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[88] United States Air Force. "Air Force Satellites contribute to Space Neighbourhood Watch." Updated 22 July 2014, http://www.afspc.af.mil/news1/story_print.asp?id=123418619.

crucial warning necessary to avert casualties like those suffered in Chelyabinsk caught unawares of the impending explosion.

In closing our review of the American capability towards NEO and space debris, it is clear from the perspective of the impact event concern, that NASA will be one of the lead players in the proposed UN NEO protocol, and most certainly among the primary nations contributing to the deflection / deterrence missions undertaken against a NEO judged to be a credible threat to Earth. On the slightly lower threshold, but still very important, is that the Department of Defense (via JSpOC) and not NASA, will be the premier agency for sounding alerts on de-orbiting space craft and debris. The JSpOC will also likely be the first agency to issue warnings of smaller NEO and a crucial contact in any Canadian effort to develop and maintain full space domain awareness and responsiveness to an impact event.

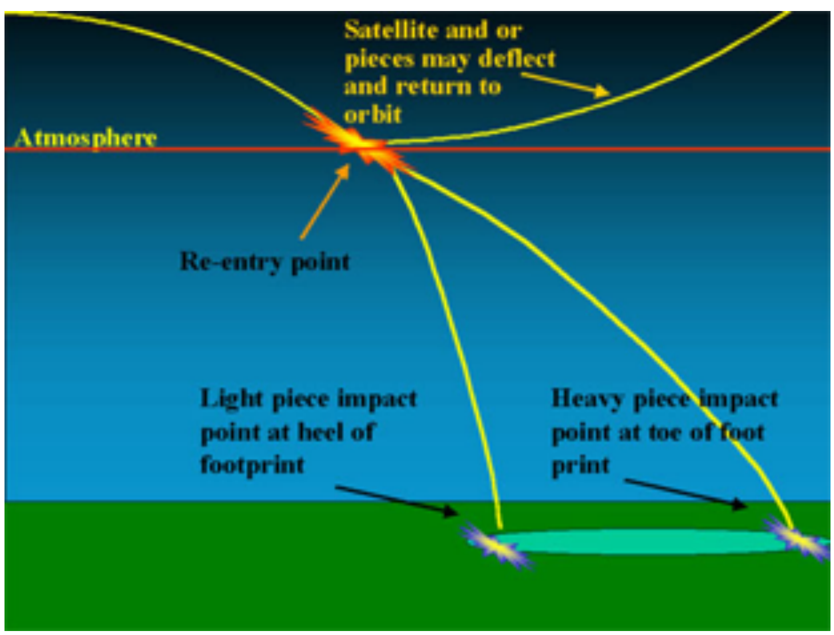

Figure 4.5: Illustration of space craft or debris de-orbitting / reentry scenario indicating the possible distribution of fragments. Note that, similar to the COSMOS 954 incident, the debris field based upon component weight can be extremely long. (Figure Credits: USSTRATCOM)

Europe and Other Notable National Initiatives

As stated earlier, despited being studied seriously by academia for some 20 to 30 years, the NEO issue has only just made the transition into the public domain and governance. The most advanced efforts on the NEO subject on a nation state level are those of the European Union (EU) via the European Space Agency (ESA). The ESA's efforts are far behind those of NASA at this point, but improving along a similar methodology as NASA employed. This is the essentially the stimulation of research and development among European academic institutes and space industry through sub-contracting and sponsorships. Most notable among these efforts is the University of Pisa which currently oversees the Near Earth Orbit Dynamic System (NEODyS), the Spaceguard legacy NEO hazard list and equivalent to the NASA SENTRY list.

The ESA also has had a network of ground based optical sensors operating under its Space Situational Awareness (SSA) program since 2009 and funded through to 2016.[89] The SSA is intended to support Europe's independent access and use of space through timely and accurate information on space conditions and orbital spacecraft and debris. It is a civilian equivalent of the American's Department of Defence role for JFCC-Space via the JSpOC and its associated space surveillance network (SSN).[90] The SSA program has a NEO segment, begun in 2013, which integrates the ESA's Tenerife one metre (1 m) telescope and a network of professional and amateur NEO hunters reporting via the

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89 European Space Agency. "Space Situational Awareness-About SSA". Last accessed 7 August 2014, http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness/About_SSA.

90 Ibid.

NEODyS automated integrator.[91] The ESA's NEO Coordination Centre (NEOCC) is located at ESA/ESRIN and opened in May 2013.[92]

Figure 4.6: The European Space Agencies one metre telescope dedicated to NEO detection and tracking located on Tenerife. The facility reports contacts via the NEODyS and is coordinated out the NEOCC at ESA/ESRIN. (Figure Credits: ESA.)

Europe, with its diverse scientific community, both professional and amateur, is also home to a number of forums and conferences which have been important platforms for the NEO issue. An excellent example of this is the Europe Scientific Foundation's IMPACT workshops. During one such meeting Dr. Charles Cockell of the UK's Open University proposed a Scientific Impact Response Team (SIRT) be identified and held in readiness of an impact event. This team would provide the kind of scientific information and advice crucial to emergency disaster management services at the applicable level of

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91 European Space Agency. "SSA-NEO Segment" Last accessd 07 August 2014, http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness/Near-Earth_Objects_-_NEO_Segment.

92 Ibid.

response, address the media with a clear and cohesive explanation and investigate post-impact effects on biology and geology as well as recovery rates of same.[93]

On the whole, Europe and the ESA mirror the activities of NASA and act as a crucial independent double check functionality between the NEODyS and SENTRY staffs by constant communication and cooperation.[94] The broader forum for discussion of the NEO issue and synergy with organizations like the International Astronomical Union, multiple Planetary Societies, and scientific foundations makes Europe's continued participation a vital element in NEO resolution.There are no ESA plans to launch an NEO space based sensor or network at this time.

Summary

Over the course of this chapter it has been shown that the very first steps of a response to the NEO threat are being marshalled at the appropriate levels. Although we are still a long way from fully appreciating the magnitude of the NEO threat, plans are either in place or underway to close the observational gap within this decade. Somewhat surprisingly, the lead agencies in much of this come from the non-governmental organizations and private sectors and pose an excellent opportunity for the niche expertise of Canadian space industry and academia. The United Nations has inaugurated a viable NEO protocol, at least in its first draft. While the UN NEO protocol is still in its infancy, it will gain momentum quickly provided the momentum started by agencies like

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[93] Charles Cockell. *Science & Global Security.*"Scientific Impact Response Team for the Aftermath of small Asteroid and Comet Impacts." Jan2005, Vol. 13 Issue 1/2, p105-115. 11p.Last accessed 04 August 2014, http://search.ebscohost.com/login.aspx?direct=true&db=rkh&AN=18001874&site=ehost-live.

[94] NASA NEO Program Office. "Sentry- An Automatic Near-Earth Asteroid Collision Monitoring System." Last updated 14 August 2014, http://neo.jpl.nasa.gov/news/news126.html.

Spaceguard, the ASE, B612 and the various Planetary Societies delegations can be transferred to the nations of the General Assembly now sensitized to the NEO peril.

With respect to America, despite the funding quandary of NASA over the last decade, the US is the first national government to have officially recognized the NEO threat and funded action on behalf of humanity to begin to address it. The work of NASA with the international agencies like the ESA (who has adopted the Spaceguard survey in Europe with NEODyS) and the NGOs will continue to be the crucial node for NEO data collection and analysis, as well as scientific advancement in the field. The recently established Joint Space Operations Centre and its mission to compile space situational awareness will address the space debris threat from LEO to GEO as well as provide the early warning required for de-orbiting debris with particular emphasis to satellites and activity in the Earth-Moon system. There is also some utility for the JSpOC to provide the last line of early warning for small diameter NEOs to take cover and avoid the casualties caused by an impact event without public warning. It is clear that Canada’s close historic relationship with NORAD, and thus possibly into USSTRATCOM, should be fostered to ensure Canada has access to this information in future.

Finally, Europe, with its smaller and more diverse efforts on NEO via the ESA and a myriad of pan-European scientific endeavours also has a role to play, perhaps most crucially as an independent double check between the two NEO risk catalogues NEODyS and SENTRY. Despite all this activity and effort, it is perhaps chilling to note that only one space based sensor with a specific purpose of NEO identification and tracking is under development at this time. This singe space based sensor is an act by private interests at the urging of a consortium of non-governmental organizations. On this note, it is time to examine Canada; what, if any policies or initiatives are we are pursuing given our clear history of impact events?

CHAPTER 5 CANADIAN NEO POLICY AND INITIATIVES

As noted in Chapter 3, impact events are not new to Canada even in recent times. What has changed is our understanding of the magnitude of those events. Dr. Russell Taylor, then President of the Canadian Astronomical Society and co-chair for the Coalition of Canadian Astronomy, stated before the Standing Committee on Industry, Science and Technology (INDU) that, despite our resource allocations to astronomy in Canada:

> The impact per astronomer of Canadian astronomy makes this country the third most important player in this area in the world, behind the United States and the United Kingdom. We're ahead of all other major science and technology supporting countries. This is despite the fact that Canada has the lowest per capita funding level for astronomy among our G-7 partners, and in fact among the OECD. We're seven times less than the U.S. and five times less than the U.K.[95]

Throughout our academic institutions the efforts of our space scientists underscore the excellent reputation Canada has built in niche areas of the space sciences.[96] The work of Western's Centre of Planetary and Space Exploration (CPSX), the University of Calgary's Near Earth Space Surveillance (NESS) program, and the University of New Brunswick's Planetary and Space Science Centre (PASSC) are but to name a few of the institutions advancing NEO research in Canada in their own ways through what funding is available. Despite Canada having scientists who are already deeply involved in the issue of NEOs working among our academic institutions and in

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[95] Parliament of Canada. "Minutes of Proceedings 22 March 2001" Last updated Last accessed 15 August 2014, http://www.parl.gc.ca/HousePublications/Publication.aspx?DocId=1040608.

[96] Canadian Space Agency. Audit and Evaluation Department. *Evaluation of the NEOSSat Project-For the period from February 2005 to December 2013 Project #13/14 02-02. (*Ottawa:Audit and Evaluation Directorate, 2014)*,* 15.

collaboration with the international community, the issue of NEO impacts were not a feature of the funding request for the CAS Long Range Plan (LRP) in 2010. To quote Dr. Taylor: “We didn't identify that [Near Earth Objects]as a high priority for Canadian astronomy and astrophysics” to which Professor Racine added that the function was entirely within the capacity of Canadian astronomy as proposed in the LRP.[97] Mr. Mauril Bélanger, a committee member replied **“**Then I might argue that this [NEO detection] would be a selling feature for the plan”.[98] It would appear that this suggestion took its form in the Near Earth Space Surveillance (NESS) project team which was inaugurated in 2005.[99] The work of these academics has led to some very promising initial efforts in the form of the Canadian Space Agency’s joint NEOSSat project in conjunction with the Department of National Defence (DND) Defence Research and Development Canada (DRDC).[100] Unfortunately, NEOSSat & NESS appears to be where the institutionalize of the NEO issue ends.

Despite Canada’s attendance at the UN’s 68th General Assembly where the COPOUS NEO program was accepted, and the ASE urging for further actions to maintain momentum on the NEO issue, this agenda was not promoted in Canada. There has yet to be a briefing to the House of Commons or the applicable sub-committees’ on the NEO threat seeking a way forward to participation in the UN NEO program.

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[97] Ibid, 0955-1000 hrs in transcript.

[98] Ibid, 0955 -1000 hrs in the transcript.

[99] University of Calgary, “NESS Project Team.” Last accessed 15 August 2014, http://neossat.ca/?page_id=162.

[100] Ibid*,* v.

Chapter 5 illustrates that Canada has not yet inculcated the threat of an impact event into its institutions, principally in areas of space domain awareness, emergency planning and preparedness. Citing the context of the applicable policy documents, principally the National Security Policy, Space Policy Framework, and National Emergency Response System, this chapter will point identify gaps in extant public policy in addressing NEO impact event threat with a view to the changes necessary to participate as a responsible member of the Global community in the UN NEO stratagem.

This chapter will be heavily predicated upon the recent *Canada's Space Policy Framework-Launching the Next Generation* released by the Minister of Industry in February of 2014.[101] As a result the initial elements of this chapter will describe the Space Policy Frameworks's key tenets and context for a wider NEO discussion. Subsequent to this, Canadian policy practice on space domain awareness, as exercised through recently established Canadian Space Operations Centre (CANSpOC), will be described and examined for utility with regard to impact events. Much like the UN plan to deal with the impact event challenge, our examination of Canadian NEO policy will take three forms:

- Detection and Warning.
- Disaster Planning
- Deterrence and Mitigation

We will begin with the Canadian Space Agency's new policy framework.

[101] Canadian Space Agency, *Canada's Space Policy Framework-Launching the Next Generation.* Last Accessed 13 August 2014,http://www.asc-csa.gc.ca/eng/publications/space-policy/.

Launching & Securing the Next Generation

The Canadian Space Agency (CSA) falls under the purvue of the Ministry of Industry and is enabled under the Canada Space Agency Act.[102] This act sets the conditions for direction and governance of all issues pertaining to the Government of Canada's space presence, collaborative space efforts, and industrial and academic stimulation towards space sciences and technologies.[103] On February 14, 2014, the Minister for Industry released the much anticipated Space Policy Framework for this nation. The policy seeks to clearly define methods to enhance the Canada's sovereignty and security through the use of space, sustain and indeed invigorate the Canadian space industry and inspire Canadians towards pursuit in the space sector.[104] It contains five core principles which I will refer to in supporting the creation of NEO related policy and activity in Canada:

- *Canadian Interests First* (i.e. using space to towards the primacy of issues of sovereignty, security and national prosperity). NEOs and averting or forewarning of an impact threat clearly falls primarily under this principle.
- Positioning the Private Sector at the Forefront of Space Activities.
- *Progress through Partnerships* (i.e. collaborative efforts towards mutual interests and in order to gain access to normally unavailable technologies or services). This approach is vital to the NEO issue as Canada cannot hope to create an effort equal to

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[102] Government of Canada. "Canadian Space Agency Act (S.C. 1990, c. 13)" Last updated 15 August 2014, http://laws-lois.justice.gc.ca/eng/acts/C%2D23.2/.

[103] Ibid.

[104] Government of Canada-Ministry of Industry. "Canadian Space Agency 2013-2014 Estimates - Report on Plans and Priorities." (Ottawa:Canada Communications Group, 2014) 3.

that of the US or EU on its own. It is through leveraging extant relationships between the space community (i.e. domestically within a Whole of Government approach, and internationally between CSA to NASA and the ESA, among academia and international associations).

- Excellence in Key Capabilities (i.e. continuation and enhancement of proven strengths while seeking emerging opportunities).
- Inspiring Canadians.[105]

These principles will be manifest in the CSA's four "avenues of strategic action": Commercialization, Research and Development, Exploration of Space, and Stewardship (Management and Accountability).[106] Of particular note is amendments to the governance of the CSA via a combination of stakeholder advice and ministerial oversight. In considering the integration of NEO missions and tasks, the Canadian Space Advisory Council and the Deputy Minister's Objectives & Expenditures Committee are two new governance bodies that will play heavily in authorizing CSA activities.[107] These bodies are in addition to the standard parliamentary protocols already governing the Ministry of Industry activities, included the Standing Committee on Industry, Science and Technology (INDU).

Within the Department of National Defence, the Chief of Force Development (CFD) is the empowered agency to enact institutional level change within the Canadian Armed Forces. The Director General - Space (DG Space) has recently been reorganized

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105 CSA. "Canada's Space Policy…", 9-10.

106 Ibid, 11-12.

107 Ibid, 12.

under CFD as this military function is itself undergoing significant realignment to mirror (on a Canadian scale) USSTRATCOM's Joint Force Command Component - Space (JFCC-Space) discussed in Chapter 2. With this understanding of Canada's approach to space established, let us now consider the implication of the principle Canadian's Interest First from the perspective the Canada's National Security Plan.

National Security and Emergency Policy

In April of 2004, Prime Minister Paul Martin released the current national security guidance.[108] This seminal document represents the first integrated response to the nation's security, one in which a "whole of government" approach is not simply advocated but directed and woven into the fabric of the new security culture:

> Securing an Open Society: Canada's National Security Policy is a strategic framework and action plan designed to ensure that Canada is prepared for and can respond to current and future threats. The focus is on events and circumstances that generally require a national response as they are beyond the capacity of individuals, communities or provinces to address alone.The first-ever policy of its kind in Canada, Securing an Open Society adopts an integrated approach to security issues across government. It employs a model that can adapt to changing circumstances over time.[109]

Although meant to address the post-9/11 and "SARS" issues of terrorism and pandemic disease, the changes taken to integrate security and emergency planning and response are ideally suited to the threat posed by NEO impact events. Tangible outcomes from this new security approach have been the establishment of the Ministry of Public Security and

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[108] Canada. Privy Council Office *Securing an Open Society : Canada's National Security Policy.* Ottawa: Canada Communications Group, 2004, vii.

[109] Ibid, vii.

Emergency Preparedness and a National Emergency Response System.[110] This new framework “operationalizes” the normally bureaucratic integration of the whole of government through a number of command, control, communications, coordination and intelligence capabilities that will neatly integrate the civil / military reaction to crisis.[111] In many respects all of the elements necessary to address the practical issues of impact event reaction, certainly from the Emergency response piece, are in place. Canada’s reorganized emergency management organizations are simply awaiting the direction to consider a new problem set as, at the time of this writing, no extant contingency plan exists at the federal or provincial level for a Torino Impact event (8+).[112]

Having established the policy framework is in place in most respects, it is now time to examine in detail the elements implementing a NEO policy in Canada along the lines of the UN NEO stratagem accepted General Assembly in December 2013.

Canadian Space Domain Awareness and NEO Early Warning

Early warning is comprised of two components, sense and communication. Since 2005 Canada has had a coalition of experts led by Dr. Brad Wallace (Defence Research & Development Canada-DRDC) and Dr. Alan Hildebrand (University of Calgary) working upon Earth's first *dedicated* NEO spaced based sensor, the NEO Surveillance Satellite (NEOSSat).[113] The NEOSSat's mission was three-fold, and the architecture flows very

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[110] Canada, Public Safety Canada. *National Emergency Response System-January 2011*. Ottawa: Public Safety Canada, 2011),3.

[111] Ibid, 7.

[112] Ibid, 10.

[113] CSA, Audit & Eval “NEOSSat Project Evaluation…, 3.

neatly into facilitating early warning capability as well as acting as a detecting and follow-up element of the Spaceguard Survey contributing to the SENTRY and NEODyS risk lists.[114] NEOSSat is an experiment being leveraged to produce value for money, simply research in its own right. As such the NEOSSat missions include:

- High Earth Orbit Space Surveillance (HEOSS) for the Department of National Defence scanning the MEO to GEO zone for improved space domain awareness as part of Canada's "…commitment to keeping orbital space safe for all activities."[115]
- Near Earth Space Surveillance (NESS) for the Canadian Space Agency with a specific focus on the inner solar system (noted as unobserved in Chapter 2) for Aten and Apollo orbiting NEO close approaches and potential impactors (PHA).
- Developing an affordable multi-mission bus for future CSA / DND missions.[116]

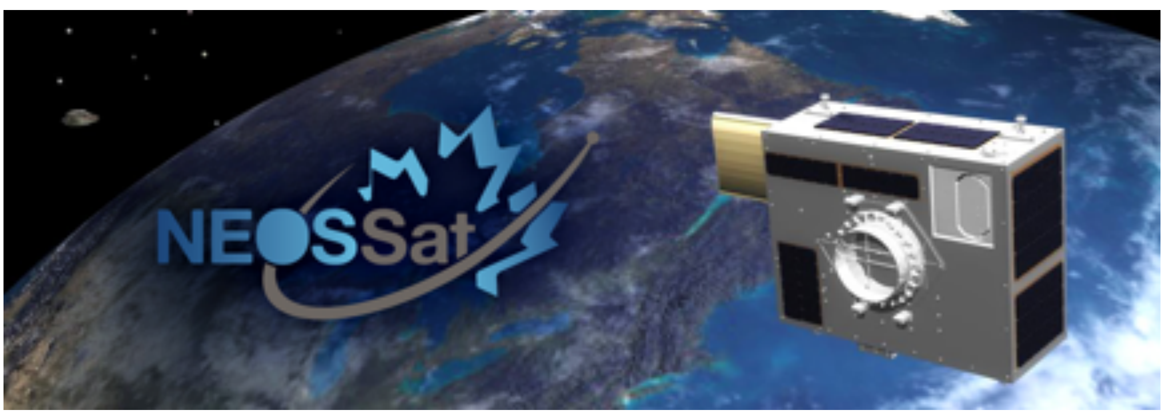

Figure 5.1: Image of the 65 kg Near Earth Orbit Surveillance Satellite (NEOSSat) designed by the CSA and DRDC for dual missions. Under the auspices of CSA's Near Earth Space Surveillance program out of the University of Calgary it will carry out NEO Detection and Tracking of ATEN and Apollo orbiting PHA. It will also define the resident debris objects occupying the High Earth Orbit (HEO, from 10,000 to 37,000km above the Earth. (Figure Credit: Canadian Space Agency)

[114] Ibid, 19.

[115] Ibid, 3.

[116] Ibid, v.

NEOSSat was intended to provide observation of that most vulnerable observation zone, Sunward, unimpeded by infrared interference of a heated daylight atmosphere (Figure 5.2). NOESSat would provide the only space based NEO detection and tracking without daylight and sunward limits until (and if) the privately funded B162 Sentinel is operational.

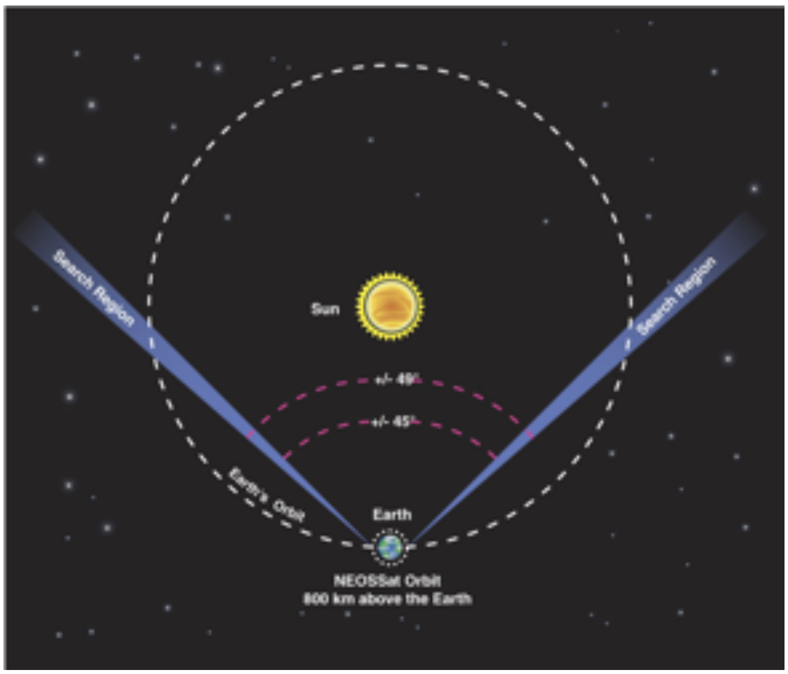

Figure 5.2: Illustration of the NEOSSat NEO observation profile. This pattern wold allow the continual scan for potentially hazardous objects (PHA) of near term concern to Earth, particularly smaller bodies of the size of the Chelyabinsk object. The Satellites observational time was to have been shared 50% for NEO observation / 50% for HEO debris detection and tracking. (Figure Credit: CSA)

A 41 month project delay saw NEOSSat launched 25 February 2013, well after NASA's Wide-field Infrared Survey Explorer (WISE) system had been repurposed for the NEO search roll (as NEO-WISE) in 2010 to 2011.[117] Though only partially functional, as its infrared capability is defunct due to lack of coolant, NEO-WISE was put into

[117] Ibid, 22.

hibernation in February 2011 for lack of operational funding.[118] Unfortunately NEOSSat has not completely addressed the lack of a space based NEO sensor as it was launched "somewhat prematurely" and is experiencing ongoing issues in obtaining workable imagery for NEO detection.[119] Despite software upgrades there are concerns that NEOSSat may never actually achieve the 288 image per day target it was designed for.[120] Imagery concerns aside, Canada's NEOSSat *remains the only dedicated spaced based NEO sensor Earth has at this time* (although NEO-WISE could be reactivated with funding).

With respect to terrestrial NEO sensors, there are ten (10) optical and radio telescopes in Canada and one (1) in Hawaii under partial Canadian control.[121] The telescopes are all capable of contributing to NEO detection and tracking efforts and do so by contributing direct observation data to the Minor Planet Centre amongst a severe demand for their observation time. This is particularly true of the superb 3.6 metre tripartite Canada-France-Hawaii Telescope (CFHT) which recently aided in the removal of Asteroid 2007 VK184 from the Sentry Risk List.[122] There is another means of accessing NEO sensor data, by way of alliances and partnerships. Canada already

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118 Permanent. "Observing Asteroids." Last Updated / Accessed 14 August 2014, http://www.permanent.com/asteroids-discovering.html.

119 CSA, Audit & Eval "NEOSSat Project Evaluation…, 17.

120 Ibid, 19.

121 Royal Astronomical Society Canada. "Observatories." Last accessed 14 August 2014, https://www.rasc.ca/observatories.

122 NASA. "Asteroid 2007 VK184 Eliminated as Risk to Impact Earth." Last updated 17 August 2014, http://neo.jpl.nasa.gov/news/news183.html.

possesses several aerospace command and control assets which have access to, or are in communication with, sensors dedicated to tracking orbital traffic and debris.

To summarize NEO Early Warning sensors from a Canadian perspective, there is one partially functioning *but purpose built* space based sensor , eleven (11) Canadian (or Canadian taskable) observatories with "as available" observations reported via NASA's Minor Planet Centre (MPC) for input into SENTRY, and access to outputs from others as reported to Canada via connectivity between various agencies (NASA to CSA, JSpOC to CANSpOC, etc). In his testimony before the Parliamentary Standing Committee of Industry, Science and Technology (INDU) in 2010, Dr. Russ Taylor indicated that NEO search programs were both inexpensive and un-prioritized on the Coalition of Canadian Astronomer's 10 year Long Range Plan (LRP).[123] Other measures could be taken to improve this contribution within the Space Policy Framework. These additional NEO detection and definition efforts will be discussed later under the recommendations in Chapter 6.

Communicating Warning and Coordinating response

As noted in Chapter 2, the time available to react to a NEO impact event could vary from minutes to a century depending upon the size of the NEO. As a general rule, the larger the object, the lengthier the warning time required as well as the time necessary to deal with the threat, i.e. lengthier deflect / deter task. This is conversely so with the smaller objects i.e. with later detection and less time necessary to remediate (if sufficient time exists to deploy a deterrence at all). Thus the venues for communicating risk, or

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[123] Taylor…

indeed to highlight credible risk above others such as confirmation of a Torino 8+, and coordinating the response could range from annual meetings to operation centres manned 24 hours a day / 7 days a week. Although there are a number of command and control nodes that could be employed for this function the Canadian Space Operations Centre (CANSpOC) would be the preferred agency for the following reasons:

- Space domain awareness primacy: CANSpOC is responsible for the generation of the Space Common Operating Picture (Space COP) for the Canadian Armed Forces.[124] It is already responsible for the early warning of satellite and space debris de-orbiting impacts in Canada.[125]
- CAN SpOC is responsible for providing early warning of missile warning domestically and abroad and among other government departments (OGD).[126]
- CANSpOC is in direct communications with US JSpOC for SAPPHIRE tasks.
- CANSpOC is the mission tasked for NEOSSat and could easily include early warning on NEO contacts upon the advise of NEOSS mission team.
- CANSpOC is collocated with the Canadian Forces Integrated Command Centre (CFICC) which would initiate any CAF support to the domestic emergency response efforts called for by the situation.

Summary

In concluding this review of Canadian NEO policy, particularly in comparison with the United States and the United Nations, Canada has issues to address. They require

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124 Department of National Defence. Concept of Ops CANSpOC (Draft)…6.

125 Ibid, Annex G.

126 Ibid, 5.

smaller initiatives than might first be imagined however, as our NEOSSat initiative and associated ground segment is unique among the nations of the world, our relationship between the American military command responsible for space surveillance is extremely mature through the fifty plus years of NORAD cooperation, and the vast array of environmental challenges we already face make alteration of emergency response protocols exceptionally straight forward. What is called for now is simply that focus by the applicable experts to collaborate to define and establish this new line of operations. In one case this will be CSA, DND and NRC marshalling and coordinating the space domain awareness and early warning protocols, perhaps to include longer term plans for NEOSSat or a follow on program. CANSpOC, CSA Mission Operations, and the NESS Operations cell are all well suited to these tasks.

On another line, emergency response, these discussion would be between the Federal and Provincial jurisdictions on a new line of emergency management operations for NEO. Once these NEO emergency response protocols are matured, and coordinated between the US FEMA and our own Ministry of Public Safety our IDPAG representative can fully participate in assisting the UN with a global response to a NEO impact. These are simply plans, and even more basically, alterations to existing plans that just need an expansion in scope and scale from the days of civil defence plans.

If Canada is to succeed in the future, it must be ready for the leap into space which is just on the horizon. Asteroids will be that future and there are a number of initiatives already in progress for the commercial exploitation of these bodies. Money spent by the CSA, passed through our space sector, in addressing the NEO threat is a solid investment in Canada's place in exploiting this next horizon.

CHAPTER 6 SUMMARY AND RECOMMENDATIONS

Canada has more than enough environmental hazards. Between the winter and its blizzards, the summer and its tornados, floods and forest fires, and the possibility of epidemics and disease, it is inviting to dismiss something as infrequent as the NEO impact threat. Although we are not postured to react to NEOs, we could be with relatively moderate policy adjustment and resource allocation. Indeed, to do otherwise is to shirk our part of the Global responsibility in this matter and squander the opportunity to advance our endeavours in space so increasingly vital to a modern economy. Canada has, throughout its history, risen to the defence of others often at a terrible and tragic cost. Joining the UN call to address the NEO threat, aiding our neighbours continentally and on this island Earth, is in keeping with that noble tradition and without that terrible cost.

Summary of Findings

This research began with four fairly simple questions, but it has taken a great deal of research to provide the answers. It has been demonstrated that:

- **There is a threat to Canada from NEO impact event**. *Canada has a historic rate record of nearly 17% of known impact events*, with an annual occurrence of at least one 5 kiloton or greater. There are 514 identified NEA at the time of this writing, and estimated half a million potentially hazardous asteroids within the inner solar system of which only one percent (1%) have been located. *Canadians as individuals face a 1:20,000 chance of dying in a impact event*, greater than their chance of dying from food poisoning or a tornado, and just slightly less than an aircraft accident all of which have significant risk mitigations resourced to them.

- **There are no extant contingency plans or procedures for NEO Impact events. NEO Early Warning is not responsive to localized impacts or "City Killers"**. There are no contingency plans for an NEO impact event among the federal or provincial emergency response agencies at this time, but recent UN NEO protocols and an open letter from the Association of Space Explorers (ASE) could stimulate action in addressing this. Contingency plans, observation and tracking of de-orbiting satellites and space debris are in place via the JSpOC but require clearer linkage between CANSpOC and responding emergency services. Canada does have the only space based sensor dedicated to NEO detection and tracking towards the inner solar system, but it is not fully functional. The National Research Council (NRC) supports eleven (11) observatories which could contribute to NEO detection and follow up tracking but to the expense of other scientific endeavours.
- **There is a gap between the extant national security and public safety polices and the NEO Impact threat**. As noted, there are no specific plans at this time, although a simple modification of the Emergency Services Framework and Response System could easily accommodate this.
- **Most nations of the world are at or below Canada's level of preparedness for a NEO impact event**. The United States has made some more advanced work in emergency management of this issue between the USAF, NASA and the Federal Emergency Management Agency (FEMA). Canada could model its NEO impact

policy upon US efforts, but it is not so far advanced that a Canadian parallel planning effort would be particularly delayed. In fact, a Canadian process would act as a useful comparative process to confirm the validity of the planning process.

Recommendations

As an immediate interim measure, the task of monitoring and reporting the NEO risk should be given to CAF as part of of the Space Domain Awareness mission task. CAF would execute this responsibility via the CANSpOC situated in the CFICC in Ottawa and in conjunction with the CSA for analysis support and advice from the NESS Mission Operations in Calgary. Furthermore, the UN NEOP protocol should be briefed by the UN Delegation to the appropriate government leadership in the Ministries of Industry, Public Safety and Defence as recommended in the Association of Space Explorers open letter.

Under the principle of “Inspiring Canadians” an effort should be made to engage amateur astronomers, clubs and public schools in the search for NEOs or follow up observation. Canada, with its vast spaces, generally available night sky and highly dispersed population could be contributing to the integration of amateur astronomers in the NEO search similar to the ESA’s Space Situational Awareness (SSA) program. Such a CSA initiative would both broad base of interest without being unduly alarmist and re-engage Canadian youth in space activities for a very modest investment.

Similarly, under the principle of “Inspiring Partnerships” the NEO challenge offers a number of opportunities. Canada could contribute funding to the non-profit B612 Foundation Sentinel program in conjunction with, or if needs be as a replacement for, the capabilities of NEOSSat. Collaboration could be negotiated for access to the Sentinel data feeds via the NESS Operations Centre at the University of Calgary that may otherwise not be utilized.[127] Adding an additional processing node would add resiliency to the Sentinel program and broaden the international involvement it currently lacks. Other possibilities will undoubtably arise once the issue of NEO threats gains traction as a legitimate goal of government through the CSA's leadership and advocacy. Further to this would be Canada's presence in the United Nation's NEO Protocol through designated and coordinated representation among the International Asteroid Warning Network (UN-IAWN) and, in particular, the Steering Committee. Designating continued CSA participation in the Space Mission Planning Advisory Group (SMPAG) will continue to pay dividends like the OSIRIS-Rex mission to Asteroid Bennu, for Canadian space industry and astrophysical science. Finally, inaugurating Canadian representation in the International Disaster Plans Advisory Group (IDPAG) as the culmination of Impact Event contingency planning. This will serve the dual purpose of communicating the issue at the provincial level and coordinating the potential response necessary to address a disaster of the type and magnitude of an impact event.

Within our own domestic agencies, and pursuing the "whole of government" approach to problem solving, the close relationship of DND / DG-Space and Ministry of Industry / CSA should be fostered with integration of key command and control elements within the National Emergency Response System of Public Safety Canada. It is crucial that a single, clearly communicated and periodically practiced protocol is in place for the provision of early warning, deterrent actions and coordinated emergency response to the

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NEO threat. The challenge lies with the complicated and lengthy response to a large (1 km +) NEO versus the shorter response time available for sub-global / regional and local impact events. This can only be resolved through a thorough "whole of government" planning exercise, carried out in accordance with the federal All Hazards Risk Methodology, on the subject involving all stakeholders along the lines of the USAF Impact event .[128] It is recommended that such a process, led by the Ministry of Public Safety and supported by DND and the CSA be carried out as soon as possible to set the framework participation in the UN ENO protocol as accepted at the 68th Session of the General Assembly in December 2013.

Conclusion

Canadians face a threat from an impact event five times greater than the level of than that "one in a million chance" and yet there are no formal plans to deal with this threat at either the Federal or Provincial level. For Canada's part, via efforts like NEOSSat, the NRC's modest sponsorship of astrophysical sciences, CSA's close collaboration with NASA and CAF's long standing connectivity with NORAD, and thus US STRATCOM's Joint Space Operations Centre (JSpOC), we are not completely unaware of the peril. But we as a nation, in the face of a credible threat, are highly uncoordinated and as yet incapable of representing ourselves cohesively with the United Nations NEO asteroid warning networks or advisory groups, much less the Ad Hoc committee or contributing nations. Simple measures, taken in the context and principles

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[128]Institute for Catastrophic Risk Reduction. *Canadians At Risk: Our Exposure to Natural Hazards-Canadian Assessment of Natural Hazards Project.* ICLR research paper series – Number 48. Edited by David Etkin, (Toronto: Institute for Catastrophic Risk Reduction, 2010), .

of the Ministry of Industry's Space Policy Framework and guided by extant public safety and emergency management doctrine*,* can achieve most of the necessary remedial actions required. In the process, Canada's space sector will be invigorated, Canadian youth engaged, Canadian's at large more secure. The time to act is now, before the time to react is upon us, before Canadians rightly pose the question "If you knew these things could happen, why didn't you do something?"

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