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(54) METHOD FOR DISPOSAL OF RADIOACTIVE WASTE IN SPACE.

(57) A method for disposal of radioactive waste in space provides for placing the radioactive waste in a cosmic module, launching the cosmic module with the radioactive waste into a near-earth orbit and then transferring it into a heliocentric orbit. The heliocentric orbit of disposal is conjugated with the orbit of one of the selected planets of the solar system, provided that the full revolution period on the heliocentric orbit, corresponding to the time of probable impact of the cosmic module with the selected planet, is no less than the time of decreasing of the radioactive radiation intensity of the waste up to a desired level. The plane of the disposal orbit is inclined to the ecliptic plane at an angle chosen from the condition of the passage of said orbit in relation to the other planets of the solar system at distances no lesser than the gravitation field sphere radii of those planets.

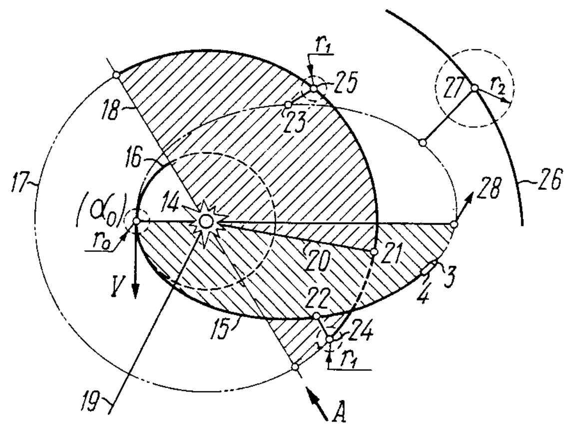

FIG. 5

Field of the Invention

The invention relates to the protection against radioactive radiation, and more specifically it deals with a method for burying radioactive wastes in space.

State of the Art

The amounts of radioactive wastes are increasing nowadays in view of ever increasing use of nuclear power plants and instruments containing radioactive isotopes, and disposal of such wastes presents a tremendous problem.

The protection against radioactive radiation from such wastes is most frequently ensured by burying them in the soil or in the ocean. Thus low-activity liquid and gaseous wastes are discharged for dissolution in water in open water reservoirs or into sea streams, or they are emitted into atmosphere after preliminary dilution with water or air. To dispose of industrial radioactive wastes of a medium specific activity, they are concentrated and then enclosed in special tightly sealed containers which are placed for a long-term storage (tens of years) in so called burial grounds in the form of isolated underground halls (cf. SU, A, 803874). This method for burying radioactive wastes does not, however, rules out their effect on the Earth biosphere during a long-term storage. It calls for substantial technical and financial effort for the construction and operation of burial grounds and does not make it possible to ensure a reliable burial of radioactive wastes (with a high activity) which release much heat to heat the surrounding rocks which is not safe for the environment and may result in a damage to the ecology of the Earth.

Other methods are also known for burying radioactive wastes in space (Jr. Astronautics and Aeronautics, 1980, IV, vol. 18, p. 26-35), which include burial of radioactive wastes on a circular heliocentric orbit extending between the orbits of the Earth and Venus.

This prior art method comprises placing radioactive wastes in a space module and launching to an orbit with, subsequent formation of a heliocentric burial orbit. The heliocentric burial orbit is formed by imparting to the space module two velocity impulses of which the first impulse is imparted at leaving the terrestrial orbit for moving to a transitional elliptical heliocentric orbit, and the second impulse is imparted at this heliocentric orbit at the aphelion thereof for moving to the end circular heliocentric burial orbit.

The above-described method cannot, however, bring a solution to the problem of safety for the Earth because in the event the first velocity impulse is not sufficient or in the event the second impulse cannot be imparted to the space module, there is a risk that the space module can reenter the range of the gravity field of the Earth which might result in the module falling down to the ground.

This method for burying radioactive wastes calls for substantial power consumption because two velocity impulses have to be imparted to a space module, and additional fuel is needed so that the useful load carried by the space module to the burial orbit is reduced.

Summary of the Invention

The invention is based on the problem of providing a method for burying radioactive wastes in space which can ensure launching of a space module containing radioactive wastes to, and retention of the module on a chosen orbit for a preset time period so as to ensure ecological safety of the Earth and preservation of natural environment on the planets of the Solar system while lowering power requirements.

This problem is solved by the fact that in a method for burying radioactive wastes in space, comprising placing radioactive wastes in a space module and inserting it to a near-Earth orbit, with subsequent transfer of the space module to a heliocentric burial orbit, according to the invention, the heliocentric burial orbit is conjugated with an orbit of at least one planet chosen from those in the Solar system for which the period of complete revolution is set forth which corresponds to a time after the lapse of which the space module may eventually hit the chosen planet and which is at least equal to the time during which the intensity of radiation of the wastes decreases to a preset level, the plane of the orbit being inclined with respect to the ecliptic plane at an angle chosen in such a manner that this orbit should extend at a distance from the orbits of other planets of the Solar system equal to at least the radius of the sphere of influence of the gravity fields of such planets.

The provision of the heliocentric burial orbit conjugated with the orbit of a chosen planet allows safety of waste burial to be enhanced as a result of a reduced number of velocity impulses to be imparted to the space module for moving from the terrestrial orbit to the heliocentric burial orbit so as to substantially reduce power requirements for interorbital flights and increases the probability of successful flight of the space module to the burial orbit. In addition, this allows the size of the area of the pre-solar space used for burial of radioactive wastes to be reduced.

The preset full orbital period of the space module in a chosen orbit corresponding to a reduction of intensity of radioactive radiation of wastes to a preset level rules out a premature rendevouz with the planet, whereby safety of burial of radioactive wastes is enhanced.

The inclination of the plane of a chosen burial orbit with respect to the ecliptic plane allows safety for planets of the Solar system to be ensured.

According to one embodiment of the invention, before the space module is inserted into a heliocentric orbit, it is inserted into an intermediate elliptical heliocentric orbit conjugated with the orbit of the Earth, and the space module is then transferred to the heliocentric burial orbit coinciding with the orbit of the Earth from the point of conjugation of these two orbits, the distance from the space module to the Earth being chosen at least equal to the radius of the sphere of influence of the gravity field of the Earth.

This contributes to the ecological safety of burial owing to the use of a ballistically stable orbit of the Earth which is the best studied body in the Solar system, and power requirements for the transfer to the burial orbit can be reduced.

In accordance with another embodiment of the method, before inserting a space module to a heliocentric burial orbit, it is inserted to an intermediate elliptical heliocentric orbit conjugated with the Earth orbit, and this orbit is formed with respect to the Earth orbit as a halo-orbit with the center in the Earth orbit, any point of the halo-orbit being spaced at a distance from the Earth which is at least equal to the sphere of influence of the gravity field of the Earth. Apart from ecological safety, this ensures the possibility of monitoring of the burial during the period the radioactive wastes are retained in the burial orbit, whereby control and correction based on monitoring results are possible to enhance reliability of burial and safety for the Earth.

In still another embodiment of the invention, before inserting a space module into a heliocentric burial orbit, it is inserted into an intermediate elliptical orbit conjugated with the orbit of the Earth and with an orbit of another planet chosen from the Solar system, and the space module is sent along this orbit to the sphere of the gravity field of this planet, whereafter the space module is transferred into a heliocentric burial orbit by carrying out a perturbative manoeuvre in the gravity field of the chosen planet with a simultaneous alteration of the radius of perihelion, eccentricity and inclination with respect to the ecliptic plane. The heliocentric burial orbit is formed as an ellipsis with the perihelion spaced at a distance from the Sun at which the radiation incident upon the radioactive wastes turn them into plasma, or the heliocentric burial orbit is formed with an eccentricity at least equal to unity.

This embodiment of the method allows power requirements for launching a space module containing radioactive wastes to a burial orbit to be reduced where the wastes are completely annihilated in the orbit by turning them to plasma or from where they are sent to an area outside the Solar system.

Therefore, the method for burying radioactive wastes in space according to the invention brings solution to the burial problem with an enhanced ecological safety both for the Earth and for other planets of the Solar system with lower power requirements.

Brief Description of the Drawings

The invention will now be described in detail with reference to the accompanying drawings illustrating specific embodiments of the invention, in which:

Fig. 1 schematically shows a general view of a spacecraft with a space module mated thereto and containing radioactive wastes;

Fig. 2 schematically shows a general view of a launcher missile with the spacecraft installed thereon;

Fig. 3 schematically shows a flight path of the launcher missile in inserting the space module into a near-Earth orbit;

Fig. 4 schematically shows the initial portion of a space path of the space module towards a heliocentric orbit;

Fig. 5 schematically shows planet orbits and a burial orbit outside the Earth orbit (in the plan view);

Fig. 6 is a view taken along arrow A in Fig. 5;

Fig. 7 is ditto of Fig. 5 showing position of the orbits in space;

Fig. 8 is a schematic representation of conjugation of a burial orbit with the orbits of two chosen planets;

Fig. 9 schematically shows the orbits of the planet and a burial orbit inside the Earth orbit;

Fig. 10 is ditto of Fig. 9, with the burial orbit intersecting the orbits of the planets;

Fig. 11 schematically shows portions of the burial orbits and Earth orbit at the moments they are coming close to each other;

Fig. 12 is a functional relationship for the distance from the module to the Earth;

Fig. 13 a functional relationship for a parameter characterizing the level of radioactivity of wastes versus time;

Fig. 14 shows functional relationships for the number of revolutions during which the wastes are kept in a burial orbit and the total velocity impulse versus the full orbital period in this orbit;

Fig. 15 schematically shows the orbit of the Earth and a burial orbit (in the plan view) when the module is in the Earth orbit, with the outside position of an intermediate orbit of the module;

Fig. 16 is ditto of Fig. 15, in an orbital system of coordinates with the respect to the Earth;

Fig. 17 is ditto of Fig. 15, with the inside position of an intermediate orbit of the module;

Fig. 18 is ditto of Fig. 17, in an orbital system of coordinates with respect to the Earth;

Fig. 19 schematically shows a burial orbit and the Earth orbit (in the plan view) when the module is inserted into a halo-orbit with respect to the Earth;

Fig. 20 is ditto of Fig. 19, in an orbital system of coordinates with respect to the Earth;

Fig. 21 is ditto of Fig. 20, with a turned plane of the halo-orbit;

Fig. 22 is a view taken along arrow B in Fig. 21;

Fig. 23 schematically shows a path of flight of the module with respect to the Earth in forming a halo-orbit after one revolution of the module in an intermediate orbit;

Fig. 24 is a view taken along arrow C in Fig. 23;

Fig. 25 schematically shows a path of flight of the module with respect to the Earth in forming a halo-orbit around the Earth (in the plan view);

Fig. 26 is a view taken along arrow D in Fig. 25;

Fig. 27 schematically shows orbits of the planets and a burial orbit (in the plan view) during flight of the module towards the Sun;

Fig. 28 schematically shows a path of a perturbative manoeuvre of the module in a gravity field of a planet with a flight pattern of Fig. 27;

Fig. 29 schematically shows the relative position of velocity vectors of the flight of the module and a planet in carrying out the manoeuvre of Fig. 28;

Fig. 30 is ditto of Fig. 28 showing position of the path in space;

Fig. 31 is ditto of Fig. 29 showing the position of the velocity vectors in space, wherein C_{46}, C_{47} are lines normal to the orbits;

Fig. 32 schematically shows planet orbits and a burial orbit (in the plan view) during the module flight to an area outside the Solar system;

Fig. 33 schematically shows a path of a perturbative manoeuvre of the module in the gravity field of a planet with a flight pattern of Fig. 32;

Fig. 34 schematically shows the relative position of velocity vectors of the flight of the module and of a planet in carrying out a manoeuvre of Fig. 32.

Preferred Embodiments of the Invention

A method for burying radioactive wastes in space according to the invention is carried out in the following manner.

Radioactive wastes 1 (Fig. 1) to be buried in space are loaded into a carrying container 2 and transported to a launching base where they are placed into a space module 3 mated to an insertion spacecraft 4 of a conventional type having accelerating stages 5.

Module 3 with spacecraft 4 is placed into a cargo carrier container 6 (Fig. 2), and container 6 with module 3 and spacecraft 4 is mated to a conventional launcher rocket 7 which is then launched from the Earth 8 (Fig. 3). As a result module 3 and spacecraft 4 are inserted into a near-Earth orbit 9. A necessary increment of the flight velocity is then imparted to module 3 so that module 3 is transferred by means of spacecraft 4 into a heliocentric burial orbit. For that purpose a necessary increment of the flight velocity is imparted to module 3 at a boost path 10 (Fig. 4) so that module 3, which moves along a path 11, can leave a sphere 12 of influence of the gravity field of the Earth 8. Radius r_o of sphere 12 of the Earth influence is from 0.95 to 2.5 million km depending on the final result.

A vector of velocity U_o of the flight of module 3 with spacecraft 4 with respect to the Earth at a point 13 on sphere 12 of influence of the gravity field of the Earth adds to a vector W_o of a velocity of the orbital movement of the Earth around the Sun 14 to determine a vector V_o of a departure velocity of module 3 with spacecraft 4 which, together with a vector R_o of position of module 3 with respect to the Sun, sets up parameters of a heliocentric burial orbit 15.

In embodiments of the method in which the departure velocity V_o complies with the condition $V_{02}>V_0>W_0$ (wherein V_{02} is the escape speed in the Earth orbit at which the module leaves the Solar system) orbit 15 (Fig. 5) is in the form of an ellipsis extending outside an orbit 16 of the Earth. Orbit 15 is conjugated with orbit 16 of a chosen planet of the Solar system (the Earth orbit in this embodiment) with an intersection or tangency (at the moment the orbits are spaced at a distance of maximum r_o) or in opposition (with the minimum distance between the orbits that does not exceed 10 r_o and is at least equal to r_o).

An example of implementation of the method in which heliocentric burial orbit 15 is conjugated with orbit 16 of the planet Earth with tangency is given in Figs. 5, 6, and 7. In this case a conjugation with the Earth orbit is chosen to ensure minimum power requirements.

The position of burial orbit 15 in space is determined by an angle "i" of inclination of its plane (Fig. 7) with respect to the ecliptic plane (the plane of orbit 16 of the Earth). This angle "i" is chosen in advance in planning the flight to the burial orbit. This must take into account the inclination of an orbit 17 (Fig. 6) of another planet of the Solar system which intersects the plane of orbit 15 and also the angular position of a nodal line 18 of orbit 17 (Fig. 5) with respect to a certain constant direction 19 and the position of the Earth in its orbit 16 at the moment of departure of module 3 (i. e., the launching date). The plane of burial orbit 15 intersects the plane of orbit 17 of another planet (e. g. Mars) along a line 20, the orbit 17 proper intersecting the plane of burial orbit 15 at a point 21 (portions of orbits 15 and 17 which are above the ecliptic plane are shown with solid lines and the respective planes of the orbits are shaded in Fig. 5). The choice of angle "i" of inclination of burial orbit 15 is made taking into account evolution of orbits of planets of the Solar system and the evolution of the orbit proper during a time interval from the moment module 3 has been inserted into burial orbit 15 until the moment when intensity of radioactive radiation of the wastes decreases to an admissible level. In making choice of angle "i" of inclination of burial orbit 15, points 22 (23) and 24 (25), respectively, are determined in this orbit and in orbit 17 of another planet at which the distances between the orbits are minimal. These distances should not exceed the radius r_o of the sphere of influence of the gravity field of another planet so that perturbations of the orbit under the effect of this field can be insignificant. At the same time, the minimum distance from orbit 15 to an orbit 26 of another planet (e. g., Jupiter) is controlled which is achieved at a point 27 and must be greater than a radius r_2 of the sphere of influence of this planet for the same reason.

During the flight of module 3 in burial orbit 15 at the initial stage, corrections of the orbit parameters can be made at preset points 28 to shift the perihelion of orbit 15 away from orbit 16, to improve accuracy of achievement of the desired burial parameters, and to ensure a correct phase at transit over the perihelion of orbit 15.

It should be noted that the launching date is preferably chosen in such a manner, bearing in mind the ecological safety for the Earth during evolution of its orbit 16 over thousand of years of the flight of the wastes in burial orbit 15, that the departure from the Earth orbit take place in its aphelium (α_o) in the case orbit 15 extends outside. It should be also noted that orbit 15 is phased by corrections to ensure the ecological safety for the Earth with the aim of ruling out a premature entrance of module 3 into the sphere of influence of the Earth 8.

An example of conjugation with the orbits of two planets chosen for the conjugation - with orbit 16 of the Earth (opposition) and with orbit 26 of the Jupiter (intersection) is shown in Fig. 8. The implementation of the method for burying radioactive wastes in this examples, including the choice of the angle "i" of inclination of the orbit involves operations similar to those used in the preceding example, including corrections aimed at increasing the elevation of the perihelion of burial orbit 15 which is shown at 15 before the correction and at 29 after the correction.

It should be noted that shading in Fig. 8 shows those half-planes of burial orbit 15 and orbit 26 of the Jupiter which extend above the ecliptic plane.

In embodiments of the method in which the departure velocity V_o complies with the condition $W_o > V_o > 0$ orbit 15 is in the form of an ellipsis extending internally with respect to orbit 16 of the Earth (Figs. 9, 10). In these embodiments burial orbit 15 may as well be conjugated with orbit 16 of the Earth with tangency (Fig. 9), intersection (or opposition) (Fig. 10) and it may also be conjugated with orbit 26 of one of chosen inner planets of the Solar system. In this case, similarly to the above-described embodiments of the method and bearing in mind the same ecological safety considerations, it is preferred that the launching date be chosen in such a manner as to ensure the departure from the Earth in its perihelion (π_o). A correction of burial orbit 15 is carried out with the same aim as described above.

Procedural basis for making choice of parameters of burial orbit 15 is illustrated in Figs. 11 through 14 for an external position of this orbit with respect to orbit 16 of the Earth when these two orbits are conjugated with tangency. It will be apparent that this conjugation of the orbits may be conducive to a premature entry of the module containing wastes (or entrance of wastes 1 if module 3 has been damaged under the effect of factors of the space flight) into the sphere of influence of the Earth unless certain steps are taken in advance. Such re-entry can result in wastes 1 either reaching the surface of the Earth or moving to a new heliocentric orbit with unforeseeable results.

This situation can be ruled out if the relative position of module 3 and the Earth at moments they come to be the closest to each other is analyzed for each revolution "n" of burial orbit 15, with the formation of such a period P of complete revolution of module 3 along burial orbit 15 around the Sun 14 and such an initial position of module 3 in orbit 15 (including corrections at first revolutions in the orbit) that an eventual rendevouz with the Earth, i. e. entrance of module 3 (or of wastes 1) into the sphere of influence of the Earth occurs during a revolution of orbit 15 numbered $n > N_o$, wherein N_o is determined on the basis of a time T_{max} during which the wastes must be kept in orbit 15 until they have a safe radiation level. Assuming the initial position of the Earth (at 20) at the moment of departure of module 3 from orbit 16 of the Earth is the initial position (Fig. 11), a current position 31 of the Earth in its movement around the

Sun 14 in orbit 16 with a radius R can be characterized by a value of an angle at center Φ. Angular positions of the Earth at points 32, 33, 34 of the closest position with respect to module 3 correspond in Fig. 11 to revolutions of burial orbit 15 numbered $n=2$, N_o-2, N_o-1. In these positions distances D(n) from module 3 to the Earth should be at least equal to r_o.

The relationship for a current distance L from the Earth to module 3 in the vicinity of their closest position is graphically shown as functions of angle Φ in Fig. 12 in which curves L (Φ) are shown with dotted lines for revolutions of the orbit which occur just before the entrance of module 3 into the sphere of influence of the Earth.

To make choice of the period P of complete revolution of module 3 in orbit 15, it is necessary to use relationships of characteristics of radiation of the wastes versus time "t". This characteristic may be in the form of radiation activity of the wastes in terms of the number of events of spontaneous nuclear transformations in a given waste isotope per unit of time or an exposure dose rate, etc. Typical relationships for a characteristic J of waste radiation are given in Fig. 13 in which curves 35 and 36 correspond to different isotopes (e. g., Curium-245 and Americium-243).

It can be seen in Fig. 13 that a time T_{max} of a decrease in a radiation control characteristic for wastes consisting of two isotopes having their masses in a predetermined ratio corresponds to an final admissible level of residual radiation J_{lim}.

In a similar manner, a certain intermediate level of a radiation parameter J_m may be set up with a respective time $T_{max} = T_m$ for keeping wastes in orbit 15 at which in case fragments of the radioactive wastes fall down to the Earth an eventual local alteration of the radiation background would not impair the ecological situation.

Given the data on an admissible time during which wastes have to be kept outside the Earth, an admissible number of complete revolutions N_o in the burial orbit can be determined depending on the period P of one complete revolution in this orbit (Fig. 14).

When appropriate calculations are made to find out the relationship of the number of revolutions N in burial orbit 15 after which module 3 enters the sphere of influence of the Earth versus period P, with the typical results which are shown in Fig. 12, ranges of admissible values of the periods P of complete revolution in burial orbit 15 can be determined (not shaded in Fig. 14). A typical curve 37 is used to determine power requirements for such periods (characteristic velocity W_s) to achieve the burial orbit in the embodiment of the method shown in Fig. 5.

The use of this method ensures, in comparison with the prior art:

- enhanced ecological safety for the Earth in burying wastes in space;
- increased probability of transfer of wastes to a burial orbit;
- lower power requirements for the implementation of the method;

These advantages are obtained owing to the following:

- a reduced number of orbit-to-orbit transits (active portions of operation of thrusters of an insertion spacecraft imparting velocity impulses);
- use of burial orbits which are closer to the Earth orbit, with the wastes being kept in orbit for a time after the lapse of which the wastes become safe in terms of their activity and can fall down to the Earth or to another planet;
- possibility of providing additional power supplies at vehicles used to transfer radioactive wastes into space so that if a sustainer fails in a larger number of cases, module 3 containing wastes could be put in a burial orbit in accordance with an emergency schedule.

It should be emphasized that the implementation of the method with values of P close to the period of complete revolution of the Earth around the Sun requires additional steps which may be carried out as described below.

In the embodiment with superposition of heliocentric burial orbit 15 on heliocentric orbit 16 of the Earth (Figs. 15 through 18) module 3 with radioactive wastes is transferred to an intermediate elliptical orbit 38 which is conjugated with orbit 16 of the Earth (with tangency) and which extends externally with respect to orbit 16 of the Earth (Figs. 15, 16) or internally thereof (Figs. 17, 18) before inserting module 3 to burial orbit 15. After at least one revolution of module 3 in orbit around the Sun 14, module 3 is transferred to burial orbit 15 which is superposed on orbit 16 of the Earth, with the distance L_o (Figs. 16, 18) from the module to the Earth being equal to at least the radius r_o of the sphere of influence of the gravity field of the Earth. After being inserted into orbit 15 and during the initial phase of the stay of the wastes in the orbit, orbit 15 is corrected to increase accuracy of the above-mentioned parameters of the orbit.

While Figs. 15, 17 show movement of module 3 in absolute coordinates with respect to the Sun 14, Figs. 16, 18 show the movement in relative XY-coordinates with respect to the Earth, with Y-axis being directed along a current radius-vector R of the Earth from the Sun, and X-axis being perpendicular thereto and directed in the direction of the Earth movement (along velocity W_o). The origin of XY-coordinates coincides with the center of the Earth, and for this reason orbit 16 of the Earth is represented by a line 39 on X-axis, and burial orbit 40 in an ideal case also coincides with X-axis (module 3 is represented by a point spaced at the distance L_o from the origin). A path of movement of module 3 in intermediate elliptical orbit 38 (Figs. 15, 17) in relative XY-coordinates is in the form of a cycloid 41 (Figs. 16, 18).

It should be noted that the transition from intermediate elliptical orbit 38 to burial orbit 15 is carried out after one or more complete revolutions in orbit 38 by imparting a deceleration velocity impulse V_1 (with the external tangency of orbits 16 and 38) or an acceleration velocity impulse V_2 (with the internal tangency of orbits 16 and 38) by means of thrusters of spacecraft 4. In ideal cases, module 3 should be put at the distance L_o along X-axis and have a zero velocity with respect to the Earth after imparting a velocity impulse V_1 or V_2.

Eventual inaccuracies in imparting the impulses are compensated for by consecutive corrections 28 during the initial phase of flight of module 3 in burial orbit so as to ensure the secular motion (drift) of module 3 with respect to the Earth and entrance into the sphere of influence of the gravity field of the Earth at least after the lapse of a preset time during which the wastes are kept to achieve a safe radiation level.

This embodiment of the method:

- reduces power requirements for the transfer of wastes to a burial orbit;
- enhances the monitoring of burial conditions by using remote control and contact equipment;
- ensures utilization of wastes in the long run (if desired) when their radiation hazard will have become lower or when methods are available to ensure their safe processing and use, with such utilization being carried out with lower power requirements;
- reduces the size of an area in space in which wastes are disposed of, with a respective improvement of safety of interorbital spacecraft flights;
- improves ecological safety for the Earth.

In another embodiment of the method for burying wastes in space, a burial orbit with a period P of complete revolution around the Sun close to the period of complete revolution of the Earth in its orbit is formed as a halo-orbit.

In this embodiment of the method, before module 3 is inserted into burial orbit 15, the module is transferred to intermediate elliptical orbit 38 (Fig. 19) conjugated with orbit 16 of the Earth (e. g., with tangency). Module 3 is then inserted into heliocentric burial orbit 15 which is in the form of a halo-orbit 42 in a system of coordinates with respect to the Earth (Figs. 20 through 26) with the origin in orbit 16 of the Earth (this orbit is shown as line 39 on X-axis), any point of halo-orbit 42 being spaced from the Earth at a distance at least equal to the radius r_o of the sphere of influence of the gravity field thereof. Burial orbit 15 in this case is conjugated with orbit 16 of the Earth with intersection. The transit from intermediate orbit 38 to burial orbit 15 may be carried out by using various flight patterns. Fig. 19 shows a diagram in which a velocity impulse V_3 is imparted after one-half of revolution of module 3 in orbit 38 for transit to burial orbit 15, i. e., to halo orbit 42. Halo orbit 42 (Fig. 20) is in the ecliptic plane and is spaced from the sphere of influence of the gravity field of the Earth at a distance at least equal to $\Delta_{min}>0$.

In this embodiment orbit 38 is represented in XY-coordinates with respect to the Earth in the form of a cycloid 43, and orbit 16 of the Earth is represented by line 39 on X-axis similarly to Figs. 16, 18.

Figs. 21, 22 show a similar diagram which differs from the preceding diagram by the fact that a velocity impulse V_3 for a transit from an intermediate orbit in the form of cycloid 43 to burial halo-orbit 42 causes the plane of halo-orbit 42 to turn at a preset angle with respect to the ecliptic (the vector of the velocity impulse has two components V_{3x} and V_{3z} at this transition), whereby halo-orbit 42 is at the shortest distance from the surface of the sphere of influence of the gravity field of the Earth at a point E equal to $\Delta_{min}>0$. The Z-component in YZ-coordinates in Figs. 22, 24, 26 corresponds to the direction of a vector of the angular momentum of the Earth orbit, and the Y-component corresponds to the radius-vector of a current position of the Earth.

Figs. 23, 24 show a schematic of a flight in which a velocity impulse V_3 is imparted to module 3 after one complete revolution in orbit 38. In diagrams of Figs. 25, 27 the velocity impulse V_3 is imparted after one incomplete revolution, whereby halo-orbit 42 extends around the sphere of influence of the gravity field of the Earth in the relative system of coordinates.

It should be noted that Figs. 19-26 show the ideal cases of implementation of the method. In practice a position of halo-orbit 42 should be chosen in such a manner that, bearing in mind corrections during the secular motion with respect to the Earth, its eventual contact with the sphere of influence of the Earth occurs at least after the lapse of the preset time during which the wastes have to be kept in the burial orbit. It is preferred that halo-orbit 42 be inclined from the ecliptic plane at a certain angle which depends on parameters of the halo-orbit and the radius of the sphere of influence of the planet and which ensures a gap (minimum distance) of $\Delta_{min}>0$

The use of this embodiment of the method:

- enhances conditions for monitoring the burial and allows wastes to be utilized (if necessary) with lower power requirements;
- reduces the size of the area in which the wastes are buried;
- enhances ecological safety for the Earth;
- improves safety of interorbital flights of spacecraft.

The method according to the invention involves more sophisticated embodiments shown in Figs. 27-34 which are implemented with conjugation of intermediate orbit 38 with orbit 26 of another chosen planet. After module 3 is inserted into intermediate orbit 38 (Figs. 27, 32) it moves along this orbit into the sphere of influence of another planet (e. g., the Jupiter) by means of several corrections (correcting velocity impulses). Module 3 enters the field of gravity of such planet at the moment when the planet is at a point 44 and leaves it when the planet in its orbital movement reaches a point 45. A perturbative manoeuvre is carried out within the sphere of influence of the gravity field of this planet so that module 3 goes through the sphere of influence of this planet at points 46, 47 (Fig. 28) and moves in an orbit 48 to transit to a heliocentric burial orbit 49 simultaneously with a change in the radius of the perihelion, eccentricity "e", and angle "i" of inclination with respect to the ecliptic plane in comparison with intermediate orbit 38. During the manoeuvre, additional velocity impulses may be imparted to module 3. The desired parameters of orbit 49 are formed within the sphere of influence of the planet. Those are the position of an entry point 46 (Figs. 28, 30, 33) and a sighting range "d" ("d" is the distance from the line of a vector U_1 of relative velocity of entry of module 3 into the sphere of influence to the center of the planet). The implementation of this manoeuvre is geometrically explained in Figs. 28 through 31 and Figs. 33, 34 in which Y-axis is directed along a radius-vector R_p of the planet position with respect to the Sun 14, X-axis extends in the plane of the planet orbit in the direction of its orbital velocity W_p perpendicularly with respect to the radius-vector R_p, and Z-axis extends perpendicularly with respect to the plane of the orbit of the chosen planet in the direction of the vector of the angular momentum of the orbit. As a result of the relative velocity U_2 being turned at an angle ψ with respect to the vector U_1 at leaving the sphere of influence of the gravity field of this planet, the vector of absolute velocity of module 3 is changed. Velocity vector V_{46} at entry point 46 changes for velocity vector V_{47} at exit point 47. The radius-vector R_p is also changed in accordance with position of points 44 and 45 to change the vector of position of module 3 with respect to the Sun. The value of angle ψ of turn of the velocity vector depends on sighting range "d" and value of velocity V_{46}: with $d = r_3$ angle $\psi = 0$ and with $d \to 0$ angle $\psi \to 180°$. In case velocity impulses are not imparted to module 3 in intermediate orbit 38 the values of U_1 and U_2 are identical.

Therefore, by implementing appropriate parameters of orbit 38 (vectors V_{46} and V_{47}) and sighting range "d" and by guiding module 3 to appropriate entry point 46 of the sphere of influence of a chosen planet, the module can be transferred from intermediate orbit 38 either to elliptical heliocentric burial orbit 49 (Fig. 27) with the perihelion spaced from the Sun 14 at a distance at which the effect of solar radiation turns the radioactive wastes to plasma (at a point 50) or to a parabolic heliocentric burial orbit 51 (with $e = 1$) or a hyperbolic heliocentric burial orbit (with $e > 1$) 51 (Fig. 32) with the exit of module 3 during its flight to the stellar space outside the Solar system.

This embodiment is characterized by the fact that it allows wastes to be completely annihilated (during the flights toward the Sun) or to be irreversibly put out of the Solar system with their natural deactivation during the flight which will last for many thousands of years through the stellar space. It should be noted that in implementing the flight toward the Sun, the position of the perihelion of orbit 49 is chosen to be such as to ensure the destruction of modulus 3 (melting and evaporation) and transformation of the radioactive wastes into plasma without allowing them to get into the lower strata of the heliosphere (atmosphere of the Sun) and to the surface of the Sun. The specific value of the relative perihelion of orbit 49 depends on the structural material of the module, its design, the material of the container carrying the wastes, composition and configuration of fragments of the wastes and a moderator filler surrounding the wastes in the container.

This embodiment of the method allows high safety of disposal to be ensured because in case the required departure velocity V_o has not been achieved, or if corrections 28 cannot be carried out for guiding module 3 into the sphere of influence of another chosen planet, a redundancy flight schedule along an intermediate burial orbit can be implemented, the burial orbit being formed by means of auxiliary thrusters of spacecraft 4 and a leftover fuel stock (with the use of a simplified control logic).

In comparison with a method for burying radioactive wastes making use of a direct guidance of module 3 to the Sun, which calls for an increment of velocity of the module at the departure from a near-Earth orbit at 24 m/s, in this embodiment of the method it only takes a velocity of 8 m/s so that this embodiment is much more efficient as regards power requirements. The comparison of the method involving the direct guidance of module 3 to a path of flight towards the space outside the Solar system and the method according to the invention also shows that there is a gain in terms of power requirements because the total necessary increment of velocity W_s of module 3 can be lowered by about 2 km/s.

Industrial Applicability

The method according to the invention may be implemented by using both non-reusable and reusable space equipment and is designed for evacuation from the Earth and for burial in space of radioactive wastes of various origin.

Claims

1. A method for burying radioactive wastes in space, comprising placing radioactive wastes into a space module and inserting the module into a near-Earth orbit, with subsequent transfer of the space module to a heliocentric burial orbit, characterized by conjugating the heliocentric burial orbit with an orbit of at least one chosen planet of the Solar system and setting up a period of complete revolution in this orbit corresponding to a time of an eventual rendevouz of the space module with the chosen planet which is at least equal to the time during which intensity of radioactive radiation of the wastes decreases to a preset level, with the plane of the orbit being inclined with respect to the ecliptic plane at an angle chosen in such a manner that this orbit is spaced at a distance from the orbits of other planets of the Solar system at least equal to the radius of the sphere of influence of the gravity field of these planets.

2. A method of claim 1, characterized by the fact that, before inserting the space module into a heliocentric burial orbit, it is inserted into an intermediate elliptical heliocentric orbit conjugated with the orbit of the Earth, with subsequent transfer of the space module from the point of conjugation of these two orbits to a heliocentric burial orbit which is superposed on the orbit of the Earth, the distance from the space module to the Earth being set up to be at least equal to the radius of the sphere of influence of the gravity field of the Earth.

3. A method of claim 1, characterized by the fact that before inserting the space module into a heliocentric burial orbit, it is inserted into an intermediate elliptical heliocentric orbit conjugated with the orbit of the Earth, with subsequent transfer of the module to a heliocentric burial orbit which is in the form of a halo-orbit with a center in the Earth orbit, any point of the halo-orbit being spaced from the Earth at a distance which is at least equal to the radius of influence of the gravity field of the Earth.

4. A method of claim 1, characterized by the fact that, before the space module is inserted into a heliocentric burial orbit, it is inserted into an intermediate elliptical orbit conjugated with the Earth orbit and with the orbit of another chosen planet of the Solar system along which the space module is sent into the sphere of influence of the gravity field of the chosen planet, with subsequent transfer of the space module to a heliocentric burial orbit by carrying out a perturbative manoeuver within the gravity field of the chosen planet with a simultaneous alteration of the radius of the perihelion, eccentricity, and inclination with respect to the ecliptic plane.

5. A method of claim 4, characterized by the fact that a heliocentric burial orbit is formed as an ellipsis with the perihelion spaced from the Sun at a distance at which solar radiation incident upon radioactive wastes turn them to plasma.

6. A method of claim 4, characterized by the fact that a heliocentric burial orbit is formed with an eccentricity at least equal to unity.

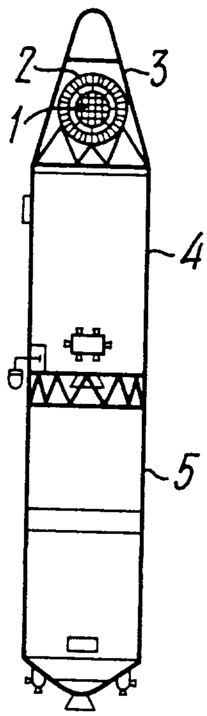

FIG. 1

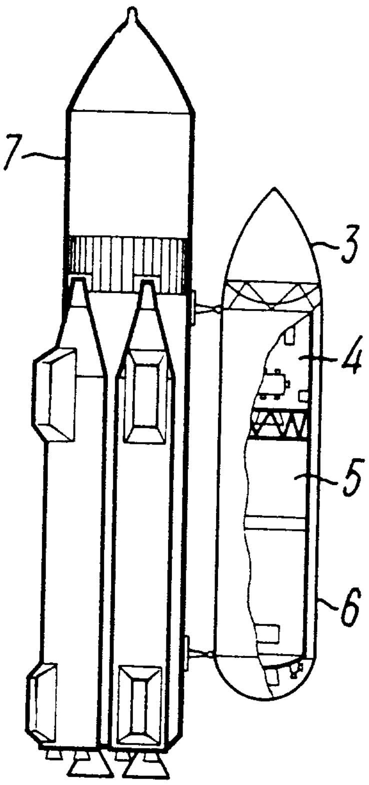

FIG. 2

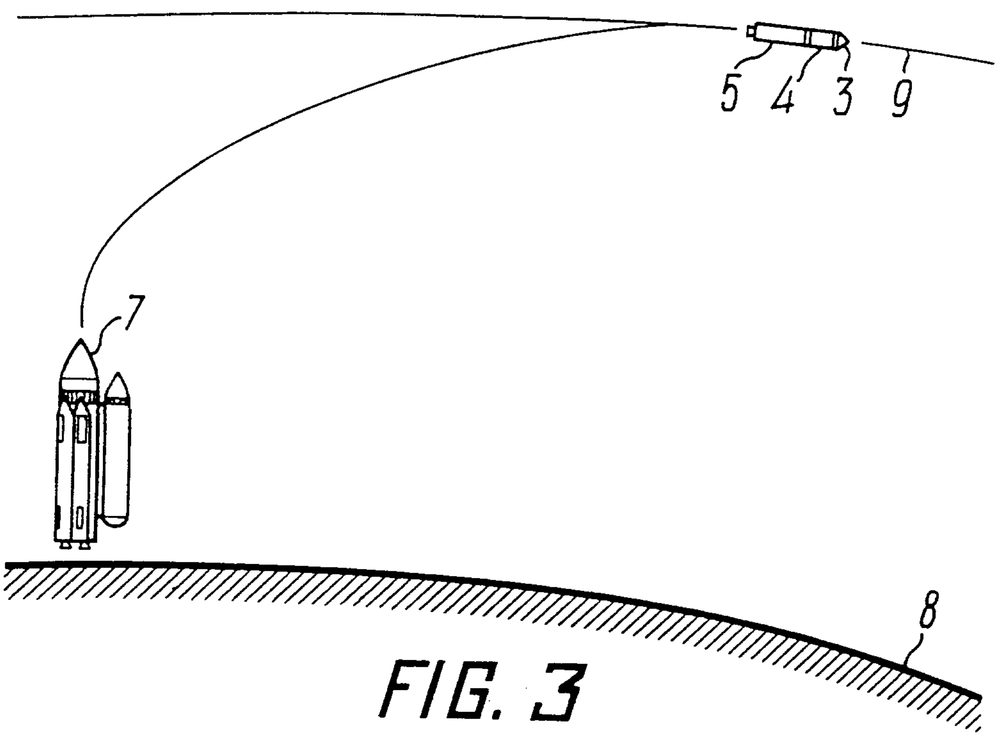

FIG. 3

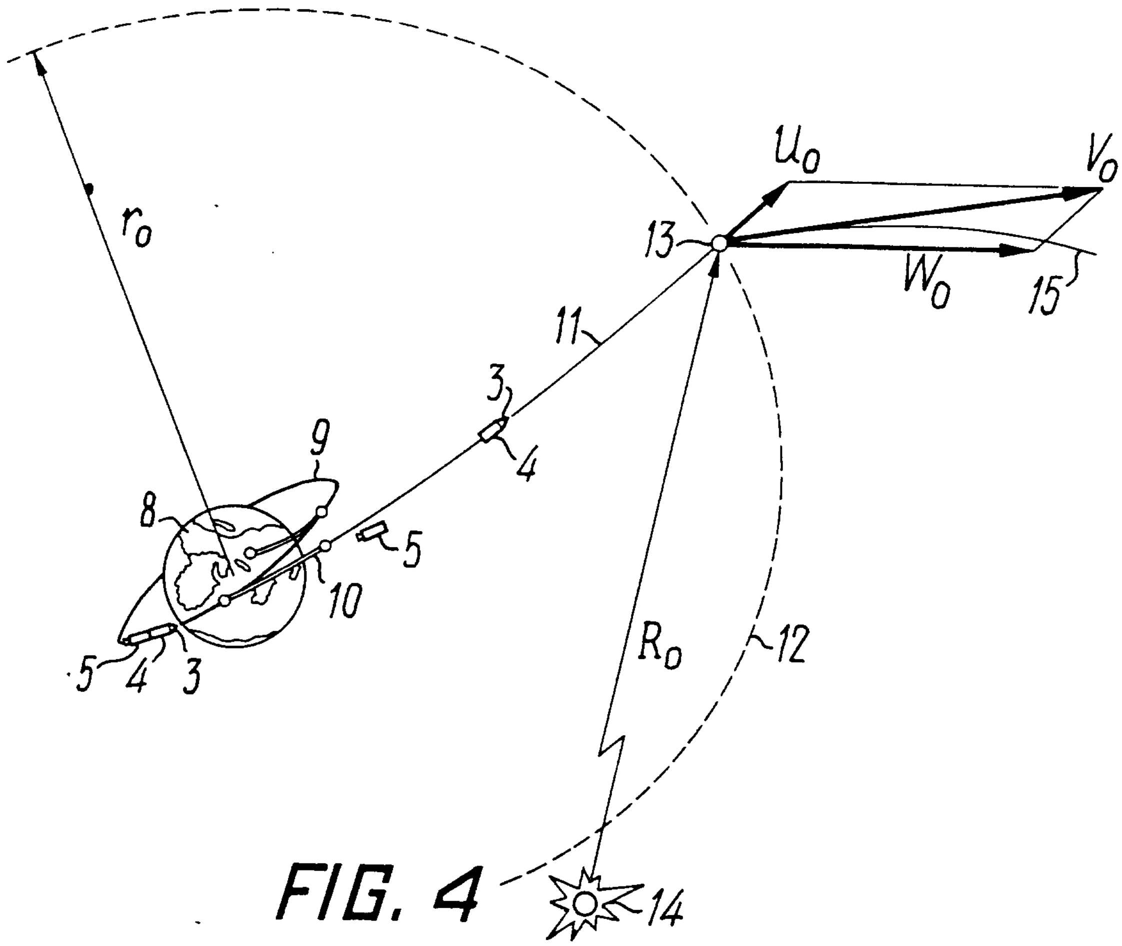
r0
U0
V0
13
W0
15
11
3
4
9
8
5
10
5
4
3
R0
12
14

FIG. 4

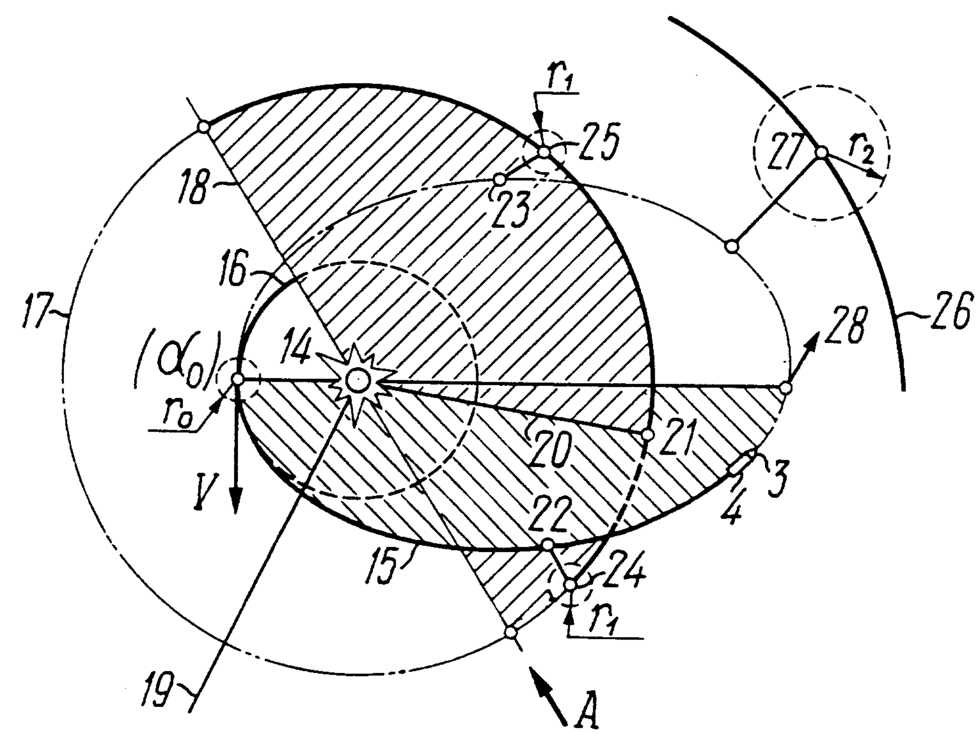
r1
25
27
r2
18
23
16
17
28
26
(α0)
14
r0
20
21
V
3
4
22
15
24
r1
19
A

FIG. 5

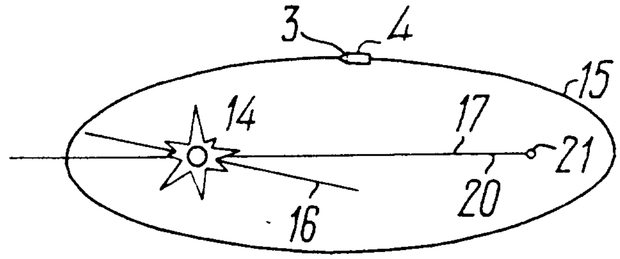

FIG. 6

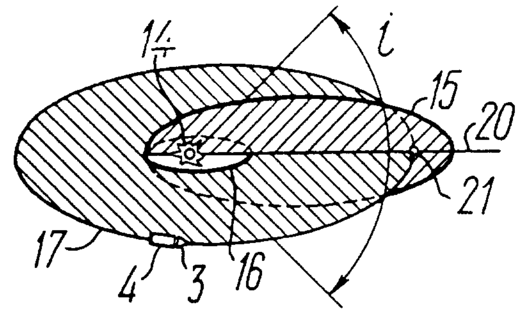

FIG. 7

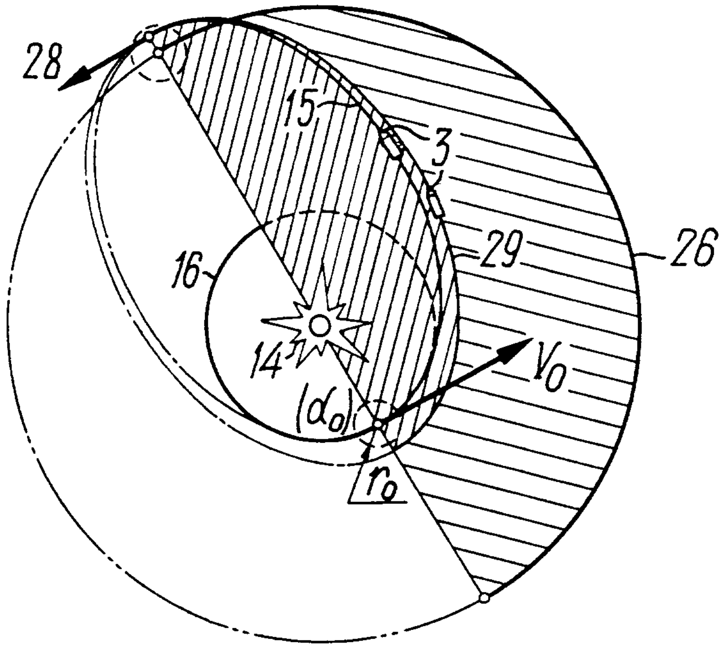

FIG. 8

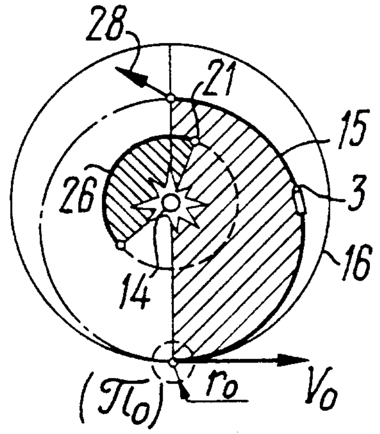

FIG. 9

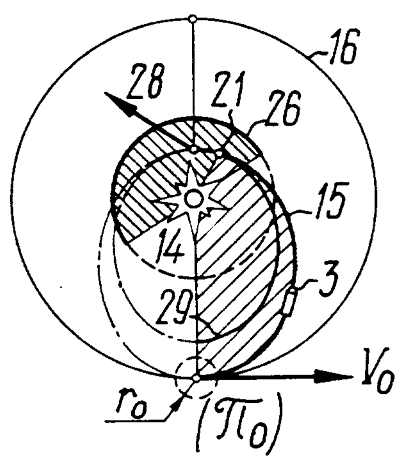

FIG. 10

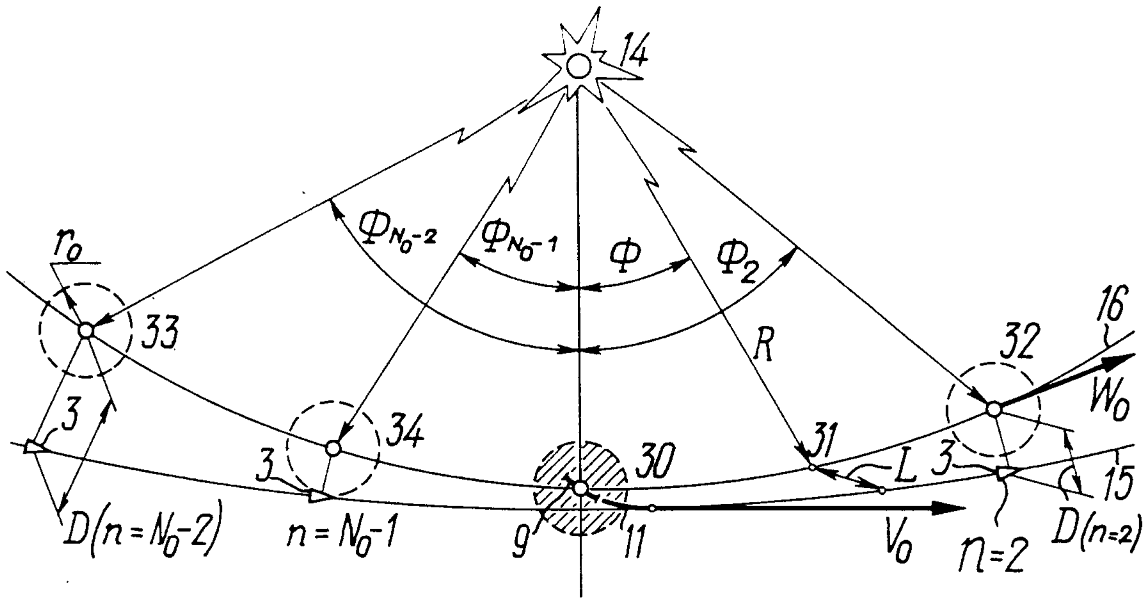
14
Φ_{N_0-2}
Φ_{N_0-1}
Φ
Φ_2
r_0
33
R
32
16
W_0
34
31
L
3
30
15
$D(n=N_0-2)$
$n=N_0-1$
9
11
V_0
n=2
D(n=2)

FIG. 11

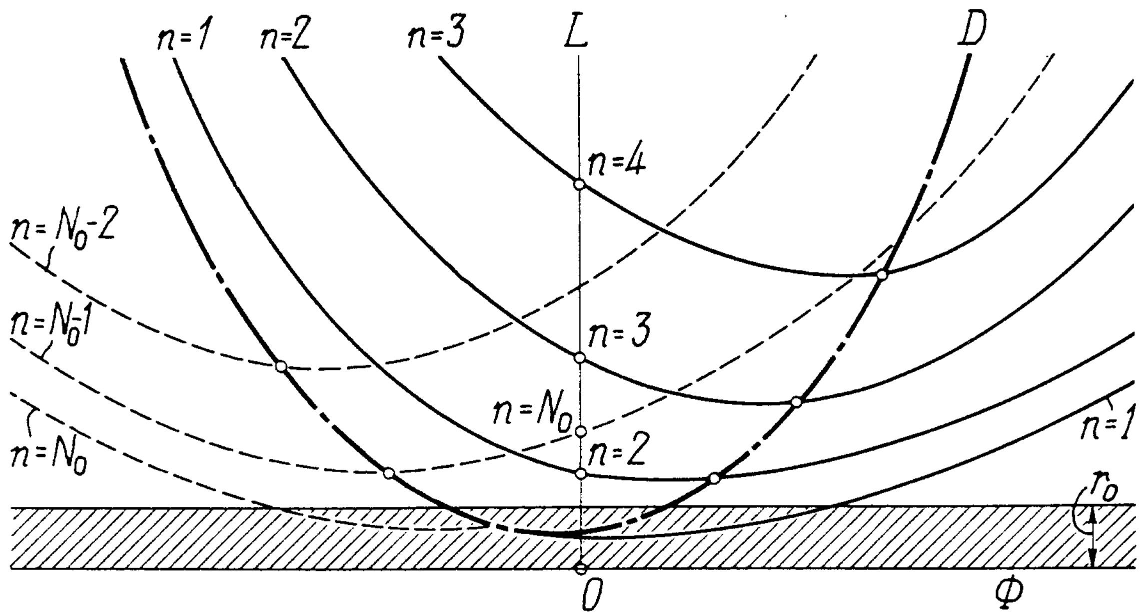
n=1
n=2
n=3
L
D
n=4
$n=N_0-2$
$n=N_0-1$
n=3
$n=N_0$
n=2
$n=N_0$
n=1
r_0
0
Φ

FIG. 12

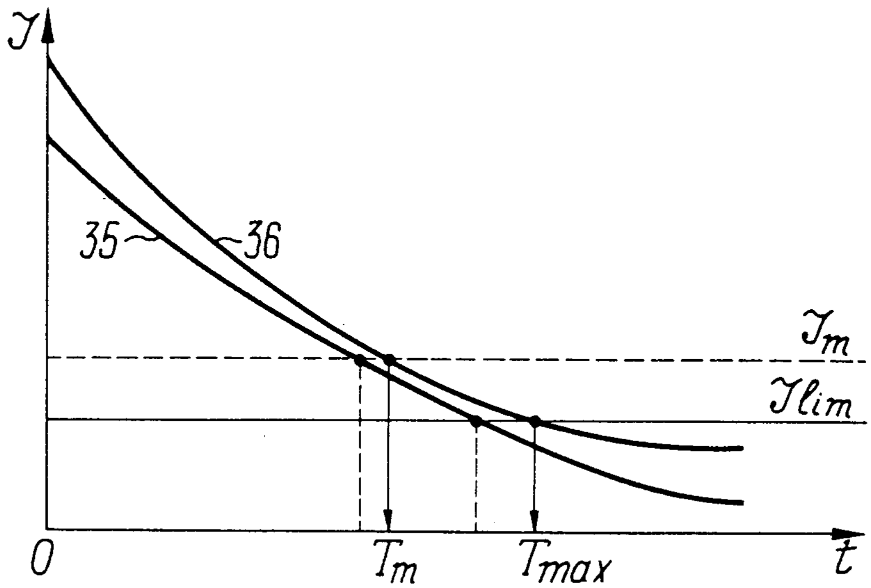

FIG. 13

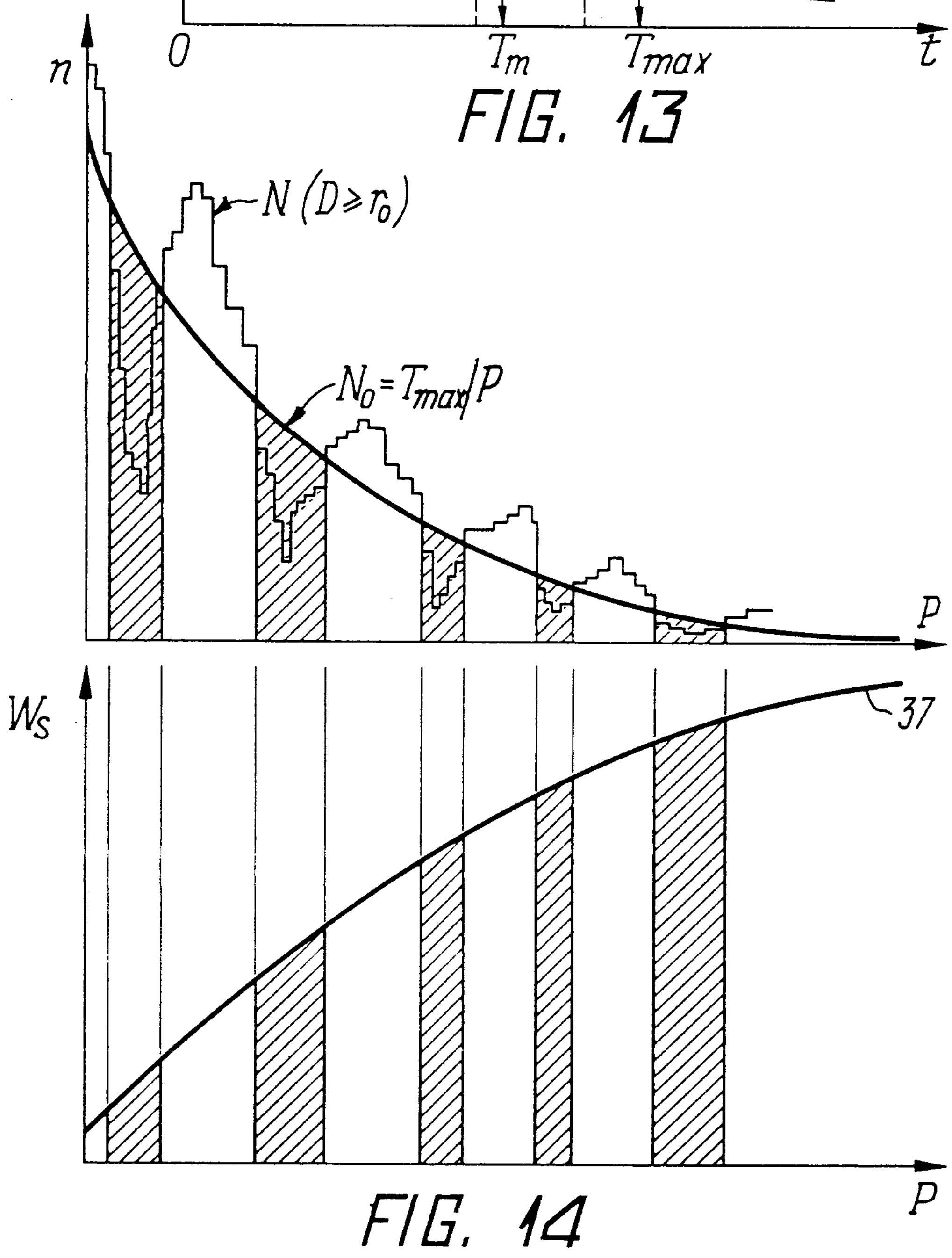

FIG. 14

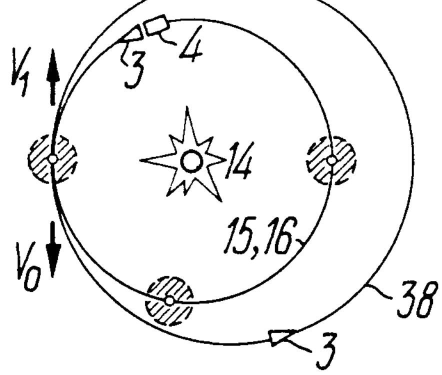

FIG. 15

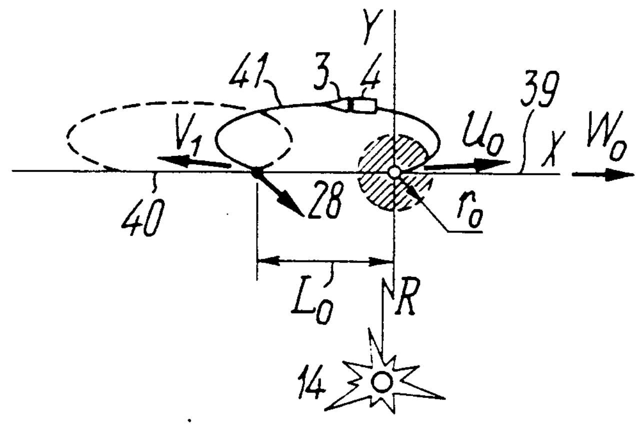

FIG. 16

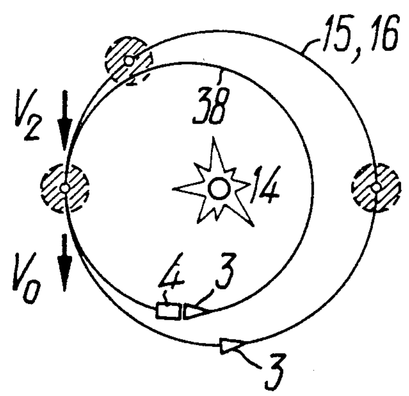

FIG. 17

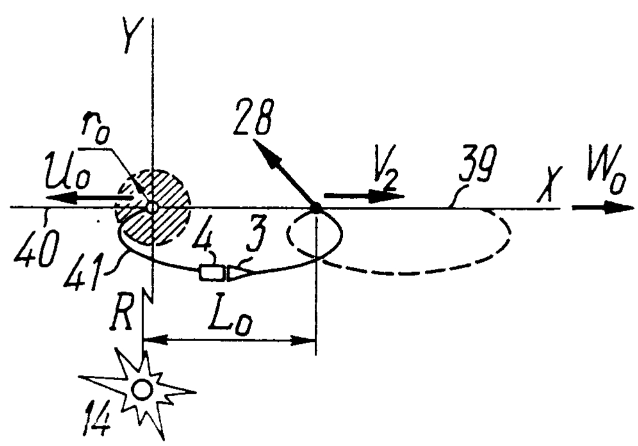

FIG. 18

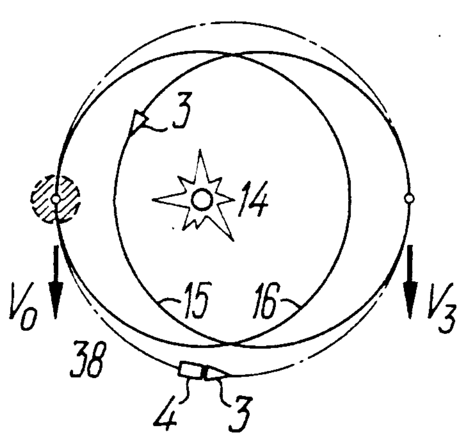

FIG. 19

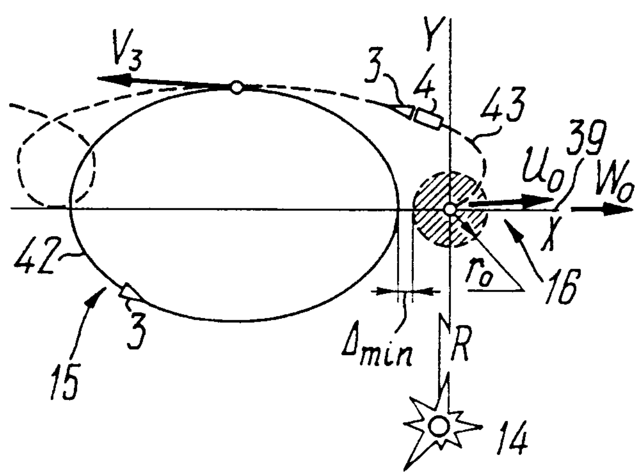

FIG. 20

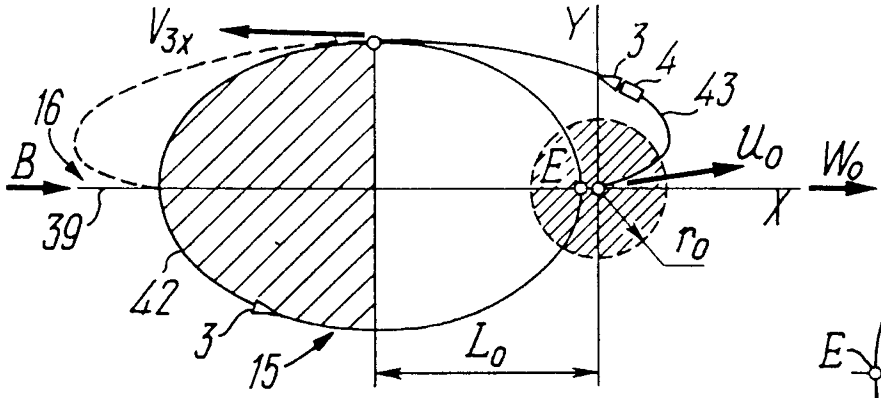

FIG. 21

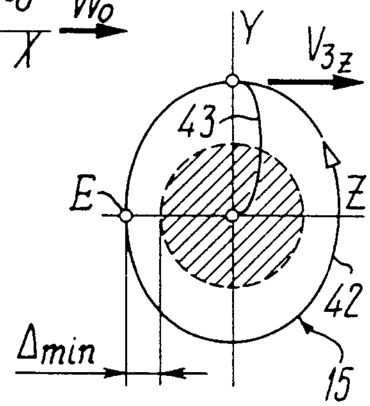

FIG. 22

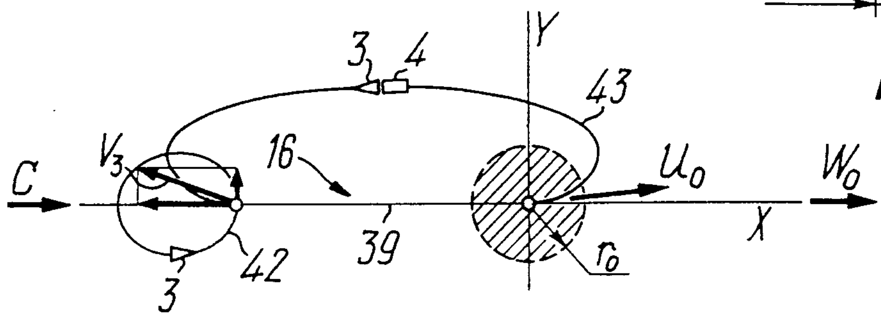

FIG. 23

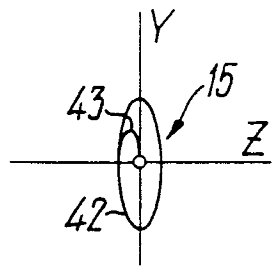

FIG. 24

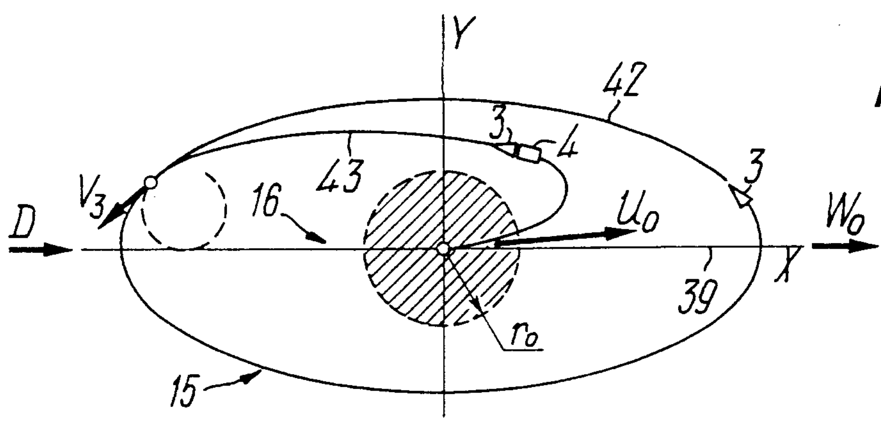

FIG. 25

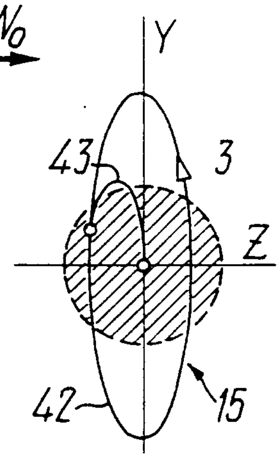

FIG. 26

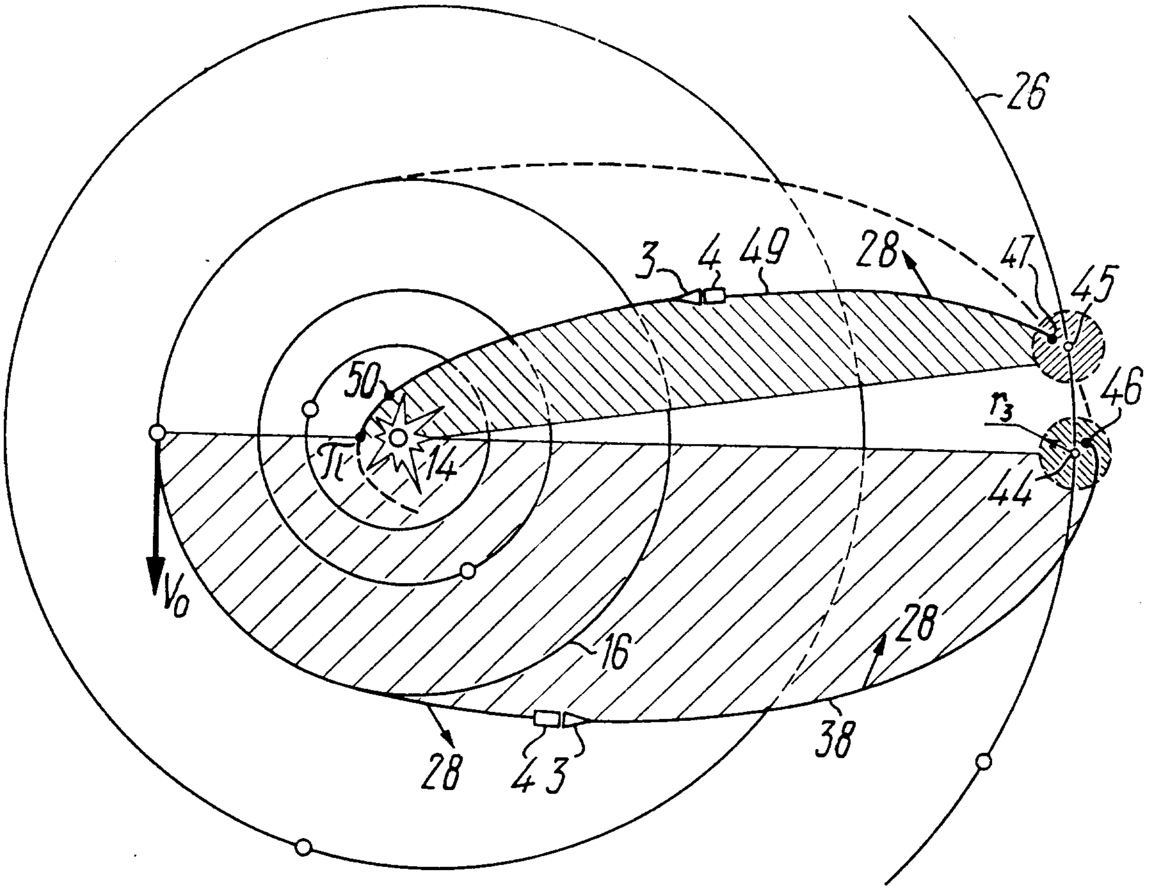

FIG. 27

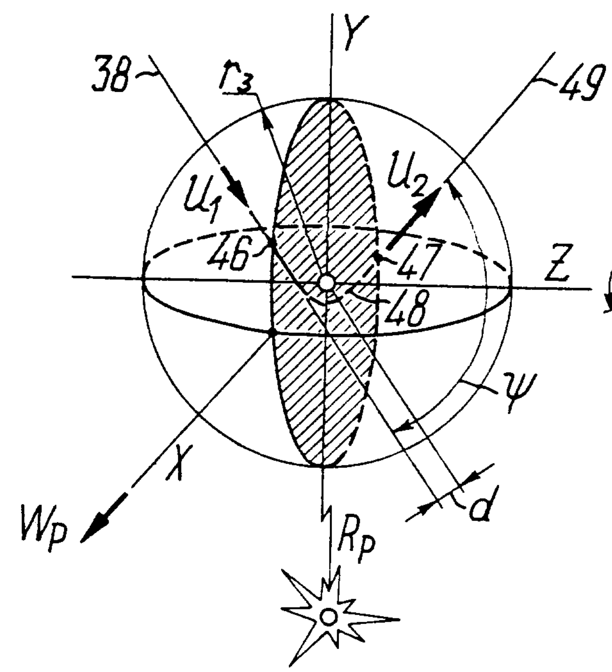

FIG. 28

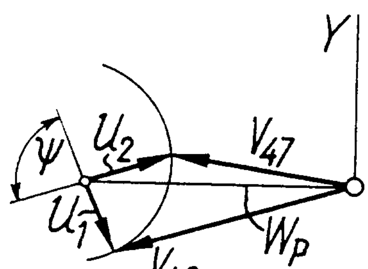

FIG. 29

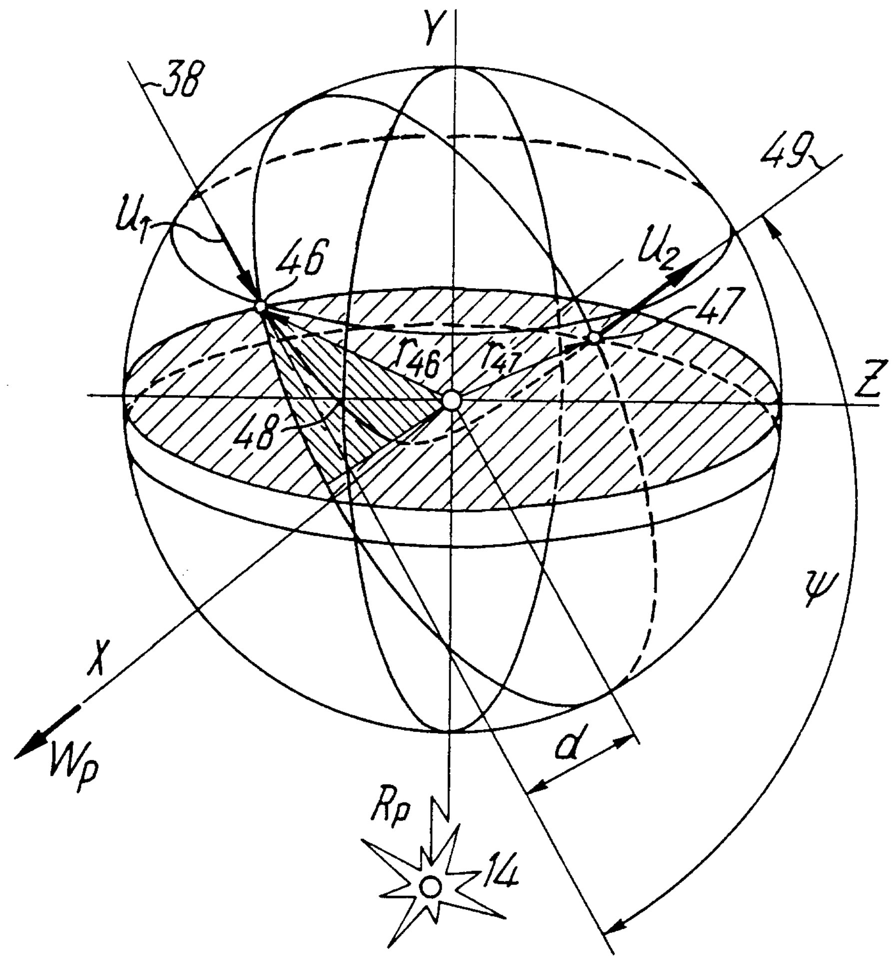
Y
38
49
u_1
46
u_2
47
r_{46}
r_{47}
Z
48
X
ψ
W_p
d
R_p
14

FIG. 30

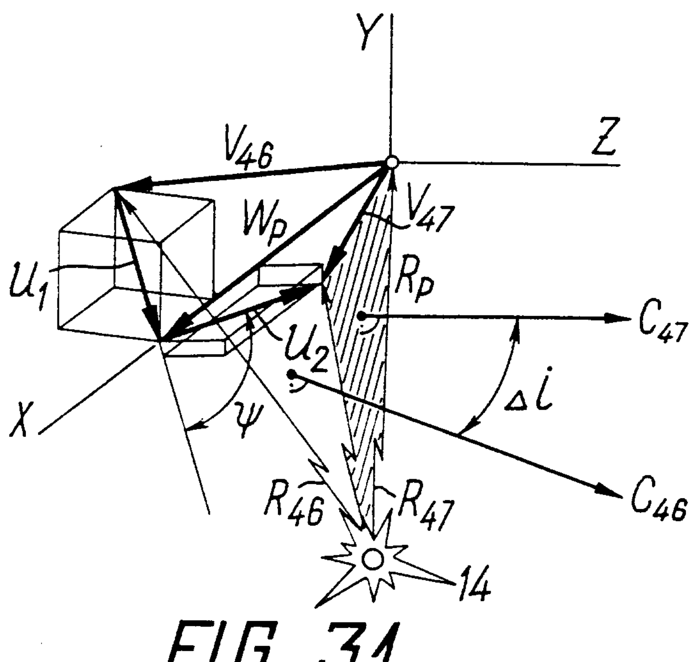
Y
Z
V_{46}
W_p
V_{47}
u_1
R_p
C_{47}
u_2
X
ψ
Δi
R_{46}
R_{47}
C_{46}
14

FIG. 31

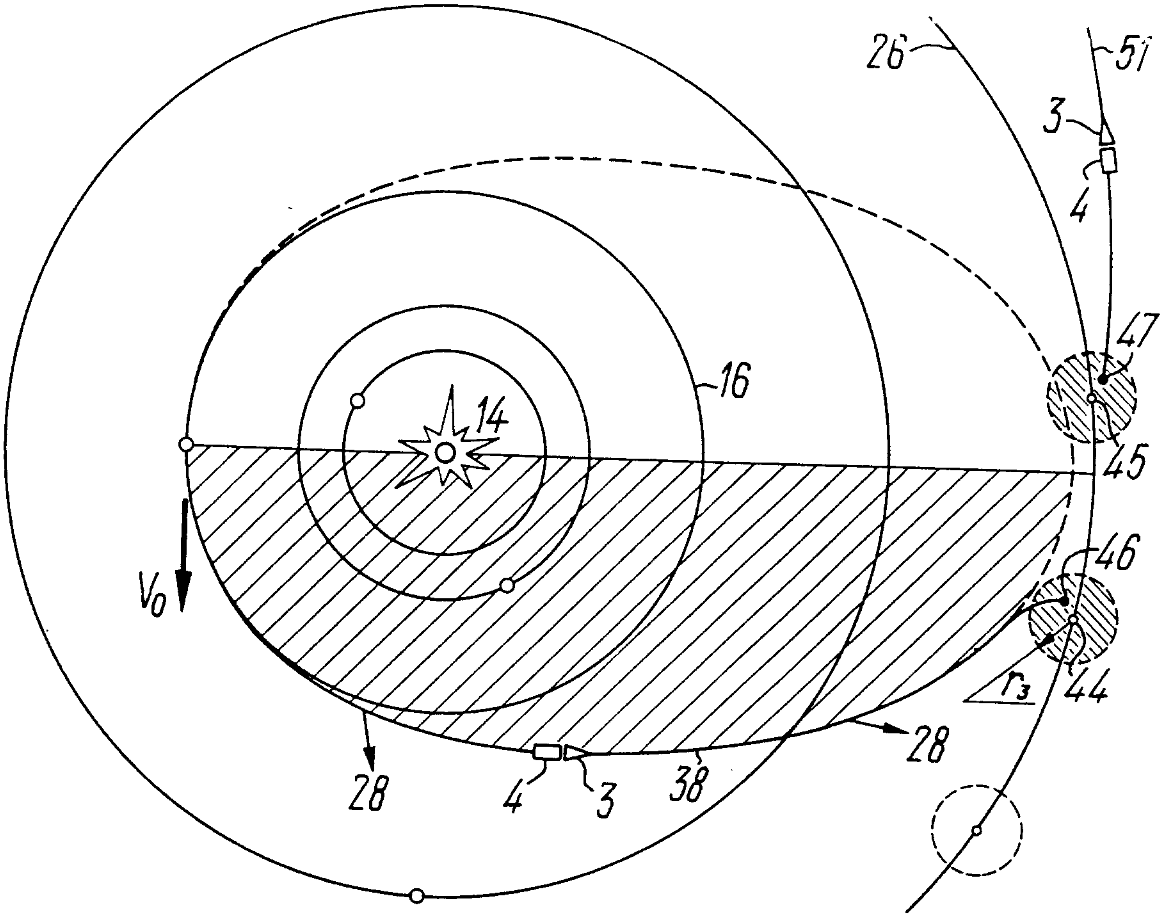

FIG. 32

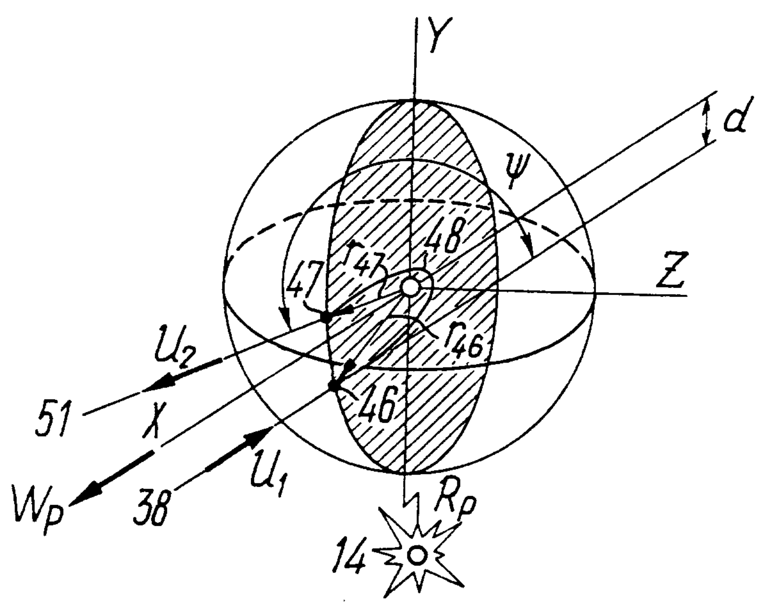

FIG. 33

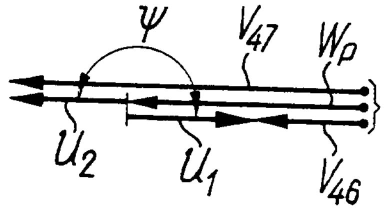

FIG. 34

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SU 91/00248

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 5: G21F 9/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl. 5: G21F 9/34, 9/36

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Astronautik, heft 2, 1981, (Organ der Hermann-Oberth-Gesellschaft e.V., Bremen), H.O. Ruppe und D. Hayn, "Entsorgung radioaktiven Abfalls durch die Raumfahrt Analyse der Möglichkeiten", pages 42-45	1-6
A	Astronautics & Aeronautics, April 1980, Claude C. Priest and Robert F. Nixon and Eric E. Rice "Space Disposal of Nuclear Wastes", pages 26-35 (cited in the description)	1-6
A	Gagarinskie nauchnye chtenia po kosmonavtike i aviatsii", 1991, Nauka (Moscow), A.D. Koval et al. "O perspektivakh udalenia radioaktivnykh otkhodov v kosmos", pages 184-185	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04 JUNE 1992 (04.06.92)	18 JUNE 1992 (18.06.92)

Name and mailing address of the ISA/	Authorized officer
SU	
Facsimile No.	Telephone No.