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A Scientific Impact Response Team for the Aftermath of Small Asteroid and Comet Impacts

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Most asteroid and comet impacts cause localized destruction, not global-scale extinctions. The way in which the international community would respond to such events has not been defined. During the 10th European Science Foundation IMPACT workshop in 2003 a method of scientific response to an impact event was proposed. A Scientific Impact Response Team (SIRT) would achieve the rapid assembly of a scientific and logistics team to access and study a newly formed impact crater (or blast zone under an airburst). Its purpose would be to (1) provide scientific advice and information for disaster and emergency services if such an event occurs near to a populated area, (2) provide scientific advice to media and public information channels, (3) investigate immediate postimpact geological and biological effects in and around the crater, and (4) document geological and biological changes at the site of impact over time and the rate of recovery. The team would exist in a latent state. In order to ensure a coherent response to such an event, the team could be activated by international bodies such as the UN and would maintain links with other emergency response organizations.

Key Words: Asteroid; Disaster; Comet; Impact; Disaster response; Scientific study.

INTRODUCTION

In 1908 an asteroid entered the Earth's atmosphere and exploded above the Siberian region of Tunguska, flattening two thousand square kilometers of Siberian forest. It took 19 years for the first scientific expedition to enter the region and characterize the effects of the explosion of an extraterrestrial object over this remote region of Siberia.[1] It is often said that had the object exploded

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six hours later it would have destroyed St. Petersburg. Irrespective of the real or potential effects of this explosion, it demonstrated that the international community had no agreed process on how to respond to such an event. Today, although the hazard from asteroid and comet impacts and the potential effect of impacts on civilization is better understood[2] and there are proposals for diverting these objects[3,4] and mapping them,[5,6] there is still no well-defined process for an international scientific response to the localized destruction caused by an asteroid or comet impact with the Earth.

The effects of an impact event have been discussed in the scientific literature. If the impact energy is less than ~10 Megaton equivalent of TNT, then a crater may not be formed and instead an airburst may destroy the biota and local property. The Tunguska explosion of 1908 in Siberia is such an example. For energies between 10 Mt and 10^6 Mt, a crater will be formed. The effects of the impact are confined to "local" effects, where the effects become more widely manifested with greater energies, until at approximately 10^7 Mt the effects of an impact are believed to be global, that is, potentially causing worldwide extinctions.[7] In the past, impacts on this scale are thought to have been responsible for large-scale biological changes, such as those purported to have made the dinosaurs extinct 65 million years ago.[8]

Events on the scale of $\sim 10^6$ Mt are believed to occur with a frequency of about once every 100 million years (Figure 1), but events that form a crater of ~1 km diameter, and could devastate an area of approximately 8,000 square kilometers, can occur on average about once every 1,000 years. These differences in energy are the basis of the Torino scale, which is a scale to assess the risks from impacts.[9] Of course, events with global scale consequences are unlikely to be survived by large sections of society. This article concerns the international response to the much more common locally-destructive asteroid and comet impacts of energy $\sim 10^5$ Mt and less.

Garshnek et al. gave consideration to the disaster response requirements for impacts, and they identified some of the key areas of uncertainty in how civilizations would respond to such an event, most notably the response in provision of food and emergency relief.[10]

From a disaster response point of view, impact events present an unusual amalgam of natural disasters. Wild fires initiated by heated rocks (ejecta) thrown out during impact require the response of fire services. Faulting and shock waves generate problems more often associated with earthquakes. The blast wave from the impactor creates problems usually associated with storm damage, particularly in forested regions. In the case of an oceanic impact, tsunamis may also inundate coastal regions, creating response problems similar to those of coastal hurricanes or undersea earthquakes.[11] Some of these consequences, particularly wild fires, will depend upon the biome in which the impact occurs.

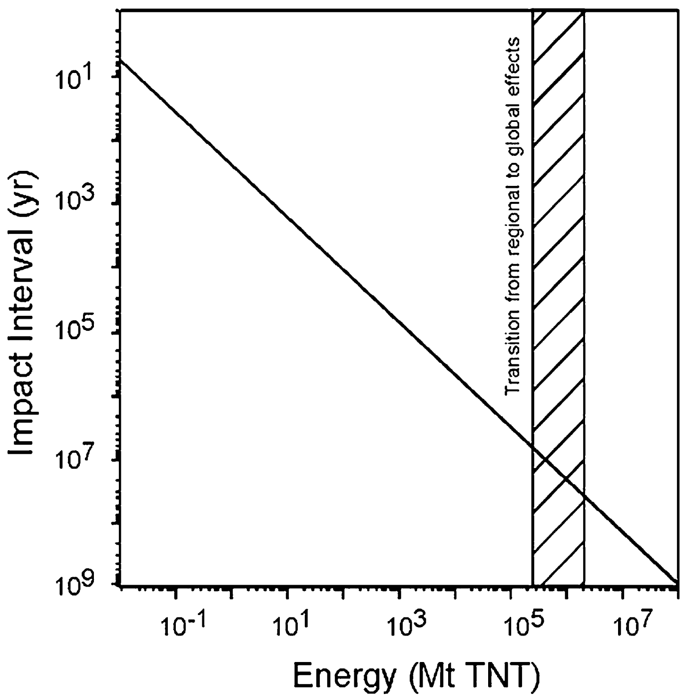

Figure 1: The interval between impact events of given energies. The shaded area represents the transition from local to global effects. The graph shows that the majority of impact events cause local destruction.

All of these problems, and the responses assigned to them, can benefit from accurate scientific knowledge of the effects of impacts. As each of the effects is related to the total energy of the impact, impact scientists can provide a synthetic understanding of the potential effects and the hazards associated with them.

In addition to providing scientific information for effective disaster response, studying an impact crater is of immense scientific interest because we have never previously had the opportunity to observe the changes occurring in and around a fresh impact crater, although we know impact events have been very important in shaping biological evolution on Earth.

One way to gather the relevant scientific information to assist in the scientific and disaster response to an impact event would be to activate a team especially created for this purpose, what I call for convenience here a Scientific Impact Response Team (SIRT). The purpose of this article is to discuss this concept.

PURPOSE OF A SIRT

A Scientific Impact Response Team would have four primary objectives. Two of them are public service responsibilities and two of them are scientific responsibilities. They would:

1. *Provide advice and information for emergency services.* The immediate type of information requested by the emergency services will include the following and similar questions: What is the extent of the fire zone? What is the extent of the blast zone? The extent of these problems will be influenced by the energy of the impactor. The SIRT would gather information on the size of the crater or region destroyed by an airburst, and its associated environmental effects. They would pass this information to the relevant disaster response agencies. They would do this using satellite information, aircraft overflights and ground assessments. This information would be gathered and assessed by the disaster response personnel in the SIRT.

   Some of this information could be acquired by disaster relief organizations independently using real time data gathered by satellite photographs, and does not necessarily require impact scientists or the SIRT. However, as explained in the section dealing with the composition of a SIRT, impact scientists can provide a great deal of information to disaster relief personnel, not least they can provide more accurate interpretation of satellite and aerial photographs. Their prior knowledge of the environmental effects of impacts is likely to make appraisal of the data effective.

2. *Provide public scientific advice.* Following impacts, particularly small-scale impact events where the zone of devastation is less than a few hundred to a thousand square kilometers, the public is likely to be (a) fascinated, (b) anguished, and (c) concerned about safety. Some members of the public are likely to want to visit the site of the impact or explosion, others will be confused and may seek to leave the area. The purpose of a SIRT would be to bring together in a very rapid time space ($<$24 hr) an immediate scientific assessment of the effects of the impact and the danger it posses to the public, which can be used in civil response and to keep the public informed of events through media channels in regions unaffected by the impact. This information would also be fed to civil defence networks working towards evacuation and civilian planning.

   Although much of this data could be transmitted to the public by observations by nonimpact scientists, the public may have questions such as the following. "Will the impact cause earthquakes later on? Do impacts spread poisonous fumes? Are asteroids radioactive?" The public will expect to hear from impact specialists to be reassured. A SIRT can provide a pool of immediately accessible specialists to provide advice and information, not just about the specific event, but its effects in the context of impact events in general.

3. *Investigate immediate geological and biological changes.* The SIRT would gather information of scientific interest concerning the effects of impact events. There is no fresh crater on the Earth today with which to study immediate postimpact geological and biological changes. The formation of

hydrothermal systems from the pulse of heat delivered by the impactor, the extent of slumping of the crater from collapse following the carving of the transient bowl, and the immediate effects of fire and blast on the local ecology are all areas of scientific knowledge that are not well constrained. Their current assessment depends mainly on modeling and field observations of the 160 buried and eroded craters that have so far been identified on Earth, as well as studies of extraterrestrial craters. The scientific information gathered following an impact event will be of great importance to the scientific community in piecing together the immediate effects of impact events. This information has relevance for assessing the role that impact events had on the Earth's biosphere in the past.

4. *Document changes over time.* The geological and biological changes that occur inside impact craters and in the surrounding environment immediately after impact are not well understood.[12] A SIRT could take responsibility for establishing long-term monitoring programs within and around the crater to study long-term changes in a similar manner to the way in which geological and biological changes are observed by long-term ecological research projects following volcanic eruptions. These monitoring programs would provide the first systematic long-term dataset of the geological and biological changes occurring from the immediate time of impact, in contrast to today's geological and biological studies that start some considerable time after impact. This information may also have implications for civil planning. For example, when can hydrothermal systems be expected to have cooled to a point where it is safe for the public to be within the immediate area of the crater? By establishing long-term monitoring programs around the crater, the SIRT will provide information that will allow a well-orchestrated response for civil planning for a long period after impact.

COMPOSITION OF A SIRT

The composition of a SIRT can be broadly separated into two types of individuals: (1) scientists gathering information for scientific use and to feed to disaster relief personnel; and (2) disaster relief personnel working closely along side the scientists to interpret the data and feed it to disaster relief and humanitarian organizations. In theory, an alternative approach to a SIRT is to integrate impact scientists within existing disaster relief organizations. This would be valuable alongside a SIRT. However, the value of a separate team is that they can achieve an integrated discussion of the various effects of impact (fire, faulting, blast, etc.) among various impact specialists. Because the assessment of impact events requires knowledge of geological and environmental effects, it may be an unnecessary duplication of effort to have these impact specialists embedded in every disaster relief organization involved. Because of the rapidity of modern communications, a centralized SIRT should be effective at disseminating a coordinated and coherent set of information to many organizations.

Some suggested categories of personnel are listed below, and comments are made on the contributions they would make to a SIRT:

Scientists

Geologists provide information on shock pressures, characteristics of substrate, faulting, and so on. They must be able to communicate this information in a meaningful way to civil engineers and disaster relief personnel dealing with practical implications of geological changes.

Biologists and Environmental Scientists provide information on postimpact ecological effects. They would communicate with civil defence and disaster relief personnel to establish risks from toxins, fires, and other potentially dangerous side-effects of ecological changes caused by the impact.

Hydrologists provide information on tsunami effects and coastal threat from oceanic impacts.

As well as helping interpret data for disaster response organizations, these different scientists would achieve a coordinated scientific study of the immediate effect of the impact and a coordinated long-term ecological study of the impact area. Thus, the scientific personnel of the SIRT would constitute the basis of a long-term ecological research group.

Disaster-Relief Personnel

Civil Engineers use geological data provided by the impact geologists to assess effects on buildings and other important civil structures (dams, etc.). Impact events cause very distinctive patterns of faulting and slumping, and impact geologists working along side civil engineers could provide a much more coherent appraisal of the effects.

Fire Response Personnel provide fire response in ejecta zone and coordinate fire suppression in consultation with impact environmental scientists.

Earthquake engineers assess geological data from the impact geologists in the context of earthquake effects on important civil structures.

Doctors provide medical response to human populations if they are affected by the event. In consultation with impact ecologists they would try to assess the potential medical problems (toxins from impact fires, blast lacerations, etc.) and the location where these problems will be most prevalent. They will thus coordinate medical facilities.

Civil Defence provide coordination of public evacuation and safety with geologists, biologists and engineers, providing information on extent of destruction.

Humanitarian aid agencies (food, supplies, etc.) provide coordinated response in food, medical supply delivery, and so on.

Military personnel provide feedback and coordination to military forces involved in public safety and disaster response including airlift operations.

The SIRT would be divided into two segments. The first would be the IMPACT response team responsible for immediate insertion into the postimpact environment and might consistent of ~10 people. The second would be the bulk of the SIRT which would be sent to the site when safe locations have been established by the IMPACT team. The attributes of both of these segments are described in a later section on post impact response.

DEPENDENCE ON LOCATION OF IMPACT

The relative importance of the different categories of people within the SIRT will depend on where the impact event occurs. In the composition of the team I have described above, I have assumed a worst-case scenario: that an impact occurs into a land-based heavily populated area, which is the most prudent assumption from the point of view of preimpact planning.

Because three-quarters of the planet is ocean, the most likely effect of an impact is a tsunami in coastal areas and in these cases the geological effects of the impact may be less important. The focus would be on the secondary effects of tsunami on populations and buildings along coastal areas. The consequences are not strictly “impact” effects, but will be changes associated with any coastal tsunami. Even in this case, however, the views and knowledge of impact scientists will be useful to assess the scale of the tsunami and its origin, and thus to map the worst affected areas.

On land, the majority of impact events will be into unpopulated regions. In this case, the purpose of a SIRT is purely to gather scientific information (roles 3 and 4, above). Its disaster relief responsibilities may be limited. The Tunguska event is a good example of this category, where a SIRT team would have been valuable to gather information on the immediate effects of this event, which is now lacking. Scientists gathered scientific information only some 19 years after the event. Although the explosion flattened two thousand square kilometres of forest and affected some local villages, its human impact was limited. In such situations the SIRT can be downgraded into a primarily scientific response team with some disaster relief response if required.

ACTIVATION OF A SIRT

How would a SIRT be activated? The team described above would exist in a latent state. Its activation could become the responsibility of a major international organization such as the United Nations. The nation affected by an impact event or blast would call upon the UN to activate the SIRT which would then be deployed in the sequence outlined in the following section (Figure 2).

A great degree of redundancy must be built into the system for two reasons. First, if the impact event occurs in a small country and in the process destroys the capital city or the nation's government then it must be possible for the neighbours of that country or other international bodies to activate the SIRT without requiring activation from the government of the country affected.

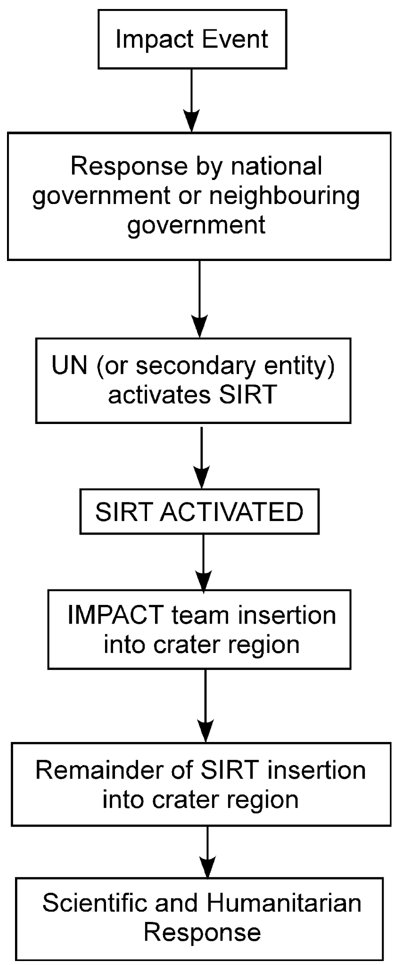

Figure 2: Proposed stages in the activation of a SIRT.

Second, although less statistically likely, the UN itself might be destroyed by an impact. An impact event in North America or in the Atlantic Ocean is likely to cause destruction in New York and may affect the operation in the UN, although its subsidiary offices could still activate the SIRT. A series of secondary and tertiary bodies might be defined that have the authority to activate the SIRT. Thus, redundancy must exist in the ability to call for a SIRT response and also in the ability to activate it.

The members of a SIRT might be distributed globally. They too must have redundancy as members of the team may themselves have been affected by an impact, depending on the scale of the event and its location. Means of communication to SIRT members must be effective and could be accomplished by satellite.

STAGES IN THE POSTIMPACT RESPONSE

Following the activation of the SIRT, there must be a well-defined sequence of response. The first response must be by a highly-trained unit that could be inserted into the postimpact environment to gather immediate information on postimpact conditions and the effects of the impactor using real-time satellite technology. I call this team the IMPACT team and it is comprised of a subset of the SIRT listed in the section on the composition of the SIRT. This IMPACT team should be small, perhaps ~10 personnel. It might be composed of a geologist, biologist, fire and civil engineer, and the rest of the team might be military personnel trained in operating in extreme environments.

The scientific subset of the IMPACT team would have received prior training with military units in extreme environment operation. The military personnel operating within this team and used to train the scientists might come from existing elite military units. The SAS and Delta Force are just two examples of elite military units that are trained to operate in many different environments involving urban, jungle, desert, and polar warfare. The value of military units specifically relates to the indiscriminate nature of impact events. Unlike volcanic eruptions, which are localized to specific hotspots, asteroids or comets impacts are not localized to particular regions of the Earth. Because an impact event could potentially occur within any biome, elite military units are of obvious interest to a SIRT because they are trained to operate in any environment. Clearly many of the normal operational roles of these military units, which involve covert action against people, are not relevant to a SIRT, but their value, even if only as training units, would lie in their extensive experience in multienvironmental training and their training in rapid insertion into some of Earth's extreme environments.

The IMPACT team would have several responsibilities. They are to: (1) locate safe sites near to the impact crater or region of airburst destruction for the rest of the SIRT team to coordinate disaster and humanitarian relief (if appropriate) and long-term scientific monitoring; and (2) gather immediate information on the extent of the blast zone, fire zone, and area of faulting and shock for scientific documentation of the effects of impact to act as the initial data set of a long-term monitoring program.

Hours to days following the insertion of the IMPACT team, the SIRT would set up operations around the site of the impact crater or region of airburst destruction to coordinate longer term disaster relief and scientific monitoring with the composition previously outlined. The total size of the SIRT might be ~50 people.

CONCLUSION

The mapping of asteroid and comet trajectories and the development of countermeasures deployed in space to deflect them from Earth[13–16] may reduce impact hazard, but such countermeasures probably do not have guaranteed 100% effectiveness. Furthermore, prior to such countermeasures, Earth remains vulnerable. Regardless of the development of planetary protection measures for Earth, human civilization should have procedures in place to respond to an impact event.

Here, I have described a possible architecture for how the international community might respond to the collision of a small asteroid or comet impact event. A Scientific Impact Response Team (SIRT) would provide a coordinated scientific response and a coordinated interface between the scientific community and international emergency services for dealing with the immediate effects of a locally destructive asteroid or comet impact event. I present this as a basis for future discussion and emphasize that a more coherent postimpact response plan will actually require considerable discussion amongst different disaster response personnel and scientists.

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