TEACHING RISK MANAGEMENT THROUGH THE LENS OF ASTEROIDS AND DISASTER STRATEGIES F. Cepeda, A.V. Araujo-Salcedo[1], [1] Research Studies Centers, Gimnasio Campestre, Bogotá, Colombia; felipe.cepeda@campestre.edu.co

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Introduction

Since implementing the Warning Network Systems for near-earth objects and bolide events, everything has changed for the safety of the planet [1, 2]. However, this has not been the case, as in 1908 in Tunguska, Siberia, when an extraterrestrial object burned around 2150 km^2 without any injury. Nowadays, the IAWN (International Asteroid Warning Network) is tasked with developing a strategy using well-defined communication plans and protocols to assist governments in analyzing asteroid impact consequences and planning mitigation responses.

In disaster management and impact response, for example, there is a crucial fact to remark: More than a thousand people were injured because the sonic wave during the Chelyabinsk event collapsed the city's hospital system [3]. Among these, and regarding the communication of such events, it is crucial to know how one can communicate to be responsible and efficient with facts. In 2024, we are in a critical era for planetary defense, particularly regarding the asteroid 2024YR4. Advances in astronomical observations and impact prediction models have heightened awareness of the potential threats of near-Earth objects (NEOs). 2024YR4 has drawn significant attention due to its trajectory, sparking discussions within the scientific community and global agencies about possible mitigation strategies. While the likelihood of impact has been clarified, the mere possibility necessitates preparedness and now is the opportunity to establish and test well-defined protocols around risk mitigation, covering the pre-impact, impact, and post-impact phases.

This work offers a training and education program for cities with populations exceeding $5,000,000$ to cope with the likely repercussions of such catastrophes in heavily populated metropolitan areas. Community awareness and avoidance of asteroid-related dangers are the aims of this program, which is based on earthquake preparedness standards. The risk of an impact is still low, but it's not zero, just like with earthquakes. Both catastrophes can seriously damage or destroy structures and people. For example, a region's tectonic setting affects the yearly risk of earthquakes, which may range from 0.01% to 1%. Similarly, bolide impacts cannot be foreseen, but we must be prepared for the worst because of how dreadful they may be. The training program teaches people to detect early warning signals of an explosion or atmospheric impact, such as a blinding flash of light, and to take timely action to reduce injury. Important things to remember include staying away from windows to avoid being harmed by broken glass, finding a safe place to hide to decrease the risks of hearing loss and debris hits, and following evacuation instructions to the letter. Like in earthquake-prone countries, this project attempts to educate citizens to establish a resilience culture that will help minimize the impacts of these uncommon but high-impact events. Through education, metropolitan centers may greatly strengthen public safety and raise their ability to respond effectively to foreign hazards, and therefore not generate dread in society.

Asteroids and Near Earth Objects

Asteroids are rocky objects, generally opaque, whose orbits evolve around the Sun, just like the planets in our Solar System. They exist in varying sizes, dynamic parameters, and chemical composition. Asteroids are considered corpses of the formation and evolution of our Solar System. So it is of most importance to know their chemical and geological characteristics. For this reason, NASA through the Center for Near-Earth Object Center for Near-Earth Object Studies (CNEOS) provides information on all those objects that are close enough to the Earth and those that could represent a possible risk of impact with the Earth. In 2018, through the analysis of multiple data from the second data release of data from the European Aerospace Agency (ESA) Gaia, it was possible to determine the orbits of more than 14000 asteroids in our Solar System. However, in the last released data Gaia 3 in June 2022, this number increased considerably. The results showed the orbits of more than 150.000 asteroids [4]. Now, while it is true that none of these objects currently represent a threat, nevertheless, the dynamics between them give rise to small fragments that possibly end up entering the Earth's atmosphere.

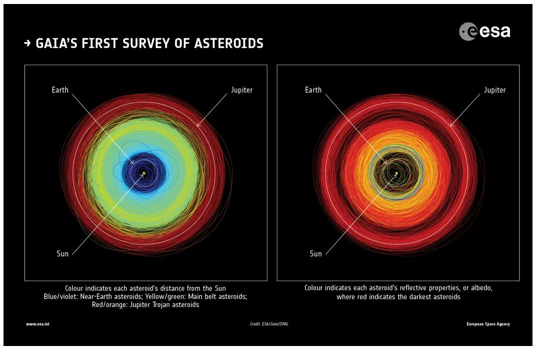

Figure 1: Gaia view of more than 14.000 asteroids. Gaia Data Processing and Analysis Consortium (DPAC); P. Tanga, Observatoire de la Côte d'Azur, France; F. Spo- to, IMCCE, Observatoire de Paris, France; NASA/WISE, 2022

Most of the time, at the moment of talking about asteroids, the first thing that comes to mind is not precisely how important they are for understanding the evolution of our planet but, on the contrary, we think of the danger that these objects may represent for the survival of the Earth. On the one hand, thanks to SENTRY, a software of NASA's Jet Propulsion Laboratory (JPL), there is a constant monitoring of what are called Near-Earth Objects (NEO). As in one of the SENTRY reports, Earth has more than 30.000 NEOs, and, so far, thanks to the previous results of NASA's OSIRIS-REX mission, it is known that the asteroid Bennu, one of the first of the SENTRY risk list, has a small probability of impact in the year 2182 [5]. That is, despite the large number of objects close to our planet, there is not a single one that, so far, represents a danger of any magnitude of climate change or extinction levels. In recent decades, it has become increasingly clear that the impact of interplanetary bodies on other planetary bodies is one of the most important geological processes in the Solar System and plays a fundamental role throughout the history of the Earth, resulting in both destructive and beneficial effects.

The surface of the Earth has been shaped by numerous geologic processes over the past four and a half billion years as well as for meteorite impact events. However, the latter was not recognized as a fact of real in the geological processes of the planet [6]. So, that is why, there are several fireball monitoring centers around the Earth [7, 1] allowing us to keep a constant record of these this types of events and those capable of reaching the Earth with a considerable amount of mass. Among these types of events, the CNEOS keeps updated on the

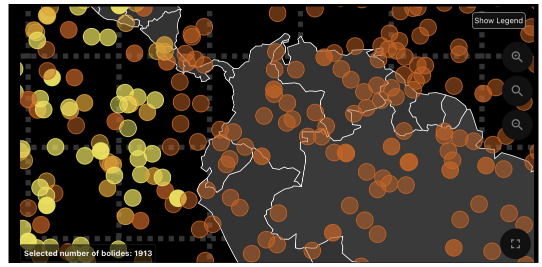

Figure 2: Images of the Fireball impact in Colombia, between 01/01/24 and 01/11/25

fireball events, indicating its location, indicating its geographic location, as well as the total impact energy and the total calculated impact energy of each one of them. Regarding this, there is in particular an important event. The object that burst into the atmosphere on February 15, 2013, over Chelyabinsk Oblast, Russia was an object of approximately 20 meter in diameter object exploded while it was still in the air, leaving more than $1,500$ people injured due to the impact of the shock wave on several buildings.

On the Cheliabisky Event

One of the important aspects to highlight around the Cheliabisky event is the fact that 1.500 people were injured by the shock wave blast. There are several aspects to consider regarding this, and we should think about the possible executable methodology to manage these scenarios to avoid damage.

Figure 3: One of the injured persons after the shockwave blast during the Chelyabinsk. FUENTE

Some Physical Aspects

On February 15, 2013, a bolide entered over the city of Chelyabinsk in Russia. This represents the largest recorded object to strike the Earth in more than a century. The bolide released 440 kT of energy–around 27 times the energy released for the Nagasaki bomb–causing widespread damage around the area.

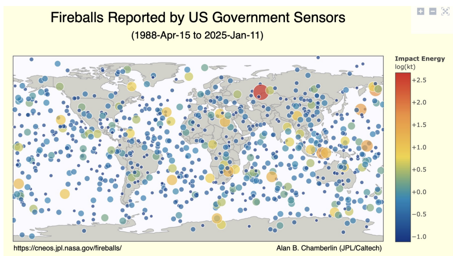

Figure 4: The Image shows the Fireball from 1988 Apr 15 to 2025 Jan 11. In particular, it highlights the Cheliabisky event, The Red Big Dot. CNEOS NASA

There are several important facts to take into account concerning possible damage to people and infrastructure in general, the energy, the decibels (dB) of the intensity of the sound, and the area covered by the event.

The Threshold of hearing for human beings is equal to 0 dB, and the upper limit in dB for eardrum damage is around 100 dB [8], which means that any event causing a sound over this number will affect the population in the area. Now, considering the reference value of the pressure for the Human being threshold hearing $P_0 = 20\mu Pa$ (MicroPascal), and the blast's peak pressure P around $500 - 700\ Pa$ at the distance around 20 Km, the sound pressure in decibels for the Chelyabinsk bolide is

$$I = 20 \log \left(\frac{P}{P_0} \right) \sim 150dB \tag{1}$$

So, with this value closing to the upper limit, this is one aspect to consider when constructing a viable and safe management plan for these kinds of risks.

Now, in this case, there was no way to prepare, given the specific circumstances of it. However, there are several events discovered within a few hours of impact on Earth. This was the case of the object name **2023 CX1**. A small object was discovered on Feb 12 at 20:18 UTC, almost 7 hours before impact, by Krisztián Sarneczky at the GINOP KHK observatory in Hungary. Within minutes of the discovery's posting on the Minor Planet Center's Near-Earth Object Confirmation Page, JPL's(The Jet Propulsion Laboratory) Scout system identified the possibility that the asteroid could be on an impact trajectory with Earth.

Figure 5: Ground track of 2023 CX1: Projection on the ground of the location of 2023 CX1 as the altitude decreases from 100 km to 20 km.

Given the high risk posed by a bolide impact in populated areas, it is imperative to have a well-structured and effective mitigation plan that minimizes human and material losses. Preparation for such events not only involves early detection and monitoring but also the implementation of clear strategies that guide the population through each phase of the impact, from the moments before the event to the immediate response and recovery. In this context, the following mitigation plan establishes a set of measures organized into different stages, covering everything from preventive education to the immediate actions that must be taken at the moment of impact and its aftermath. These strategies have been designed based on the analysis of past astronomical events and the application of scientific principles, with the objective of maximizing community safety and resilience in the face of this high-energy phenomenon.

The Mitigation Risk Plan for Bolide Events

The frequency of danger from near-earth objects (NEOs) to global security is very modest, although the potentially catastrophic implications of an impact event are substantial. This extensive risk mitigation strategy incorporates cutting-edge technical innovations, global protocols, and disaster management methodologies to comprehensively handle NEO impact risks, including early detection, monitoring, public education, and catastrophe response. The major emphasis is on building a framework suited to Colombia, with the plan also proposing worldwide ideas aimed at boosting cooperation and readiness. The ultimate purpose is to establish a systematic and coordinated effort to reduce the loss of life, economic damage, and long-term environmental damages arising from NEO impacts.

Phase 1. Early Detection and Monitoring Systems

Goal: To promptly identify near-Earth objects that might crash with the Earth, allowing a lead time for mitigation operations so that they can be effectively successful.

Action plan:

Step 1: Collaboration with space agencies and worldwide networks. Leverage existing systems such as NASA's Planetary Defense Coordination Office (PDCO), the European Space Agency (ESA) NEO Segment, and the International Asteroid Warning Network (IAWN). (UK, Brazil, Canada) For nations like Colombia to be included in the global detection system, providing a shared pool of resources and information.

Step 2: Use of ground and space-based telescopes Use current and prospective observatories, such as Pan-STARRS (Hawaii) and the Vera C. Rubin Observatory. Rubin Observatory, which is intended to detect smaller objects on a collision path with Earth. The building of the LSST (Large Synoptic Survey Telescope) will boost detection rates by monitoring a wide section of the sky each night. In this approach, it will be feasible to monitor if any NEO is likely to affect.

Step 3: Deployment of radar tracking systems Establish radar tracking capabilities that enable real-time monitoring of NEO trajectories. For example, the Arecibo Observatory in Puerto Rico, which is presently inoperative, should be replaced with high-power radar installations strategically dispersed across the globe. In Colombia, these radar systems may be put in distant places with minimal human activity, enabling continuous and uninterrupted surveillance.

Step 4: Early warning communication structure Develop a warning system that automatically interacts with government agencies, emergency services and the public. This system should incorporate interaction with national weather and disaster warning systems, ensuring that notifications reach all concerned parties in real time. Alerts should contain information such as the magnitude of the NEO, its trajectory and probable impact zones. In Colombia, mobile apps and SMS-based alerts should be built to reach rural and urban regions and with them deliver emergency warnings. Likewise, a link must be built with the media so that the community accepts the information as truthful.

Step 5: Data exchange and analysis An international cooperation structure should be designed to facilitate NEO data exchange across space agencies, academic and business entities. A cloud-based infrastructure might give real-time data on the location, velocity, and trajectory of NEOs.

Phase 2. Detection Tools and Systems

Goal: To increase the capabilities of existing detection techniques to offer more complete and precise information on NEO size, composition, and velocity.

Action Plan:

Step 1: Space-Based Platforms Deploy and operate modern space-based observatories like NASA's NEOWISE project, which identifies and classifies NEOs using infrared technology. This infrared technology is capable of spotting objects that reflect negligible visible light, which would otherwise remain undiscovered by optical telescopes.

Step 2: Enhanced Radar Systems for Tracking To limit the consequences of possibly minor NEOs that may go unnoticed by optical telescopes, improve radar systems with better resolution. The projected Goldstone Radar System, for instance, can follow objects as tiny as 100 meters and give data on their spin, orbit, and material composition.

Step 3: Surveillance Satellites In conjunction with international organizations, deploy surveillance satellites, particularly those intended to scan the sky for tiny, fast-moving objects. These satellites should be equipped with both visible and infrared imaging capabilities.

Phase 3. Public Education and Preparedness

Goal: To ensure that the populace recognizes the danger of NEO effects, how to spot the signals of an impact event, and how to take precautionary actions.

Action Plan:

Step 1: National Awareness Programs Leverage Colombia's current educational channels (e.g., television, radio, and social media) to communicate information about NEOs. Work with national TV networks, such as RCN and Caracol, to show public service advertisements (PSAs) describing the hazards, probable effect scenarios, and safety actions. Ensure that the message is clear and consistent.

Step 2: Educational Materials Produce instructional resources that may be provided to schools, colleges, and community centers. These materials should include:

- Flyers detailing NEO impact possibilities
- Safety and evacuation strategies for NEO strikes
- Informational websites and applications where the public may receive updates about NEO risks

Step 3: Local Workshops and Training Organize community seminars around Colombia, concentrating on cities like Bogotá, Medellín, and Cali, as well as rural regions, where risk awareness and disaster preparation should be focused. Invite local specialists in crisis management and space science to facilitate these sessions.

Phase 4. Incorporating NEO Impact Risk into National Risk Management Framework

Goal: To include Near-Earth Object (NEO) Impact Risk in national disaster management policies. The National Disaster Risk Management Unit (UNGRD) plays a critical part in this process by coordinating the integration of NEO effects into disaster preparation programs and ensuring that the public is informed and ready for such uncommon but high-impact occurrences.

Action Plan:

Step 1: Official Recognition of NEO as a National Risk

- **Classification of NEO Risk:** The UNGRD must formally identify NEO effects as part of the national risk management system. NEO hazards should be managed similarly to earthquakes, floods, and other natural catastrophes by categorizing them according to their potential effect and probability of occurrence.
- **Risk Categorization:** The effects may be grouped into low, medium, or high-risk categories depending on the size and trajectory of the possible item, and vulnerability maps can be generated to highlight locations most at risk.
- **Inclusion in National Disaster Plans:** Incorporate NEO risk mitigation into national disaster response plans, ensuring that local and regional emergency services are prepared for NEO-related occurrences.

Step 2: Public Education and Awareness Campaigns

- **Annual Campaigns:** The UNGRD should launch yearly public awareness campaigns on NEO dangers. These programs should be aimed at educating the public about the nature of NEOs, the possible risks they pose, and the precautions people should take in case of an impact threat.
- **Campaign Content:** Campaigns should educate the public about the features of NEOs, such as their composition, the possible repercussions of a crash (such as tsunamis, fires, and shockwaves), and how these impacts might affect populations. Special attention should be paid to the importance of public preparation notwithstanding the low chance of an incident.
- **Multi-Channel Approach:** Use conventional (radio, TV, newspapers) and modern (social media, websites, apps) methods to convey information. Public service announcements (PSAs) should be aired periodically to achieve wide reach.

Step 3: Education in Schools, Universities, and Businesses

- **Incorporate NEO Risk Education into Curricula:** Similar to earthquake preparation, the UNGRD should demand that NEO impact education be incorporated in school curriculum.

- **School Programs:** From elementary to higher education levels, pupils should get systematic instruction on the hazards of NEO impacts, the foundations of planetary defense, and the steps they may take in the case of an alarm.
- **University Engagement:** At universities, NEO impact research should be supported. Engineering, astronomy, and environmental sciences departments may play a vital role in disseminating awareness and creating mitigating solutions.
- **Training for Businesses:** Companies, particularly those in highly populated metropolitan locations, should be urged to conduct NEO impact response training.
- **Private Sector Participation:** Large firms and organizations should be part of the campaign by incorporating NEO impact response processes into their crisis management and business continuity strategies.

Step 4: Implementation of NEO Preparedness Drills and Simulations

- **National NEO Impact exercises:** Similar to earthquake exercises, the UNGRD should arrange yearly NEO impact drills throughout the nation.
- **Drill Phases:** The drills should be planned with three primary phases:
  - Early Warning Phase: Public warning and guidance on how to react
  - Evacuation and refuge Phase: Providing evacuation routes and safe refuge sites
  - Post-Impact Response: Coordination between emergency responders, medical teams, and local authorities
- **School and Workplace Simulations:** Schools and organizations should carry out their own internal simulations
- **Specialist exercises:** For high-risk zones, such as coastal locations where tsunamis from NEO impacts can be a worry

Phase 5. Immediate Post-Impact Response Protocol

Goal: To guarantee the safety and well-being of the impacted populations, this stage of the mitigating plan describes the required protective actions, injury control strategies, and post-impact operations.

Action Plan:

Step 1: Immediate Protective Measures If anyone sees a strong bright event in the sky, people should avoid direct viewing as the related heat radiation might either temporarily or permanently affect eyesight. Additionally, the accompanying shockwave may reach within seconds or minutes, providing a high danger of harm due to structural damage and flying debris.

Sheltering and Impact Mitigation:

- Seek immediate shelter in structurally reinforced areas
- Avoid being near to windows, glass doors, and delicate buildings
- Interior chambers, subterranean areas, and structures intended to endure high-pressure occurrences are optimum shelters
- If caught outdoors, assume a protective posture
- Lie prone with the head covered, sheltering important organs from any debris
- Protect the ears to reduce harm from the pressure wave

Hearing Protection: The extreme pressure changes after a bolide impact may cause temporary or permanent auditory damage, including tympanic membrane rupture and sensorineural hearing loss:

- Cover the ears securely using hands, cloth, or other accessible objects
- Seek urgent medical examination if symptoms such as ringing in the ears (tinnitus), hearing loss, or dizziness arise post-impact

Minimizing Communication Disruptions: Mobile networks may face congestion; consequently, phone use should be confined to urgent emergency calls.

Step 2: Emergency Medical Response and Injury Assessment Once the primary shockwave has subsided, it is essential to conduct an initial assessment of injuries and provide immediate first aid. The most common injuries in a bolide impact scenario include lacerations, blunt force trauma, burns, and auditory damage.

Triage and First Aid Protocols

- Assess the degree of injuries in oneself and others
- For severe bleeding, apply direct pressure with a clean towel to halt hemorrhaging
- If a fracture is suspected, immobilize the injured limb and minimize unnecessary movement
- In situations of unconscious patients, put them in the lateral recovery position to avoid airway blockage

Assessment and Management of Auditory Trauma

- If patients feel significant ear discomfort, loss of hearing, or balance issues, medical assessment is essential
- Persistent tinnitus or a sense of fullness in the ears may suggest barotrauma and should be handled by medical personnel

Step 3: Evacuation and Movement to Designated Safety Zones To reduce secondary dangers, participants must go in an orderly way to pre-established safety zones, following procedures defined in readiness exercises:

- Maintain group cohesiveness to avoid separation and confusion
- Avoid damaged infrastructure, since structural collapse remains a considerable danger
- Await official clearance before leaving shelters
- Follow emergency orders using authorized communication platforms

Conclusions

Considering new hazards like 2024YR4 expected Earth contact in 2032, using a planned mitigating plan for bolide occurrences marks significant progress in planetary defense strategy. Combining early detection, monitoring system enhancement, public education, risk management framework integration, and post-impact response protocols—the complete five-phase approach described in this study offers a strong basis for addressing immediate and long-term NEO challenges. The Chelyabinsk catastrophe reminds us soberly of the terrible power of even somewhat small-sized bolides with their 150 dB shock wave and extensive structural destruction. When one considers the trajectory and mass properties of YR4, the need for using these mitigating techniques becomes even more urgent. Refining our knowledge of 2024YR4 orbital dynamics and possible impact scenarios depends on the combination of advanced space-based platforms and sophisticated radar monitoring systems as described in Phases 1 and 2. Given 2024YR4 approach, the suggested public preparation policies and educational framework become much more important. Communities may build the resilience required to meet both anticipated effects like 2024YR4 and unexpected bolide occurrences by using lessons learned from past events like Chelyabinsk and Tunguska while using current communication technology and institutional frameworks. Particularly crucial is the fresh strategy, described in Phase 4, to include NEO impact risk into national disaster management systems. This deliberate inclusion of astronomical hazards into current emergency response infrastructures constitutes a fundamental advance in our approach to planetary defense. The effectiveness of this integration—shown by the cooperative efforts of space agencies and local disaster management authorities—offers a paradigm for the next worldwide collaboration in handling cosmic hazards. Looking forward, the evolution of these all-encompassing mitigating plans not only responds to current hazards like 2024 YR4 but also represents a basic change in our attitude toward planetary defense. The convergence of technology innovation, public education, and institutional coordination reflects a new paradigm in catastrophe preparedness—one that respects both the rare and the potentially catastrophic nature of NEO effects. As we continue to perfect these techniques, our ability to defend human life and infrastructure against cosmic dangers will grow, assuring a more resilient future for societies globally.

References: [1] G.-R. S. D. Book (2019) Goes-r series data book cdrl pm-14 rev a. may 2019, noaa-nasa. [2] P. Jenniskens, et al. (2018) *Meteoritics & Planetary Science* 53(12):2445. [3] A. E. Dudorov, et al.

(2016) in *Materials Science Forum* vol. 845 273–284 Trans Tech Publ. [4] L. Galluccio, et al. (2023) *Astronomy & Astrophysics* 674:A35. [5] D. Farnocchia, et al. (2021) *Icarus* 369:114594. [6] G. R. Osinski, et al. (2022) *Earth-Science Reviews* 232:104112. [7] D. Vida, et al. (2021) *Monthly Notices of the Royal Astronomical Society* 506(4):5046. [8] C. S. Keay (1980) *Science* 210(4465):11.