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The research on near-Earth objects(NEOs) and its possible protectionary methods

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Abstract. Recent year, as technologies and research have unprecedently grow in a fast speed, human's exploration toward outer space become enormous. Several private space exploration and aerospace manufacture corporations, such as SpaceX, have come into public which symbolize the development of human society and start to reshape the human civilization. Near Earth Objects(Neos) or Potential Hazard Asteroids(PHAs) have gradually focused by scientists. With the emerging of Neos 'observations, it has become vigilant that Neos 'impact to human civilization is obviously destructive refer to the distinction dinosaur. Neo impact technologies and strategies are tremendously vital in resort of continuing human civilization. This paper presents the time frame of launching of satellite and space station and their function of exploration and the information about near earth objects including its feature and propose several possible solutions toward Neos for short time scales and long times scales including nuclear explosive devices, kinetic impactor, asteroid gravity tractor and asteroid laser ablation. These methods have been list with their advantages and disadvantages and evaluation will be taken from the prospective of successful rate, time, efficiency and cost.

Keywords: planetary defense, near-earth objects, nuclear devices.

1. Introduction

1.1. The history of human development in space

Since Soviet Union have launched the first satellite, Sputnik 1, in 1957 which was sent into the low earth orbit, the gate of space age has been opened. Later on, several historical milestones have been achieved by NASA. July 20, 1969, Apollo 11(shown in Fig 1), carrying the mission of manned landing on the moon, enable the footprint of human to land on another celestials- moon. A succession of Apollo plans' exploration brings several kilos of moon's rock which have enormous research value and make a lot of contribution to human on studying the element of solar system and dating the time frame of important event in earth. So far, thousands of satellites have been sent into the space whose function have determining weather, broadband communication, GPS locating etc. These satellites are often equipped with several probes such as deep-space probes, planetary probes and lunar probes. By general category, space craft could be divided into two kinds: crewed and uncrewed. Until 2022, only three countries have the ability to launch crewed space craft including China, American and Russia. In 1961， the first crewed space craft in human history is Vostok 1 which is launched by Soviet Unions and carried cosmonaut Gagarin around the earth orbit. Also in 1961, the America's first crewed spacecraft named

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Mercury-redstone 3 was launched whose object is to determine human's capabilities in space environment and fly for 15 minutes and 28 seconds at an altitude of 116.5 statue miles. China launched its first crewed spacecraft named Shenzhou 5 on October 15, 2003.

Figure 1. Apollo 11 lunar spacecraft and the astronaut Buzz Aldrin [1]

Figure 2. The view of ISS exterior [2]

Among various spacecraft, the most magnificent and effective one is the international space station(shown in Fig 2) which is a space experiment facility combined with several experimental cabin provide specific research result in the flied of biology, astronomy, physical science, materials science, space meteorology and human studies. The international space station is mainly constructed and operated by the National Aeronautics and Space Administration of the United States, the Russian Federal Space Agency, the European Space Agency, the Japan Aerospace Exploration Agency and the Canadian Space Agency. In the first stage of construction(1994-1998), the rendezvous and docking between the US space shuttle and the Russian Mir space station were conducted for 9 times, and valuable experience was gained. The second stage (1998-2001) is the initial assembly stage. On November 20, 1998, the first component of the International Space Station - the functional cargo compartment of the dawn (funded by the United States and made in Russia) was successfully launched. On December 4, 1998, the node module of the United States solidarity was put into orbit by the space shuttle Endeavour, and successfully docked with dawn on December 7. The main objective of phase 2 is to build an initial space station with the capacity of carrying three people. The third stage (2001-2006), final assembly and application stage.

Furthermore, the launching of telescope into the space provide further exploration of space. The most famous one is Hubble Space Telescope(HST). In 1990, it was launched into the low earth orbit and still remains in operation. The instrument on it could enable observation in the visible, near-infrared and ultraviolet field of electromagnetic spectrum. The orbit outside the earth could let HST to capture high resolution image without the distortion of Earth's atmosphere compared to the big ground-based telescope. Its scientific result including finding accurately age, expansion of solar system, extending visible wavelength image etc. For example, Hubble constant[3], a standard measurement of rate of the expansion of universe, has been evaluate more accurate with the help of HST. In the past, the errors of Hubble constant could be up to about 50%. Nowadays, it have been provided with an accuracy of ±10% toward the measurement of Cepheid variable stars(stars that pulsates radially with stable period and amplitude, varying in diameter, temperature and luminosity) in the Virgo Cluster.

1.2. Description of Near-earth object

Near earth object (NEO) is a general term for asteroids, comets and large meteoroids whose orbits have probabilities to intersect with the earth's orbit and thus may have impact risks. Because of the size of this celestial body and its proximity to the earth, it is feasible to launch a spacecraft from the earth to carry out explosion or interception in the future. In fact, there are some near earth objects whose velocity changes are smaller than that of the moon. According to the international standard, Near earth objects that could be labelled as potential hazard asteroids(PHAs) should have a perihelion distance of less than

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1.3 AU and an absolute magnitude of more than 140 meters. These objects could often be seen in so called "main belt" which is the bound that separates the terrestrial celestials from the gas celestials. Up to date, there are about ten thousand Neos that have been found while most of them are very big. The overall population could be up to about one million. As long as the volume of Neo is larger than this value, if it hits the earth, it will bring serious disasters and endanger the world.

$$v^2 = (GM)(\frac{2}{r} - \frac{1}{a}) \qquad E = \frac{1}{2}mv^2$$

According to the vis viva equation, the energy of one cubic meter of asteroid flying from a far distance which crash into the Earth could be estimate. By knowing that Gravitational constant(G), Mass(M) and radius(R) are Earth's, the velocity of the asteroid could be estimate and then bring it to the dynamic potential energy formula. Finally, it could be calculated that one cubic meter asteroid could have 6.3*10^10 joules which equal to 15tons of TNT which could show the huge impact of Near-Earth Objects. One of the most serious evident in Earth's history is the Shikesuluber meteorite. The meteorite with only a 10km diameter could cause the distinction of the dominant animals-dinosaur.

Near Earth Object are also proposed by scientists as one of the most possible explanations of the extinction of water and organic matter on the Earth. They may also have plentiful reserve in rare material which is eyed by many corporations. Currently, the information and research toward near earth object was obtained by the observations with the telescope on the ground and the asteroid sample founded on the Earth which lead to the limitation of the variety of these Neos. There are only three founded space mission on researching celestials. Between 2001 to 2002, NASA's NEAR Shoemaker spacecraft [4] have remained in the orbit of the S- type planet 433 Eros with 23 kilometres in diameters. The image sent by this spacecraft shows some features of this asteroid. The little number of small craters could be explained by the earthquake caused by huge collisions which will redistribute the surface. In 2005, the Hayabusa spacecraft [5] launched by Japanese Space Agency have prospect the near-Earth asteroid 25143 Itokawa. The image suggest that Itokawa is a low-density asteroid with plentiful holes. Moreover, the relation between the smooth area and the low gravity area also shows that there are large-scale movement. In 2012, the Chang'e 5[6] launched by China visit the asteroid Toutatis after collecting and analysing the sample on the moon.

1.3. Near Earth objection classification

Considering that Near-earth objects is a population with consistent evolution and change, their lifetime are limited to a fem million years. Eventually, they will end up themselves in sun-grazing state or being ejected by the solar system while only small part of them will collide with terrestrial planets[7]. Because of the short dynamic lifetimes of Neo's orbits and increasing number of Neos been founded, there must have a continuously supplement from several major places filled with huge amount of pieces of celestials where are mostly founded in the belt region of Jupiter and Saturn.

According to the orbits element[8], near earth objects are divided into groups based on their semi-major axis (a), perihelion distance (q) and aphelion distance (Q):

Atiras group: the orbits of asteroids in this group are inside the Earth's orbit. The Atiras asteroids have smaller values of aphelion distance (Q) compared to that of Earth which shows that Q<0.983AU. it could be also concluded that their semi-major axis(a) is also less than 0.983 AU.

Atens group: the orbits of asteroids in this group come across with the Earth's orbit and have a semi-major axis of less than 1 AU. a < 1.0 AU and Q > 0.983 AU in mathematical ways.

Apollos group: the orbits of asteroids in this group also come across with the Earth's orbit and have a semi-major axis of more than 1 AU. a < 1.0 AU and Q < 1.017 AU in mathematical ways.

Amors group: the orbits of asteroids in this group are in the outside of the Earth's object. Their perihelion distance is greater than Earth's aphelion distance. Therefore, 1.017 AU < q < 1.3 AU considering that they are Neos(<1.3AU)

In terms of physical properties, Neo population have a huge variety. As observed by radar observations and light curve inversion, many objects, like Itokawa, have very long elongated shaped or complex, non-principal axis rotation states. It is very common to see binary systems among Neos that

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have been found (up to 15%of the total population). Different types of spectrums found within the population also emphasize the diversity of Neos. DeMeo et al have recently classify the Neos according to the visible and near-infrared spectra. Neos are divided into three major group(S, C, X-complexes) and several other fraction. S and Q-type asteroid have the features of poor-volatile and silicon- constituted and are dominate among Neos since they constitute 70% of the Neos' population while C-type asteroid only constitute 20% of it[9].

Preliminary relationship between asteroid groups and petrologic types of meteorites have been established based on the their spectrum and albedos. Different petrologic types of meteorites have undergo different thermal history. C-type carbonaceous chondrites are suppose to be more primitive while S-tpye and X-tpye have undergo specific thermal revolution. For instance, the rock sample which Japanese JAXA Hayabusa spacecraft bring back from Itokawa has dust particles which is similar to thermally metamorphosed metal-poor ordinary chondrites which suggests that Itokawa are S-tpye asteroid[9].

2. Nuclear explosion as means to deflect asteroid

2.1. Nuclear explosion as means to deflect asteroid

2.1.1. Information about nuclear explosion. Explode nuclear devices above, on or beneath the threaten asteroid could be a potential option of deflection while the optimal denotation height depends on the size and the composition of the asteroid. However, it is not necessary to evaporate the whole celestial to decrease the threaten. Due to strong force, it could be the most efficient way to transport energy by nuclear bomb in the future which is one of the most important focus of space travel. Nuclear explosion devices are a mature technology with operational space experience. A nuclear explosion could destroy or deflect an asteroid by transmitting energy in the from of neutrons and X-rays [10]. They will not appreciably penetrate the materials. When they encounter with the surface, they will transform into the thermal energy which will turn the materials up into the ejecta that is similar to the chemicals rocket engine exhaust. According to the Newton's third law, the object will be propelled in the direction which is opposite to the direction the ejecta released. Therefore, because of the rocket exhaust effect caused by the energy of the nuclear devices and the high speed of the vaporized ejecta, combined with the small reduction in the overall mass of the asteroid, it could be possible to make enough change in the orbit of the objects to make it miss the Earth. The greatest uncertainty for the their degree of effect is the range of asteroid compositions and structures. After nuclear explosion, the asteroid could be deflected from its original orbits which will intercept with the earth. The asteroid could also be broken into plenty small fraction which do not intercept with the earth or will be destroyed by the earth 's atmosphere during the collision[11][12]. Comparing to other methods like kinetic impact or gravitational tractor, it could save a lot of times since it is short-term. Overall, in terms of nuclear explosion device, there are two different types of methods:

(1) Stand-off approach[13]:

Its mean purpose is to intercept and change the trajectory of the comet by exploding the bomb at a height of 20m or greater. It is estimated that it will be 20-100 times more effective than normal bomb. Stand-off approach nuclear bomb produce a momentum in the direction which is opposite to the original comet's direction by depositing energy in the asteroid which will evaporate or spall the material because of the rapid thermal expansion in terms of neutrons and X-rays. Materials that buildup the comet like rock and ice could sublimate under these high temperatures and flew away from the whole body due to the loose overall structure.

(2) Subsurface and Surface explosion[13]:

Its mean object is to intercept and change the trajectory of the comet by colliding the nuclear bomb with the comet at a high-speed status. The key technologies and features is the creation of a conceptual Hypervelocity Asteroid Intercept Vehicle. The technology could enable the nuclear bomb to collide with the comet to form an initial crater without explode. When the nuclear bomb is at the depth of 1m to 10m,

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the explosion of the bomb could maximize the impact of it. The instantaneous strong energy is enough to make it form earthquakes and aftershocks inside the comet which could collapse its internal structure.

2.1.2. The concept and function of HAIV. During 2011 to 2014, NASA Innovative Advanced Concept (NIAC) have proposed studies titled "An Innovative Solution to NASA's Near-Earth Object (NEO) Impact Threat Mitigation Grand Challenge and Flight Validation Mission Architecture Development" whose major function is to destroy hazard Neos. This NIAC study have concluded a concept called HAIV which could be applied on both kinetic impactor and nuclear explosion devices. The mission of HAIV is to eliminate the threaten of Neos that could come across with the Earth orbit by giving the spacecraft a most effective and safe method to come close to the object comet and destroy it. It could be hard for any object to reach and have a rendezvous with a comet that most of them could reach the speed of more than 10-30km/s. In order to maximizing the effect, the explosion, most of nuclear bomb would choose to explode at the depth of 3-5 meters of the comet which would transmit huge energy to the asteroid whose effect is 20 to 30 times more useful that explosion without contact. However, currently, human could make the bomb useful under a maximum of 300m/s impact velocity so far. Any velocity greater than these could destroy the fusing mechanisms easily while the actual velocity is much greater than the capacity. Therefore, HAIV this concept could enable bomb to achieve this which is penetrate comet under huge velocity. HAIV is a double spacecraft system with a fore leader and an aft follower. The leader would emit first which will collide with the comet and form a crater on the comet. After that, the follower which usually be the nuclear bomb would fly to the crater and explode underground without being destroy.[14]

The experimental design of HAIV have been demonstrated in. This HAIV system is consists of the vehicle' leading impactor, the 10-meter AstroMast boom and the follower portion of the vehicle in terms of the nuclear bomb. This interval design ensure that the impactor and the follower are linear and provide appropriate delay after the impactor collide with the comet.

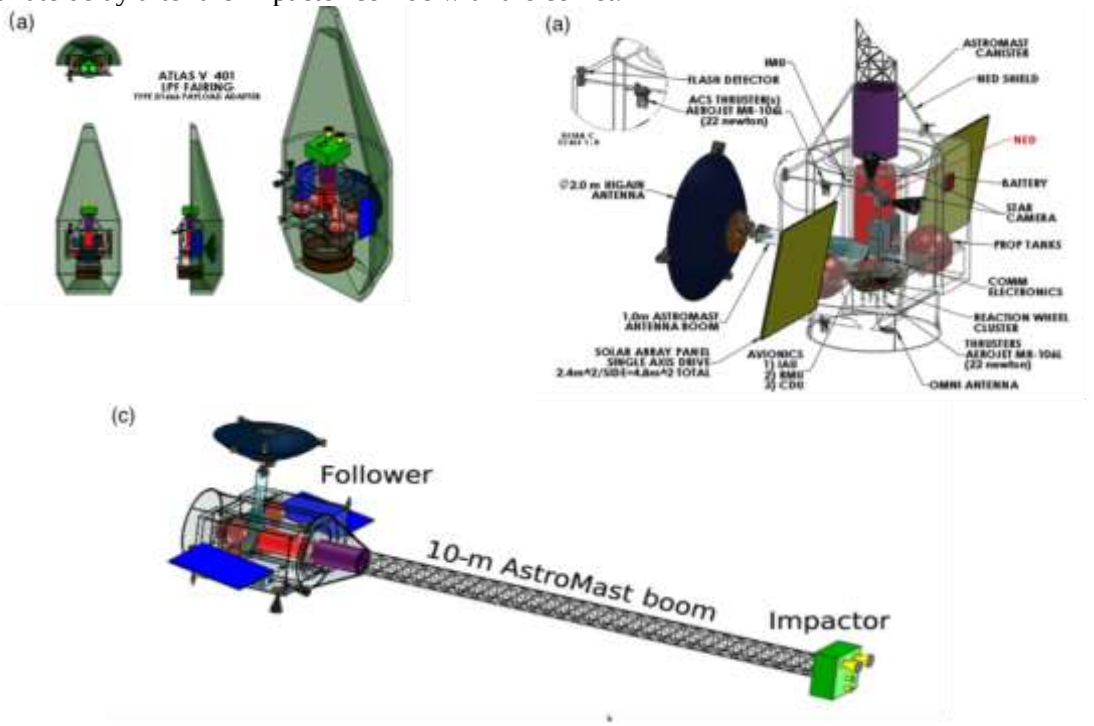

Figure 3. Design of the Hypervelocity Asteroid Intercept Vehicle (a)Leading Impactor (b) Follower (c) 10-meter AstroMast boom [15]

2.2. Example and concept of use of nuclear explosion

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In terms of Stand-off approach, NASA's Marshall space Flight Center has designed a nuclear-warhead-carrying spacecraft, to be launched by the US agency's proposed 's Ares V cargo launch vehicle, to deflect an asteroid that could threaten all life on Earth. This long "Cradle" spacecraft long 8.9m and could carry six 1500kg (3,300lb) missile-like interceptor vehicles that would carry one 1.2MT B83 nuclear warhead each, with a total mass of 11,035kg. This spacecraft would leave the Earth's orbit with 45359Kg liquid-Oxygen fuel. The Near-Earth object Target for this spacecraft is Apophis Asteroid which will pass the Earth within the orbit of Moon in April 2029.

Students from MIT have also proposed plan about Deflecting Asteroids from impacting Earth. Their research object is the Asteroid Icarus. Icarus, a large asteroid that will across Earth's orbits for every nineteen years, have probabilities to threaten the Earth. If this comet collides with the Earth, the consequence will be huge that one mile wide asteroid impact would equal to 5hundred thousand megatons whose dust might cause the Ice Age again. In order to prevent this, students have proposed possible solution toward this. The most ideal solution is to rendezvous the comet when it reaches aphelion which is the slowest of its orbit. This point enable explosion to change its direction. It has been founded that before 1967 when the comet reaches its lowest velocity, there do not have any spacecraft could conceivably meet with it or even a soft landing because of its tremendous speed. The method that could enable Icarus to get maximum bomb is to send the bomb with modified Saturn V into the orbit. Later on, the bomb will shed from the main body and its service propulsion system engine would work in order to let it to get to the Icarus.

The Icarus plan actually required nine Saturn V. In addition to the Saturn V, it is also required that modified versions of Mariner 2 deep space probe, known as Intercept Monitoring Satellite (IMS), are needed to send into the space. In the February of 1968, the First IMS were sent into the space to detect the Icarus. A month later, Interceptor one, with 33 million newtons of thrust, would rotate the Earth orbits and accelerate to go to the comet[16].

In terms of surface and subsurface explosion, there have examples of the use of Hypervelocity Asteroid Intercept Vehicle(HAIV). NASA' LCROSS moon crash plane had test this technology. NASA's probe and its fuel- depleted Centaur rocket stage crashed into the large crater in order to kick up the moon's surface dirt which enable scientists to see it there is water ice. This research provide the initial evidence of the ice water in the moon's crater.

2.3. The disadvantages of using nuclear bomb as asteroid defense

2.3.1. Current literature. Several current literatures have shown the potential trade-off of the existence of the methods of using nuclear bomb as asteroid defense. Gerrard and Barber [17] have stated that "it seems obvious that it might cause massive distinction to threaten for the deployment of nuclear weapon launching system to exist in the country such as Russia, USA, China. Compared to this consequence, it seems unnecessary to use this system to destroy an asteroid which rotates around the Earth for a long period and do not have absolute threaten to Earth." Remo [18] concluded that "nuclear deflection might promote another nuclear military race whose threaten to people living on the Earth might be higher than it of the asteroid." Sweet[19] postulates that "the threaten that the nuclear systems want to eliminate might be much smaller than itself in terms of constituting threaten to human beings" Graham and Schweickart [20] argue that the probability of the asteroid that need to be deflected by nuclear bomb is extremely low which is unable to be calculated and it is not very important to use nuclear bomb as means to deflect the asteroid. The current estimation of the effectiveness of the nuclear bomb has not compared it with the Impact of risks posed by nuclear weapons. However, Remo [21] suggested that the nuclear deflection decrease the long-term risks of the human civilization since it is inevitable to meet the collision of the large Near-Earth objects in such a long scale of time period. Human survival indeed need an effective Neo deflection mechanism. Eventually, Baum [22] thought that the benefits of using nuclear deflection to decrease the risks of Neos' impact do not exceed the negative influences of nuclear war unless nuclear deflection is managed by international organization.

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2.3.2. Violent nuclear conflict. So far, there are nine countries who have the ability to make nuclear bombs and have nuclear bombs. About 90% of these nuclear bombs are produced by Russia and American. China, India, France, England, Israel and Pakistan have an average range of 80-100 nuclear weapons. Although it is far less that the summit of the number of nuclear weapon in the cold war, it could still cause huge risks.

It could be even harder to determine the probability to of violent nuclear conflict because of the complex and dynamic social factor, compared with the probability of the asteroid collision. Since the world's first nuclear bomb has been invented in 1945, there are only one times that the nuclear bomb have been used into the wars which is the bombs with nicknames "the fat" and "the boy" being thrown in Japan. People cannot briefly conclude that the probability that nuclear war will happen in a year is 1/76. For instance, nowadays, the nuclear bomb storage is very huge in some countries compared with the second world war which will increase the risks of nuclear war. The current instable relationship between Ukraine and Russia could also increase the probabilities[23].

However, since the nuclear deterrent have existed, there do not have any nuclear war since there do not have any winners in the war such as this. There are also several misses. For example, during the Crisis of the Cuban Missile, a Soviet submarine nearly approach to launch the nuclear bomb if an crew do not stop it. This "imprudence" alarm the world that the nuclear war might be aroused by other reasons seemed impossible.[24]

2.3.3. The possible threat to earth after deflecting using nuclear bomb. Except the political effect, the impact of exploding a nuclear bomb in the space could also affect people living on the Earth. The impact of nuclear bomb on the Earth, as most of the people known, could destroy thousands of miles away from the explosion places. The transmission of heat and radiation could kill people within a seconds. It people put it into the space, this consequence could be even bigger. The mushroom cloud as a typical feature of nuclear could be easily seen on the earth. However, in the space, because of the loss of medium such as air, the cloud and the explosion wave which mostly damage the Earth could not be seen. Instead, there are not only huge amount of Gamma rays and X-rays will be released quickly which is enough to lighten the space after the explosion but also the tremendous outpouring of heat wave and light. Without the interference of atmosphere, their emission route will not be disrupted. From vision, the explosion is sphere-like. After several minutes, people could see beautiful while harmful auroras since the electron-charged particles form the blast will start to collide with and wear down the Earth's magnetic field. Moreover, the electromagnetic signals on the Earth could also been disrupted or damages. The wastage of the Earth magnetic field have several impacts such as the loss of navigation ability of animals that might cause massive distinction, the penetration of more harm universal radial, the massive failure of power station, broadcast and satellites. The highly charged electrons with high speed would create a powerful magnetic field which could also be called as EMP(electromagnetic pulse)[25]. As a wave of electromagnetic radiation, EMP often rains down on the buildings and those electrons interact with the conductive materials inside the wires and causes power strikes. Although EMP will not directly harm human body, such a large EMP caused by nuclear bomb in the space could damage broadcast facilities, power station, communication devices such as smartphones, internet service and so on. It could also destroy all the satellite or space station within the range of the EMP. This damage could be considerably huge since the shutdown of all the outer space research under the situation of having several potential hazard asteroids eliminate the possibilities of the success of other possible method against the asteroids such as kinetic impactor or gravitational tractor[25]. It is not a reasonable trade-off.

Although a lot of experiment of nuclear bomb have been held in many places, there are only several of them which have been tested in high places. Starfish Prime is one of the them. Starfish Prime[26] was an experiment about high-altitude nuclear test conducted by United states. It is an joint effort of the Defense Atomic Support Agency and Atomic Energy Commission. One W49 thermonuclear warhead was carried by a Thor racket and a Mk.12 reentry vehicle and was launched at the Johnston Atoll in the Pacific Ocean. The final explosion took place at an altitude of 400 kilometer which is close to the nowadays International Space Station's orbits. The yield of this bomb have 1.4 Megatons. The impact

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of this explosion in the form of EMP is highly bigger that expected which is hard to estimate and cause a lot of equipment to be damaged. The human-lived places that have been effected the most is Hawaii, about 1450 km away from the detonation point. The electrical damage caused by this EMP in Hawaii included the shutdown of telephone lines from Kauai island to Hawaii islands, damage of microwave link in a telephone company, destroying about 300 streetlights and setting off numerous burglar alarms. About six satellites lose the connect[27].

In the next space, the successful rate of using nuclear explosion devices as means to defense earth from the asteroid need to be queried. The shape of the asteroid could determine whether the asteroid could absorb enough energy and break into several fractions. One of the most important features of the asteroid is that they are porous or nonporous. It is generally believed that spalling or evaporate will pulse the asteroid if the surface material of the asteroid is nonporous while it must require the energy density to reach enough extent to produce evaporation on the asteroid if the surface material is porous. However, especially for porous asteroid, when the energy density is relatively low, the increment of energy density because of the less mass may make it easier to increase which will cause evaporation. As a conclusion, the surface material could determine the effectiveness of the nuclear bomb.

Secondly, it could also be possible that the nuclear explosion could accelerate the frontier part of the fraction which enable it to collide with the earth and bring a greater impact and increase the area influenced by the asteroid due to the broken pieces of the asteroid.

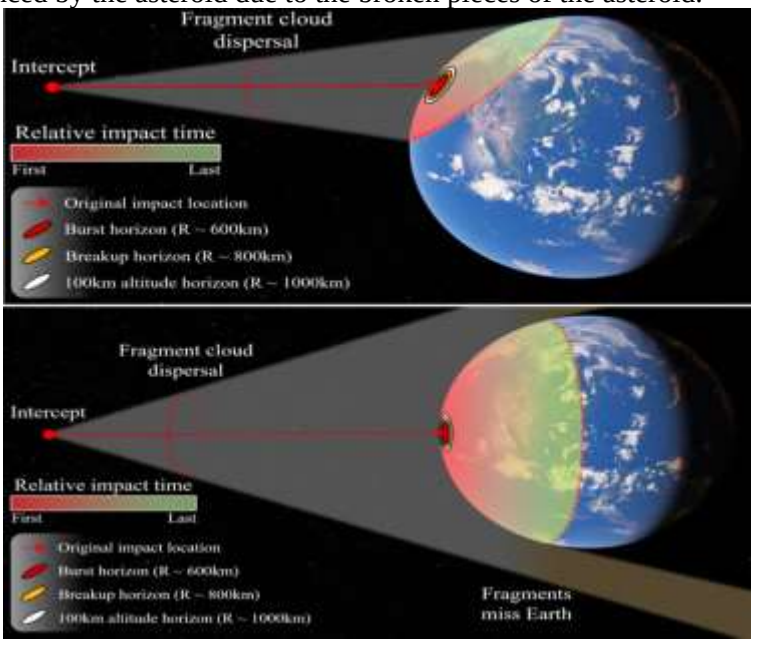

Figure 4. The diagram shows the Projection of the fragment cloud onto the surface of the Earth. The superimposed color scale shows the distribution in impact time as a function of the impact location. [28]

The graph shows the possible estimation of the impact area of the asteroid after being intercepted. It could be clearly know that the original impact area is much more smaller that the latter impact area. After explosion, nearly of the earth have the dangerousness of asteroid because of the distribution of the fraction of it. The relative impact time is determined by the distance between the places and the location of asteroid. Therefore, before deciding to use nuclear devices, scientists need to calculate the original and after-explosion casualties to test if it worth to use the nuclear weapons.

Last but certainly not least, the actual situations in the space is much more different than that in the films. It is not that easy to send a nuclear weapon and explodes it like what has been shown in the film. Currently, although people have the idea and design of Hypervelocity Asteroid Intercept Vehicle(HAIV), it still need a lot of time to really achieve it in the dramatic space station. Without the help of HAIV, there do not have any equipment that could steel maintain its function under immediately deceleration and destruction when a direct intercept impact penetration occurs up to now, as the nuclear bomb do. Human have not invented any synthetic materials that could withstand the penetration with more than a speed of 1 km/s and assure the original integrality. Moreover, the currently invented

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penetrator that can withstand relatively high impact speed do not have the function of equipping internal nuclear bomb. For example, B61-11 is an earth penetrator that could withstand 0.5 km/s impact speed. It will lose effectiveness when colliding with an asteroid with a speed of 10km/s. Furthermore, because of the limited prospecting ability, it is steel possible that the nuclear devices may lose the direction. In other word, it may not being explode at right places and cause deflection[28].

3. Kinetic impactor

3.1. Basic information

Kinetic impact will deflect the asteroid by means of sending one or multiple high-speed spacecraft into the orbits of the objects which would change its original trajectory and push it away from the Earth's orbits. NASA have accomplished the mission of Deep Impact in 2005 and the DART. If the kinetic impact have been fully prepared that they could be lunched at any time, the National Academy of Sciences alarm that there must have a warm time of at least 1 to 2 years. In the circumstance of the detection of a approaching asteroid tomorrow, the process of building and launching an impactor, reaching and impacting the asteroid and nudging it from it own orbits successfully would require for more than 20 years. For asteroid whose diameter is hundreds of kilometers, it would require decades or more. The mission that study the asteroid and seend bahc information about the asteroid would increase the success rate it the time allows. It might not be very effective when changing the orbits of very big asteroid[29].

3.2. Example of applications of kinetic impactor

3.2.1. Deep impactor. Deep impactor is a space aircrafts and probe which is launched from Cape Canaveral Air Force Station by NASA on January 12, 2005. It was designed to research the internal composition of the asteroid called Tempel 1.The main purpose of this impactor is to answer basic questions about the asteroid internal materials including the composition of the comet, the depth of the crater could be on the asteroid caused by impactor and the derivation of the asteroid. Scientists would like to compare the differences between the surface materials and the internal materials of the asteroid in order to clearly identify the formation of the asteroid by the observation of the composition [30].

Figure 5. The image of the Deep impactor compare to a person [30]

This spacecraft is mainly consisting of the "Smart impactor" which is made of copper core that weight about 372 kilograms and will impact the comet and "Flyby" section which will image the comet from a safe distance during the impact. It has two solar panels, a debris shields and multiple scientific instrument whose function includes imaging, infrared spectroscopy and optical investigation which will locate the nearest asteroid. This spacecraft also carried two cameras which is high resolution imager (HRI) and middle resolution imager (MRI). The HRI is the combination of visible light camera and an imaging infrared spectrometer on a spectral band of 1.05 to 4.8 micrometres. The impactor is mostly

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made of cupper whose mass is 49% of the total mass. The reason why to choose this material is to reduce the interruption on scientific measurement since copper could not be found on that comet. When analysing the comet, scientists could ignore any data related to the features of copper. After being launched, the spacecraft have filed for more than 429 million kilometres and spent more than 174 days to reach the comet. The impactor section use its thruster to more into the orbit of the comet and collide with the asteroid with the relative speed about 10.3km/s whose kinetic energy is more than 1.96×1010 joules that equals to about 4.8 tons of TNT[31][32].

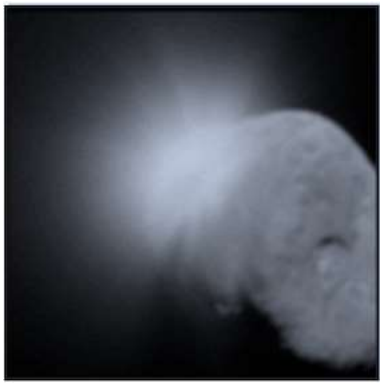

Figure 6. Image shotted by Deep impactor during the mission [32]

3.2.2. Double asteroid redirection test (DART). Double Asteroid Redirection Test (DART) was a space mission conducted by NASA whose aim is finding a possible defence toward NEOs' impact. The spacecraft was launched in November from the Earth, the propose of this mission is to deliberately send a spacecraft to let it crash to the minor-planet moon Dimorphos of the double asteroid system Didymos. This research could access the potential possibilities of the future plans of deflecting asteroids by knowing the momentum the spacecraft make and the deflection that the asteroid has [33].

The spacecraft of the DART is an impactor with 610 kilograms with no scientific payload and only navigation sensor. The sensor include a star tracker called SMART Nav software, Asteroid Camera for Optical navigation (DRACO), a aperture camera with 20 cm size and a Sun Sensor which detect the position of Sun. DRACO is based on the long Range Reconnaissance Image(LORRI) and support autonomous navigation in order to find the right position of the asteroid's moon in its centre. Its optical parts are a Ritchey-Chretien telescope with telephoto lens whose field of view is 0.29 degree and focus length of f/12.6. the CMOS type probe have 2560*2160 pixels. The wavelength that the sensor record could be 1.4 mm to 1mm. DART spacecraft was equipped with NEXT ion thruster whose impulse is three times as powerful as the NASTER thruster used on the Deep Space spacecraft and is a kind of solar electric propulsion. It is charged by solar arrays with a surface area of 22m^2 that could generate 3.5kW which is needed to initiate the NASA Evolutionary Xenon Thruster. DART spacecraft is also the first spacecraft that use the new type of high gain communication antenna with a frequency of 7.2 GHz and 8.4 GHz. The other parts of the spacecraft are the LICIACube designed by Italian which is equipped with two optical camera whose function is to observe the asteroid during the flying phase.

The target asteroid is the Dimorphos in Didymos system which is a binary asteroid system in which one asteroid is orbited by a smaller one. The main asteroid whose name is Didymos A has a diameter of 780 meters. The moon asteroid whose name is Didymos B has a diameter with 160 meters and is 1 kilometer far from the main asteroid's orbit. Start from the 10 November 2021, the engineers combined the Spacecraft with adapter which stacks on the top of the SpaceX Falcon 9 launch vehicle. The DART spacecraft was launched on 24 November 2021, at 6:21:02 UTC. The launching site was located into a high latitude and high eccentricity Earth orbit in order to avoid the moon. In the first stages, the DART spacecraft escaped from the high orbits of the Earth by using low thrust and high efficiency NEXT ion engine. In the second stage when the second thrust was initiated, Falcon 9's second stage was placed directly on the Earth escape trajectory. Ten days before the impact, the LICIACube was released. Four hours before the impact, the DART become completely autonomous and activate the SMART navigation system. Eventually, the result shown by the LICIACube demonstrate that the impact of 500

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kilograms DART spacecraft at the speed of 6.6 km/s cause 0.4 mm/s change in speed of Domorphos and change the orbit of the binary system slightly. It might be bigger and bigger in the long run. It has been estimated that the orbital period have been decreased for ten minutes while it is currently 11.92 hours [34].

4. Gravity tractor

4.1. Basic information

Gravity tractor, as a theoretical spacecraft, have been proposed as one of the means to deflect objects especially potential hazard asteroid without any physically contact. The Gravity tractor need to thrust the objects in the direction that is horizontal to the objects' original direction to force it deviate the original path. Both the vehicle and the expelled reaction mass would not need to come into contact with the asteroid. It use the gravitational field to transmit its impulse. Although the impulse transmitted is relatively small, the gravity tractor could indeed change the direction of the asteroid if the spacecraft could work at there for a long period. By using this methods, scientist do not have to know the internal composition of that asteroid while only need to know the mass of it[35].

4.2. Advantages of gravity tractor

There are some determination factors on the collision between the asteroid and the asteroidal objects when exact day has been known that the asteroid will collide with the Earth. One of the main challenges is how to transmit impulse to an unknown-mass, unknown-composition and unknown-mechanical-strength asteroid rather than remaining its particles in its original orbits. By using gravitational tractor, through accelerating the whole object slightly in long period by the using spacecraft its' own mass and gravitational field to provide necessary deflecting force, this problem could be solved. The asteroid have very little probability to break into several part since the asteroid move almost uniformly as a whole. Furthermore, by continuously monitoring the velocity and position of the traditional tractor and the asteroid system, the orbits of asteroid after deflection could be estimated relatively easier.

4.3. Limitation and disadvantages of gravitational tractor

Considering that that gravitational tractor changes the direction of the asteroid slightly in long period, it could cost several years for spacecraft to do it while except the time for planning, launching and flying. It would require human to detect the Neos at a certain time while it might always happen. The detection technology of human is not able to do this. This method is definitely not feasible when human detect an asteroid that will collide with the earth in several months. Secondly, during these long periods, it might consume huge amount of energy which would use up a lot of limited space in the spacecraft if people do not find a alternative less-space energy source. Last but not least, the former astronaut have told the American Geographical Union that there are some unpredictable negative impact for using gravitational tractor. With the change of the asteroid's direction, the risk corridor which shows that impact area of the asteroid would move along a horizontal plane. There is not any country or any organization that could determine the routine of this risk corridor which will let other countries to face the disaster that they originally do not have. No country would like to accept this effect.

5. Ion beam

5.1. Basic information

Considering several important limitations of the gravitational tractor which is less scientific payload and huge expenditure for sending the spacecraft proposed in 2005 by Lu and Love[35], scientists have proposed another possible method which is ion beam shepherd. Ion beam shepherd is a concept spacecraft that would create a force or a torque on the asteroid by using a beam of quasi-neutral plasma impinging against its surface. The ion and plasma thrusters that have been usually used in spacecraft thruster could be used to generate ion beams or collimated plasma. The ion bean produced by the

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spacecraft can act on the objects without a physical attachment. This energy generated by the ion beam have been accelerate at the speed of 30km/s in the past experiment and can achieve the identical magnitude that would be obtained if the object had the same ion thruster mounted on its own structure. This technology could also be used to clear the space trash or space debris[36][37].

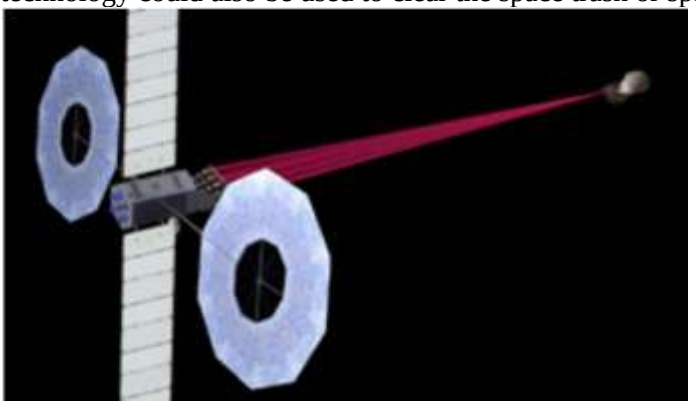

Figure 7. Design of DE-STARLITE spacecraft deflecting an asteroid [36]

5.2. Design of ion beam equipment

The purpose is to design a system that could enable the spacecraft to emit a laser whose diameter could be 1meter to 4.5 meters and reach the Neos in order to destroy it or deflect it from its original orbits. The whole system includes photovoltaic panels, ion engines, laser array, and radiator. The energy required for propulsion to optimal orbits and luach laser could be achieved by a high-power solar electric propulsion system. The photovoltaic panels could transfer sun light into the energy needed for the system. Them will be packed up at the launching stage and will deploy upon when the spacecraft reach the near-earth orbit. More than 100kw electric power could be provided by the photovoltaic panels. The ion engine will propel the spacecraft from the near-earth orbit to the position of Neos. The laser efficiency directly determine the power obtained from the panel arrays: the 35% efficiency will have 35kw of laser power , 50% efficiency would have 50kw of laser power and 70% efficiency would have 70kw power. The radiator will maintain he internal temperature of the spacecraft at 300K to prevent the damage of equipment[38][39].

5.2.1. Photovoltaic panels. The photovoltaic panels arrays will use two 15m diameter MegaFlex PV arrays, manufactured by ATK Aerospace Systems in Goleta, CA that would generate about 100kw power. The MegaFlex technology have already experience intensive test and MegaFlex arrays have relatively high Technology Readiness Level (TRL)[36]. The panels have been shown below.

Figure 8. The overall design of ion beam shepherd including the photovoltaic panels[40]

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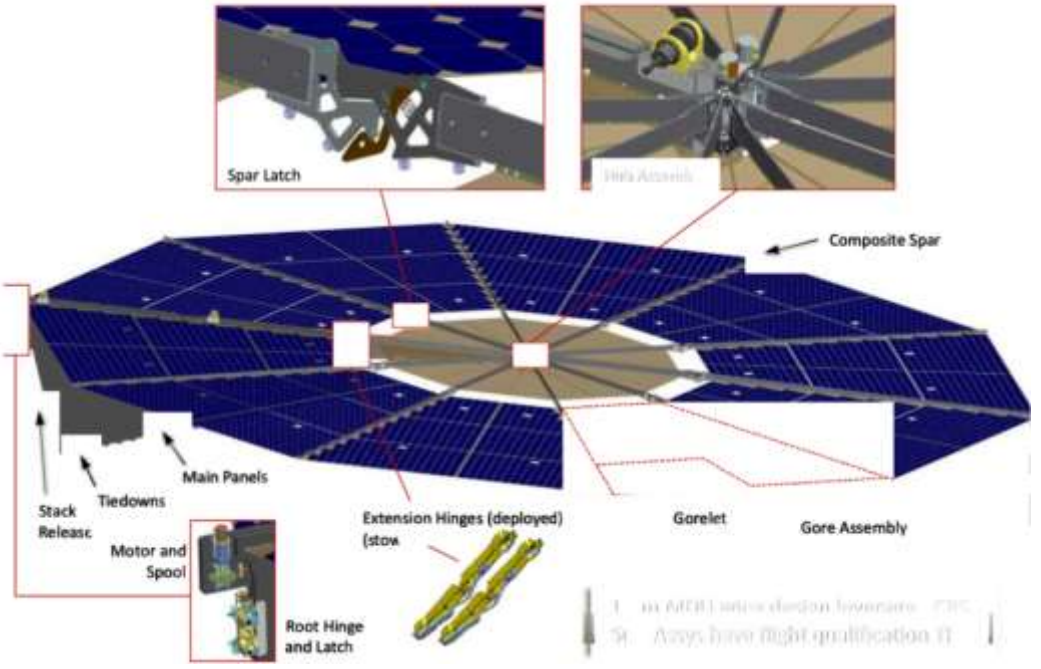

Figure 9. Details of the MegaFlex PV arrays[41]

5.2.2. Ion engines. DE-STARLITE is created with high-power solar propulsion(SEP). the spacecraft carrying DE-STARLITE will absorb energy gained from the solar panels and utilize it to ion propulsion to send out laser form the near-earth orbits to the target. Considering that ion engines are usually five to ten times more efficient to the engines that use conventional chemical propellant, ion engiens have been proposed for the DE-STARLITE[41].

5.2.3. laser array. The function of laser array system is to project a large enough laser to the surface of the object asteroid through a highly focused coherent beam in order to heat the constituent materials which is mainly composed of rock to the vaporization point. These temperatures are often 2000-3000K or have an energy density of 10^7W/m^2. The mass ejection due to the huge energy could deflect the asteroid's trajectory by reactionary thrust. In order to produce a large enough laser, this system must focus adequate beams and sufficient power. The spot size of 10centimeters or so could provide sufficient energy to let the rock to reach the sublimation point form a distance of 10 kilometers. Beam convergence have been affected by several factors including efficacy of adaptive optics techniques, pointing control and jitter, and optical aperture size. As what mentioned before, the optical energy output of the laser is estimated to be between 35kw and 70kw which is determined by the human technology of the laser amplifier efficiency. Currently, the efficiency of the amplifier is about 35% and it is estimated to 50% in the 5 years. The beam's efficiency have already exceed 50% for the non-phased-locked fiber focal plane array. The high efficiency is very important since it enable the laser to give the target a more big propulsion at. A fixed electrical input while with smaller mission mass and radiators[41].

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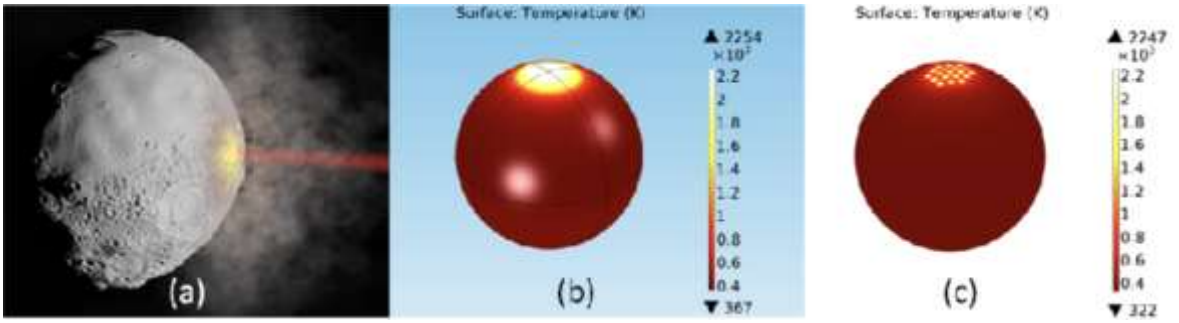

Figure 10. Heating analysis on a asteroid suffering ion beams[36]

The proposed optical system is consist of 19 basic optical element in the phased array. By utilizing an array of phase-locked laser amplifiers, the advantage is significant that it is achievable to larger systems since it is completely modular. Compared with a closed packed array which only include a single element, it has a larger range. By controlling the action of each individual elements, it could be easier to control the focus of laser and the steering of beam. Each element have been installed on a micro-positioner hexapod with 6 axis. The DESTARLITE spacecraft could be equipped with laser array within 1 to 4.5 meters. Because changes in aperture would not change the power of the laser, the radiator and solar arrays might have the same magnitude. New constraint will not be created in the difference between 1 and 4.5 meter arrays[41].

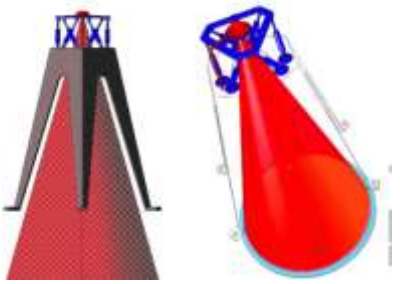

Figure 11. image of a single basic optical element [41]

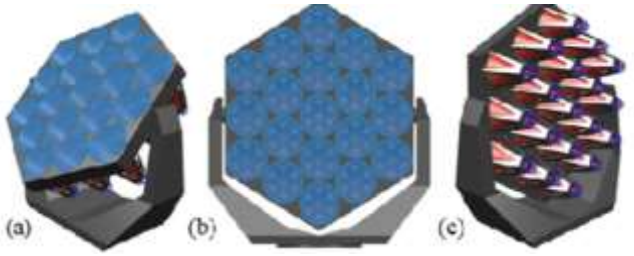

Figure 12. optical system consists of 19 optical elements [41]

5.2.4. Radiator. Radiator is one of the most important components in this system whose main function is to maintain the spacecraft and its component at the functional temperature and minimize the incident radiation. It could maintain the temperature at 300K that the laser and other control electronics are operational. In this situation, the radiator could be isolated about 408W/m^2 idealized outward flux. Considering the incident radiation, the radiator could allow 190W/m^2 net flux of energy to across its surface by using 1362W/m^2 of solar constant and the maximum light-absorb efficiency of 16%. The surface area of the radiator depends on the operating temperature, surrounding heat and probability of colliding with other spacecrafts and must be determined by thermal analysis. Furthermore, the worst cases that is the highest estimated satellite heat should also be considered. These is also depends on the efficiency of the laser amplifier. Therefore, the worst case will be the efficiency of 35% which will have the waste heat of 65 kW in 100 kW. Given these numbers, laser amplifier with the efficiency of 35%

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require 341m^2 area of radiators while laser amplifier with the efficiency of 50% only require 341m^2 area of radiators. We proposed to use cooling. Liquid or advanced heat pipes to transfer heat from the amplifier to the radiator. In order to provide a sufficient area for the radiators, a passive folded radiator which is Z shape and is consists of two deployable panels could be used. These panels will rotate around their axis so that they could increase the efficiency of cooling by being perpendicular to the sunlight[41].

5.3. Mission analysis for the 2015 PDC of ion beam deflection plan

5.3.1. Background information. On the 2015 planetary defense conference (PDC) in Italy whose aim is to have discuss on stimulating ideas on how to reduce the threat of asteroid and supporting an emergency response exercise, several scientists have proposed a hypothetical scenario of asteroid impact. There are several potential influences for the fictitious asteroid with 150-400 diameters. It has been estimated that the colliding probability would reach 1% in the middle term of June in 2015 and will reach the highest in the 2022. A nominal impact point has been found at the South China Sea which is 500km or so off the Vietnam coast at around 03:52:10 UT. The asteroid will impact with impact velocity of 16km/s at 56° form the surface. Considering the error of the asteroid orbit, the path of risks would be stretch from the eastern Turkey to the mid Pacific Ocean which across the area with high people density. Considering this potential huge impact of asteroid, the primary goal is to send a spacecraft to rendezvous with the asteroid in order to reduce the uncertain factors by collaborating with the asteroids' orbit. Analysis its influence is also one of the important parts of predicting the impact. It is very difficult to warrant deflection on the open sea since it is not possible to generate tsunami for a monolithic asteroid with diameters that is less than 500 meters. On the other hand, impact that occur inside the area whin 100km from the high-people-density places or coastline would bring huge disaster. The cost for building underground shelter might be higher than the cost for spacecraft.[42]

5.3.2. Launch mission design. Given that the high probability of the colliding estimated in the mid-term of June in 2015 and the lack of observation toward the objective, scientists need to design the plan quickly in order to confirm or rule out the impact by estimate the exact position and velocity of the asteroid. In the design of the rendezvous plan, the most important tradeoff is that whether the selected type of the spacecraft have the ability to deflect the asteroid and make sure it will not collide with the earth whose cost is higher mass and complexity[42].

At the first sight, the nuclear devices is not a reasonable choices since its complexity is too high. However, other methods such as kinetic impact and gravitational tractor will not deflect the asteroid very efficient or very successful even if the impact time is longer since they would cost so much time. Therefore, the method must have the ability which is transferring large amount of the energy at a short time. The contactless ion beam shepherd would be the best choice: it could effectively deflect the orbit of the objective without contact the surface area which decreases the use of complex technology. Eventually, the spacecraft would equip with the ion beam shepherd system and bring enough fuel in order to accomplish the deflection mission of such size asteroid for the tasks analyzed in this conference. Because the asteroid need to be tracked as soon as possible while giving the spacecraft enough time to have effective deflection, the trajectory of the spacecraft must be deigned as the fastest. The high specific impulse and low-thrust trajectory means that the required power would be very rigorous. The Dawn-type 11kW power subsystem have been proposed as the preliminary design whose is mass is about 200 kg. At the relative direction of 180°, there are two sets of ionic thrusters which have the specific impulse of 3500s, thrust efficiency of 70% and thrust ability with maximum value of 200+200mN. Each set of thrusters has 2 redundant unit which each contains four ionic thrusters. The total yield is 9.8kW which is the 90% of the yield of the spacecraft[42].

The mass of the spacecraft have be estimated preliminarily to be 1200 kg with 400 kg of Xenon which is been divided into two parts that 200 kg for the interplanetary trajectory and 200kg for the deflection process. The most favorable routine would consist of the launch in May 28, 2017 and arrival at the objective on Sep 30, 2019 which cost overall fuels of 200 kg. During the expected 2.34 years of

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duration, the trajectory would form the thrust-coast-thrust structure. The first thrust arc will maintain 223 days. The duration of the coasting phase would be 412 days and the last thrust arc would be 219 days[42].

6. Conclusions

Each method (nuclear devices, gravity tractor, kinetic impact and ion beam) have pros and cons. When considering this huge plan to deflect asteroid in the place, several need to be determined in order to know the most reliable plans. The successful rate, cost, time needed and efficiency. Up to now, the most mature technology mastered by mankind is nuclear devices and kinetic impact relatively since they both have idea model and actual experiment rather than kinetic impact and ion beam which are only theoretical. Beside the nuclear devices, the other three methods' successful rate still need to be queried since they may require several times to deflect the asteroid to a acceptable distance otherwise the asteroid would still collide with the Earth. Gravity tractor and ion beam are processes that require long periods. Therefore, scientist would need to find the asteroid ahead of time. However, gravity tractor would require relatively lower energy consumed which would decrease its cost. In terms of rate of energy transferred, it has no doubt on the nuclear devices which could destroy or deflect the asteroid rapidly. Therefore, the nuclear devices would probably be the best choice on the current human technology.

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a distance of one-third of the NEO's diameter and each detonation's X and gamma rays and neutrons would turn part of the NEO's surface into an expanding plasma to generate a force to deflect the asteroid."NASA plans 'Armageddon' spacecraft to blast asteroid". Retrieved 2014-08-03.

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