DEPARTMENT OF THE AIR FORCE
11TH WING

June 29, 2001

11 CS/SCS (FOIA)
1000 Air Force Pentagon
Washington DC 20330-1000

Mr. John Greenewald, Jr.

Dear Mr. Greenewald

This is in response to your undated Freedom of Information Act request for a copy of document entitled "Wartime Missile Strike Intelligence: An Indirect Bomb Damage Assessment System".

Information found on page 8 of the attached document is exempt from disclosure under Title 5, United States Code, Section 552 b(3) and statue 42 U.S.C. 2162.

The denial authority in this instance is Major General Franklin J. Blaisdell, Director of Nuclear & Counterproliferation, DCS/Air and Space Operations.

Should you decide that an appeal to this decision is necessary, you must write to the Secretary of the Air Force within 60 calendar days from the date of this letter. Include in your appeal your reasons for reconsideration and attach a copy of this letter. Address your letter as follows:

Secretary of the Air Force
THRU: 11 CS/SCS (FOIA)
1000 Air Force Pentagon
Washington DC 20330-1000

The Office of Nuclear and National Security Information (ONNSI) located at the Department of Energy recommends withholding the same information for the following reasons:

Title 5, U.S.C. Section 552 (b)(3). The Atomic Energy Act (AEA) of 1954, as amended, 42 U.S.C. 2011 et seq., is an exemption 3 statute. Section 141-146 of this Act (42 U.S.C. 2161-2166) prohibit the disclosure of information concerning atomic energy defense program that is classified as Restricted Data pursuant to the AEA. The portions deleted from the subject documents pursuant to exemption 3 contain information about the military utilization of atomic weapons that has been classified as FRD. Disclosure of the exempt data could jeopardize the common defense and the security of the nation.

To the extent permitted by law, the DOE pursuant to 10 CFR 1004.1, will make available records it is authorized to withhold under the Freedom of Information Act (FOIA) whenever it determine that such disclosure is in the public interest. With respect to the information withheld from disclosure pursuant to exemption 3, the DOE has no further discretion under the FOIA or DOE regulations to release information currently and properly classified.

Mr. Roger K. Heusser, Acting Director, ONNSI, is the denial authority.

You may appeal this decision in writing, within 30 calendar days from the date of this letter to the Director, Office of Hearing and Appeals, Department of Energy, 1000 Independence Avenue, SW., Washington DC 20585. The written appeal, including envelope must clearly indicate that a Freedom of Information appeal is being made, and the appeal must contain all other elements required by 10 CFR 1004.8. Judicial review will thereafter be available to you: (1) in the district where you reside; (2) where you have your principal place of business; (3) where the Department's records are situated; or (4) in the District of Columbia. In your appeal to DOE refer to their case #00SA20C000079-BD.

The undersigned is the action officer on (703) 696-7267.

Sincerely

RHONDA M. JENKINS
Chief, Documentation Information &
Services Branch

Attachment:
Releasable records

00-0454

UNCLASSIFIED

RESTRICTED DATA

ATOMIC ENERGY ACT-1954

MEMORANDUM

RM-4381-PR

JULY 1965

WARTIME MISSILE STRIKE INTELLIGENCE: AN INDIRECT BOMB DAMAGE ASSESSMENT SYSTEM (U)

L. T. Mast

PREPARED FOR:

UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation

SANTA MONICA • CALIFORNIA

UNCLASSIFIED

SECRET

UNCLASSIFIED

RESTRICTED DATA

ATOMIC ENERGY ACT-1954

MEMORANDUM
RM-4381-PR
JULY 1965

WARTIME MISSILE STRIKE INTELLIGENCE: AN INDIRECT BOMB DAMAGE ASSESSMENT SYSTEM (U)

L. T. Mast

This research is sponsored by the United States Air Force under Project RAND—Contract No. AF 49(638)-700—monitored by the Directorate of Operational Requirements and Development Plans, Deputy Chief of Staff, Research and Development, Hq USAF. Views or conclusions contained in this Memorandum should not be interpreted as representing the official opinion or policy of the United States Air Force.

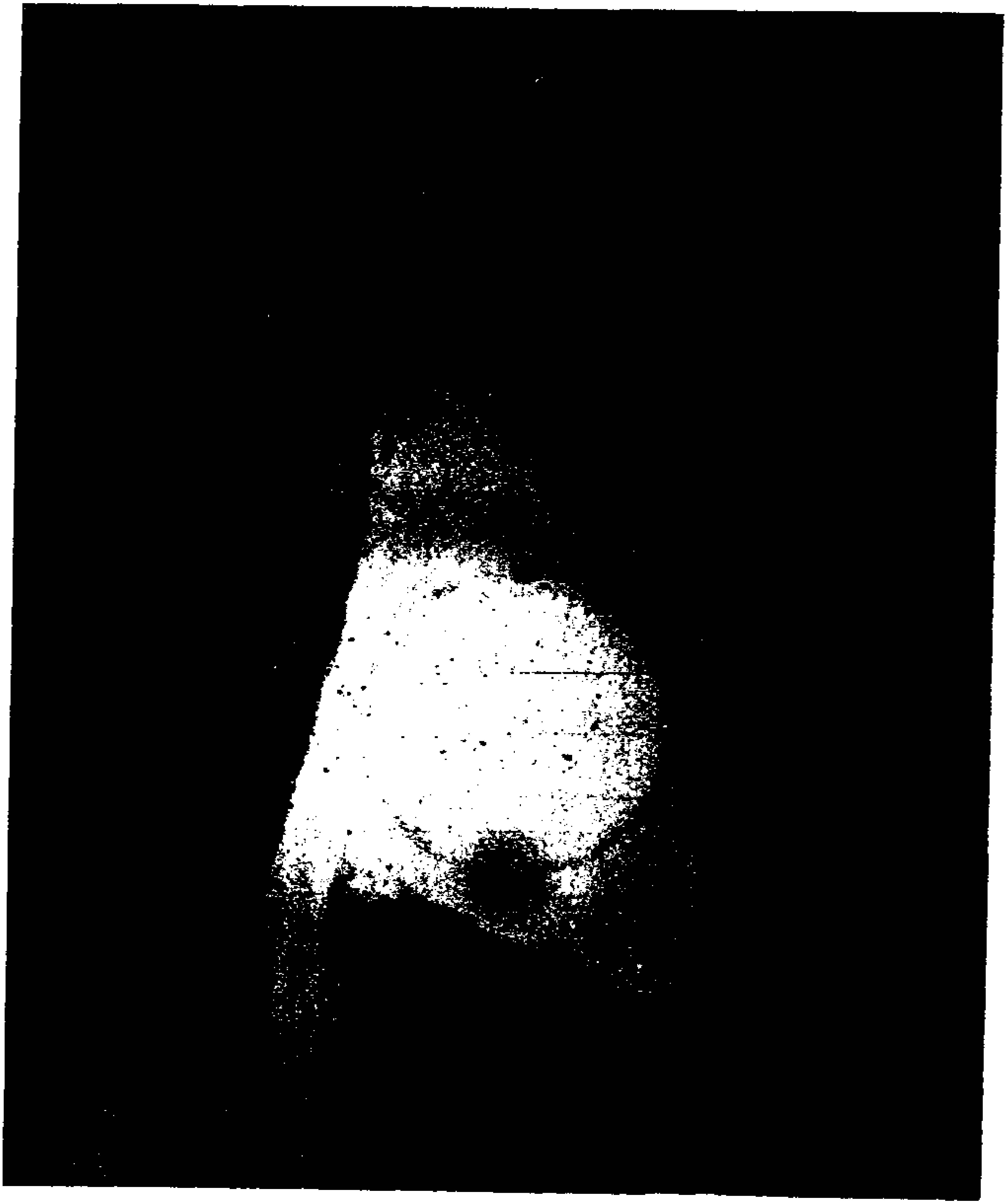
The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA • 90406

~~GROUP-1~~
~~EXCLUDED FROM AUTOMATIC~~
~~DOWNGRADING AND DECLASSIFICATION~~

~~XCLUDED FROM GDS~~

SECRET

UNCLASSIFIED



Redwing series
Shot Erie on Eniwetok—Yvonne
Tower burst—a few milliseconds after burst

PREFACE

This Memorandum suggests a possible means for increasing the effectiveness obtainable from strategic missile forces per se and from mixed forces that include such missiles. The study is a part of an on-going examination of anticipated future needs in the strategic missile force. The work builds upon previous RAND studies and war games.

SUMMARY

This Memorandum examines in some detail a possible system for increasing the effectiveness of a strategic missile force for nuclear exchanges, particularly those other than an all-out initial exchange.

The proposed system would use TV cameras carried piggyback on ICBMs. Each TV camera would be fired from the ICBM at the end of boost into a trajectory that would put it behind and above the ICBM at the time of warhead burst. The TV-camera unit would then send images back, via a satellite- or missile-carried relay, to command centers in the U.S. ZI. This Assistance in Impact and Damage Evaluation (AIDE) system provides a possible technique for real-time damage assessment, thereby making possible "shoot-look-shoot" employment of ICBMs. In the operational context this offers the opportunity to:

- kill more targets with a given missile force
- obtain very high confidence kills with fewer missile firings
- better cope with errors in estimation of missile kill probability, and
- improve the use of a mixed strategic force.

Appendices provide technical backup data, including costs, to indicate the feasibility of the technique.

ACKNOWLEDGMENTS

The author is indebted to E. Bedrosian, K. B. Bley, L. B. Early, W. R. Elswick, N. E. Feldman, R. H. Frick, F. R. Gilmore, S. A. Haggart, V. G. Jackson, T. M. Parker, and R. R. Rapp of The RAND Corporation for their technical assistance and encouragement in the preparation and review of this Memorandum.

CONTENTS

Section

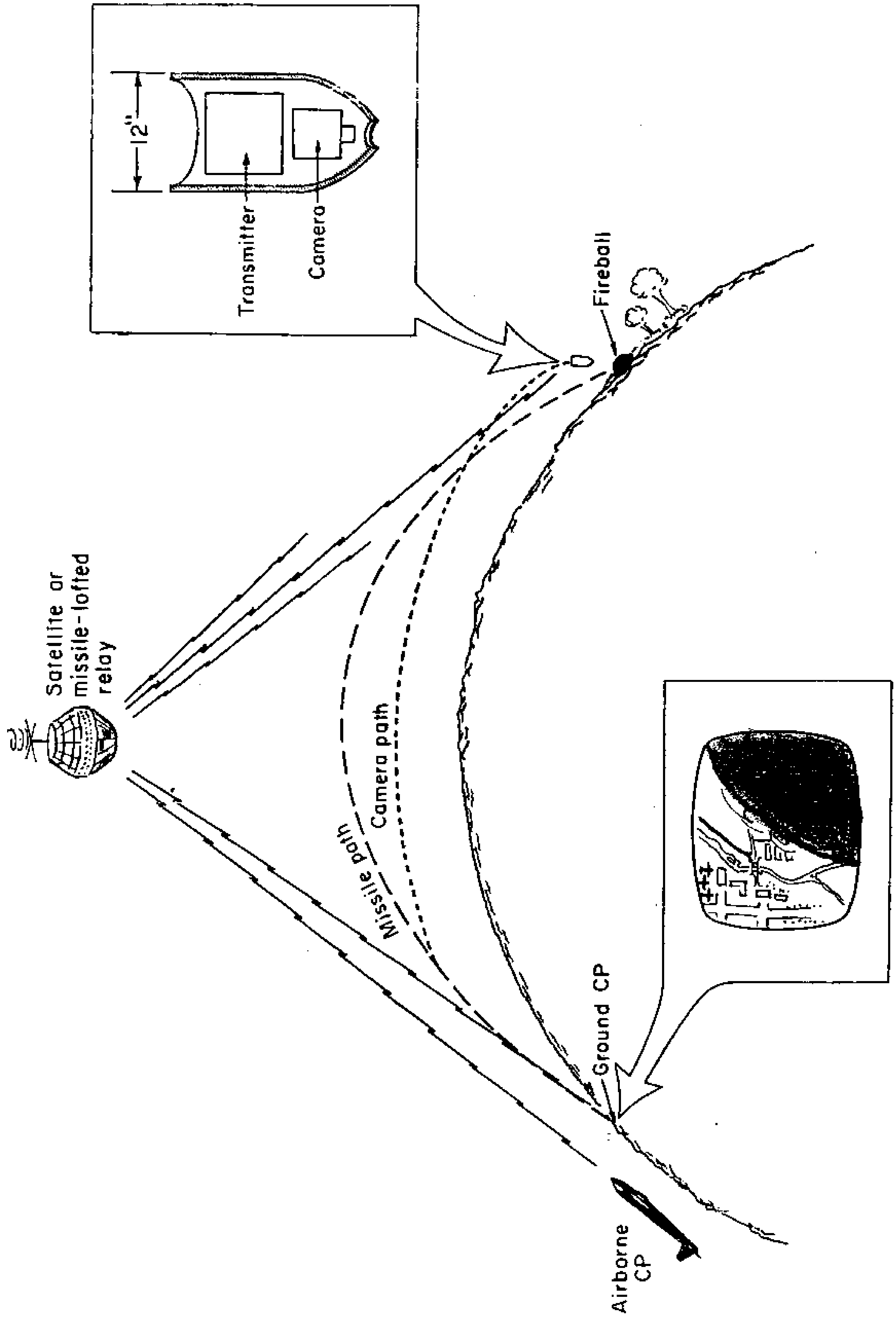
Appendices

I. INTRODUCTION AND RATIONALE

A system that could supply real-time information about the location of a missile's warhead burst and provide partial damage assessment is depicted in the figure on p. 2. A TV camera would view the warhead burst and the landscape in the vicinity of the burst and transmit the images to the missile commander via a relay. The images would be sufficiently accurate and detailed to permit rapid location of the warhead burst on the target map, thus permitting rapid assessment of the probability of target kill. This "Assistance in Impact and Damage Evaluation (AIDE)" system and its elements will be described later in some detail. First, we will examine benefits and penalties associated with such a system.

Possible nuclear wars span the range from the exchange of a single warhead of a few KT yield to the exchange of many megatons. We assume that no one today can identify with certainty which of these wars, if any, is to occur. We also assume that military force will not be used unless methods short of force fail to obtain a political objective deemed essential. However, U.S. military forces should be capable of responding with maximum flexibility to the demands placed upon them, i.e., for meeting a stated demand, minimum force expenditure with minimum side effects would be desired. As will be shown, Indirect Bomb Damage Assessment (IBDA) can increase both the effectiveness and the flexibility of using a missile force.

In the diplomatic arena, there may be special advantages associated with more complete knowledge (than would be available from present quick response information sources) of targets destroyed in a controlled



Assistance in Impact and Damage Evaluation (AIDE) system

UNCLASSIFIED

or counterforce war. As an example, if negotiations are under way, knowledge of the exact condition of targets previously attacked could be a major advantage and could reduce the chances of misjudgment. (The statements concerning missiles in Cuba before and after reconnaissance photography provide a peacetime example of the advantages of positive information.) The proposed system, although not providing precise information, would add greatly to the knowledge one would otherwise expect to have of the targets' condition subsequent to missile strikes against them.

Today's ICBMs can be compared to accurate, very long range artillery. Military experts generally agree that a front line spotter is a major asset in making artillery fire effective. The spotter provides real-time damage assessment and aiming correction as necessary. It is reasonable to postulate that gains can be made by use of real-time damage assessment in a missile war. Several authors,(1,2) have investigated utilization of and techniques for damage assessment in a "shoot-look-shoot" employment. Table 1 compares the number of missiles required with assignment on a pure probability basis and those required using a "shoot-look-shoot" technique to accomplish various hypothetical objectives. As can be seen from Table 1, shoot-look-shoot offers the opportunity to (1) kill more targets with a given missile force, (2) obtain very high confidence of target kill with a smaller expenditure of missiles (Case I compared to Case II), or (3) better cope with errors in estimation of missile kill probability (it is less sensitive to these errors in terms of the number of missiles required). For instance, 400 missiles are programmed

Table 1[a]

FORCE SIZE BENEFIT OF SHOOT-LOOK-SHOOT TECHNIQUE AGAINST 100-TARGET COMPLEX

	Number of Missiles to Ac Indicated Kill of 100 Ta	
	No-information[b]	Shoot-loo
Case I Missile p_k = 0.5[d] Desire: 90% probability of at least killing 90 targets	400	20 (4 sa
Case II Missile p_k = 0.5[d] Desire: 99% probability of at least killing 99 targets	1000	23 (10 s
Case III Missile p_k = 0.25[d] Desire: 90% probability of killing at least 90 targets	1000	40 (10 sa

[a] The mathematics to support the cited numbers are in Appe

[b] The "No-information case" is independent of missile laun and thus permits all missiles to be launched in a single sal

[c] Shoot-look-shoot employs the launching of a missile at e viving target in successive salvos.

[d] p_k = missile overall probability of kill and includes mi readiness, the countdown and launch probabilities, probabili penetration, the probabilities of fuzing and detonation, and single-shot probability of kill based on CEP and weapon radi

[e] Number of salvos cited is the maximum needed to meet the cribed cases; the actual number may be smaller.

for the no-information situation, based on an assumed 0.5 single-shot probability of kill. With shoot-look-shoot, even if the actual single-shot probability of kill dropped to 0.25, the desired level of effectiveness would be maintained. With no information, 30 targets on the average would survive and the mission objective would not be met.

The remainder of this Memorandum will describe sources of errors, possible IBDA systems, the environment in the vicinity of warhead burst, bomb and weather interaction, the elements of the proposed system, and conclusions. Appendices provide technical details and calculations.

II. SOURCES OF ERRORS IN MISSILE STRIKES AND POSSIBLE REMEDIES, INCLUDING IBDA SYSTEMS

First, let us look broadly at possible sources of error in missile strikes and, secondly, at some of the techniques that have been proposed for minimizing their effects. Failure to kill the target can result from any of a multiplicity of difficulties.

CATEGORIES OF DIFFICULTY

Intelligence Inaccuracies*

According to Air Force intelligence sources, errors exist in the designated location of some fixed targets. The accuracy with which the location is known depends upon the source of the targeting information. Normally, the information is quite accurate, however on a few occasions it has been necessary to shift target locations by several miles. Especially for hard targets, errors in location would permit the target to survive an otherwise perfect missile flight.

Mapping Errors*

Major portions of the Sino-Soviet land mass have not been accurately located in the DoD geodetic system.(3) Reference 3 shows potential errors of up to eight miles for approximately the western one-third of China, and one-half to two-mile potential errors for approximately three-fourths of the USSR.

Delivery System Failures

In this category are included failures during launch, boost, penetration of enemy defenses, and detonation. Other sources

---

*It is possible that intelligence and mapping errors may be reduced, perhaps through satellite photography, within the next decade. However, they still presumably will remain large relative to the errors in the proposed system.

of inaccuracies can be introduced by variations in reentry conditions.

Next we will look at some possible approaches for increasing knowledge of missile conditions (and therefore effectiveness). These are listed in order of time of occurrence.

CATEGORIES OF POTENTIAL REMEDIES

From Initiation of Launch Attempt to Warhead Detonation

A Signal that the Missile Has Been Launched Successfully. This could be used as an input to a scheme for replacement of missiles that fail prior to launch. This approach could permit replacement with a very small loss of time, conceptually on the order of 30 seconds.

To do this, and to implement all other schemes suggested, a command control system (at least among the missile control centers) and missiles with more than one target capability would be necessary; these are assumed to exist.

A Signal from the Missile at the End of Boost. This would inform the commander of the missile's boost reliability (or that the booster and guidance system have performed within specifications). This signal could be used to estimate the missile's projected effectiveness against its assigned target and where the estimated effectiveness is below that desired, another missile could be launched against this target. Since the boost phase takes less than five minutes, even after adding the necessary countdown and retargeting time, the replacement could be launched within five to seven minutes of the first launch.

The Detonating Signal to the Warhead. When the warhead is triggered milliseconds prior to detonation, this signal could be relayed, along with appropriate missile identification, to the missile force commander. Such a signal would ensure that the warhead had penetrated. Its absence would indicate that at least one more warhead is needed against this target. The delay between successive shots now could be as much as 30 to 40 minutes because of the missile's flight time.

Following Warhead Detonation

Sensing Detonation Outputs. There are a number of possible schemes for this, including the sensing of the electromagnetic output, the heat pulse shape, or other radiations from the warhead. Generally these techniques would provide additional information over that supplied by the last scheme mentioned above, in that they permit an estimate of the yield. [redacted] Surface or subsurface methods of warhead detonation detection can also be used in some cases, but they generally cannot measure yield and locate the detonation accurately.(2)

DoE
b(3)

Sensing Detonation Output Reflections from Nearby Topographical Features. For this, the use of visible light output appears feasible, and will be described in detail in Sec. III. Close-in sensing would be desirable for accuracy, resolution, and reduction of probable interference from cloud cover. On the other hand, satellite observation of the light or heat energy output of the warhead (assuming a surface burst) would be heavily dependent upon cloud location, altitude, and moisture content. Cloud conditions that would obscure direct visible light observation by a satellite can be expected more than 70 per cent of the time; therefore, satellite observation is considered not reliable enough (Appendix C). Observation of electromagnetic signals by a satellite would not permit accurate location of the detonation site or yield determination because of the attenuating and scattering of ionized material. Accuracy in such an application would call for either large antennas or long baselines for triangulation, neither practicable with a small, light satellite.*

All the post-detonation schemes could supply partial assessment of all three sources of error or failure: intelligence, mapping, and delivery, as well as providing a coarse measure of yield. Further, if the data were transmitted immediately to the commanders in the U.S. ZI, these "systems" would permit replacements at the same rate as would the detonation signal technique, that is, 30 to 40 minutes.

Target Area Observation After Clearing. Observation after the detonation effects have cleared appears to be possible using manned aircraft or satellites. If this could be accomplished it would permit more accurate examination of the extent of target damage than would any previously mentioned approach. With aircraft, the major problems appear to be penetration and survival over enemy territory and possibly the rapid communication of results. For satellites, the problems of positioning, atmospheric interference, etc., probably would delay receipt of information and replacement launchings by at least 24 hours. For counterforce targets, replacement speed is considered critical. However, delayed but accurate observation results would be especially

---

*There appear to be three possible techniques for performing BDA from satellites: (1) Use of 8-12 micron infrared, except during conditions of dense cloudiness or cover by heavy dust clouds, (2) use of radiometry in the 3-10 cm band, and finally, (3) use of side-looking radar, which may now permit 20-ft resolution from a satellite (Ref. 4).

worthwhile for confirmation and correction of the outputs of any IBDA system used.

The preceding examination was designed as a quick look at the general feasibility of various approaches. To summarize, it would be desirable to have a continuous intelligence stream. The initial lift-off information and good-guidance signals would be appropriate as the first and easiest data. Also, an examination of the target area well after detonation (by aircraft or satellite using optics or radar) would be useful for follow-up and perhaps for hunter-killer operations. This work describes a technique for obtaining real time information by use of an optical sensor close to the warhead detonation.

A Note on Timing

In each situation discussed previously, the time delay between the first launch attempt and a replacement was emphasized. This is because the associated time loss is the major penalty in shoot-look-shoot or IBDA schemes. During the seconds or minutes between successive launch attempts, several things can occur. For example, if the targets are weapons, they may be fired against us; the missiles we hold back for the follow-up shots may be damaged or destroyed by enemy action. Therefore, the delay between successive shots should be minimized, consistent with good missile utilization and the objectives of the particular encounter. The use of missiles held in reserve to kill surviving high priority targets is assumed to be desirable, even in the massive exchange case.

WARHEAD DETONATION AND ITS ENVIRONMENT

Now, let us look at the environment in which the proposed AIDE system is to work; that is, (a) the available knowledge of the targets, (b) possible sources of information as to where the warhead detonated with respect to the target, and (c) the characteristics of the weather in the target area and the detonation-weather interaction.

It is assumed that the target's gross physical characteristics and its surrounding topography are supplied in a target map such as those in a strike aircraft's target package.

The missile delivers a warhead to the vicinity of the target, where the warhead is detonated. The warhead burst provides, momentarily, levels of light much in excess of other light sources. This light is brighter than bright sunlight and its spectral distribution is similar to that of unfiltered sunlight.(5) Without atmospheric losses, the light level from a one-megaton warhead would be greater than bright sunlight out to more than 11.0 n mi (Appendix B).

Cloud cover occurs frequently over a major portion of the Soviet Union.(6) However, the thermal energy of a nuclear burst will evaporate a large amount of cloud, the amount varying with weapon yield and cloud density. In the Moscow area,* at least 95 per cent of the time the moisture density in clouds is less than .30 gm/m^3.(6) A 1-MT warhead will evaporate cloud of this density out to about two n mi. A 2.5 gm/m^3 or greater density cloud cover is extremely rare, but even it would be

---

*This area appears to have a cloud cover and associated weather problems as bad as or worse than most of the other parts of Eurasia.

evaporated out to about one n mi (Appendix C). Therefore, if images were recorded a few seconds following a 1-MT burst, within two n mi the target area should be clear 95 per cent of the time and within one n mi essentially all of the time.

Under some conditions dust may obscure the view during later shots in a series. However, this is not a likely event (Appendix D) if the shots are separated by at least 30 minutes.

III. AN ASSISTANCE IN IMPACT AND DAMAGE EVALUATION (AIDE) SYSTEM

The AIDE system would consist of:

1. a TV camera and transmitter package boosted piggyback with the warhead into the vicinity of the detonation
2. relays located so that they can retransmit the images from a wave of missiles back to the United States
3. ground receivers, recorders, and processors at the missile command centers in the ZI.

The warhead burst would supply both light energy for illumination and energy for clearing the atmosphere in the vicinity of the detonation, so that a camera located 10,000 to 15,000 feet above and 3,000 to 4,000 feet short in range at the time of detonation could view the detonation and the surrounding topography as illuminated by the burst. If the TV package is sent along a separate trajectory from missile burnout and has a slower reentry velocity, it can be placed in the correct location. A slower velocity after reentry is desired, to obtain the better viewing position as well as to prevent aerodynamic heating from interfering with the lenses during camera use. The missile and camera trajectories have the detonation location in common. Therefore, the camera package could be aerodynamically stabilized along its flight path and thus view the warhead burst essentially directly ahead of its position.

As envisaged, the camera package would be ejected into a lower altitude, higher velocity trajectory so that at the beginning of reentry (at the top of the atmosphere) it would be 10 miles further in range and 50 seconds ahead of the warhead. This would permit the camera to employ a lower ballistic coefficient and to reenter much slower than the warhead. Sensitivity to errors in camera position due to propulsion or alignment errors are discussed in Appendix E. The camera package starts with the velocity of the warhead and the incremental change in velocity is small; a 10-per cent error in the amount of the incremental propulsion given the camera package represents 1 n mi in range (maximum) or 5 sec in timing (maximum) or some combination of lesser amounts of each. The angle of thrust application is controlled by the missile guidance system so that precision can be expected in this alignment.

If the TV camera had a 2-n mi by 2-n mi field of view from 15,000 ft, and commercial TV camera resolution were used, the picture would permit the detection of 60-ft-square objects of medium or high contrast (large buildings, hills, etc.) and identification of objects perhaps 3 to 4 times the detection minimum size.[*] If the scanning rate were 10 pictures per second, the transmitter power requirement would be approximately 2500 watts (Appendix F). A timer can be used to control the period of picture taking and transmission to minimize battery power requirements.

Appendix G presents aircraft photography of the Redwing series of nuclear tests.(7) These photos provide a rough analogy to what might be obtained from the AIDE system. The first set (Dakota) and its corresponding map are of a 1.1-MT shot and are presented at approximately 10 photos per sec, with a 2.5-by-4-mile field of view. The second set is another shot of the same location viewed from a different angle. The third set is of special note because it illustrates how photographs taken when the camera is mislocated (but still showing the shock wave) can be used to determine the burst point. The fourth set illustrates closer frame spacing (64 frames per sec); the reader can see that the incremental increase in information is small.

---

[*] Long objects such as roads, railway roadbeds, of high contrast will also be detected even if their width is considerably below the 60-ft dimension.

For the AIDE system, the interactions among warhead, weather, and camera trajectory are of special importance. During clear weather, the pictures taken a few milliseconds after detonation would be best (Appendix G, first set), but as the camera proceeds toward the detonation, the thermal energy of the bomb may destroy it. During cloudy weather, the initial pictures may be useless, but during the time of the camera's approach the warhead continues to release thermal energy to dissipate the clouds, so the photos should improve. The duration of high-level light energy is 10 sec, as previously noted. During this time the camera would travel about 10,000 ft toward the detonation. Therefore, a 10-sec picture-taking period would greatly increase the probability of obtaining the desired information (Table 2) over the spectrum of possible weather.

Table 2

TIME RELATIONSHIP OF BURST, CAMERA RANGE, AND CLOUD DISSIPATION FOR 1-MT YIELD

	Time (sec)					
Detonation Event	0	2	4	6	8	10
Cumulative percentage of thermal energy released	0	.47	.65	.72	.78	.82
Camera range, nom, (x 10^3 ft) ± 5000 ft max	15	13	11	9[a]		
Vertical cloud dissipation (x 10^3 ft) at least 95 per cent of time (includes fireball rise)	0	7.5	8.3	9		
Horizontal cloud dissipation (x 10^3 ft)	0	7.5	7.8	8		

[a] Approximate edge of fireball.

To make the comparison of the TV picture and the target map easier, the TV picture could be identified by missile number, and the north direction (to within ± 5 deg) could be identified on the picture. A simple coder for missile identification and a coarse north reference are suggested for incorporation into the package for this purpose.*

The sensitivity of the camera package to bomb effects is discussed in Appendix H, which shows that if the camera package can withstand reentry, the initial bomb effects will not disrupt its proper functioning.

A further note to support the feasibility of the proposed camera package is the successful design, fabrication, and test of a similar camera package for a short-range ballistic missile.(8)

As shown in Appendix I, the proposed camera package would have a total weight of about 50 lb, and it is visualized to be approximately a 1-ft diameter cone with an 18-in. length. The amount of propellant is estimated to be 4 to 6 lb and the control of this propulsion after initial alignment can be coarse (Appendix E).

RELAY STATION

The relay station(s) would be a package of transceivers located so that line-of-sight communication is possible with both ends of the system. If the transceiver were near 2500-mi altitude and near mid-range, it would meet the necessary physical relationships.

---

*A number of schemes have been proposed. The simplest scheme is a magnetic compass driving a pointer in the camera field of view. Because a compass may not function satisfactorily in this environment, a gyro spun up at separation from the guidance system might be used instead.

A 5-min duration, or greater, of line of sight to both terminals (the camera and ground CP) is desired so that the time regulations are not too strict. Simple calculations show an 8-min duration for a single satellite at 2500-n mi altitude and mid-range, with an orbit inclination approximately parallel to the missile trajectory. More complex computations show that a ballistic trajectory for the relay would permit about a 14-min duration (Appendix E).

With a 10-sec message from each warhead and a 10-min dispersion of warhead detonations, each relay device can handle several warheads sequentially. With 10 transmitters working into one relay, the probability of two or more messages occurring simultaneously, assuming random distribution over 10 min, is 0.16 and the probability of 90 per cent blockage of one message is 0.015. (If lower probabilities are required, fewer warheads can be assigned per relay.) This relay package would transmit 500 watts and, based on the TV analysis, would require approximately 21 lb per channel assuming no transmitting except when a signal is present (Appendix I).

The relay station, as indicated earlier, can be in orbit or on a high ballistic trajectory. With increases in power outputs and provisions to avoid ringing (continuous retransmission of the same message), several relays could be used, one over the target area at 2500 n mi altitude and one midrange; or a method providing 100 per cent redundancy would be to place relays at the target area, halfway to the target area, and over the ground station. If the latter scheme were used, eight relays would provide continuous coverage (spaced 45° apart) until the line of sight between the relays and the target or ZI terminal passes over the horizon due to earth rotation (approximately six hours).

There are a number of methods of obtaining the desired relay. A military communication satellite could conceivably be used if it were in the right time-place relationship, or a special relay(s) for this purpose could be used; this special relay could also be used for other purposes. For this discussion, we will consider the special purpose relay(s). If the Minuteman boosters were assigned to deliver the relays, each could deliver approximately 500 lb into the 2500-n mi apogee ballistic trajectory. One relay package of this type could handle approximately 240 missile warheads maximum (Appendix I).

ZI COMMAND POST

At the missile control centers, a station suitably hardened or mobile could intercept, display, and record the relayed signals. Conceptually these signals could be displayed directly to a targeting officer, permitting him to work with information in real time (since the pictures are identified by missile warhead, north identified, and presumably he has target maps). He could assess kills and misses as the information is received. Of course, the data should be recorded for analysis later as required.

In practice one can readily visualize that the amount of data coming in from, let us say, a 240-missile strike would require 24 simultaneous displays. High-speed photography can be used to handle this amount of data. If the pictures are received, recorded by photography, and placed into a computer controlled display system, the photographs can be sorted, oriented, and displayed adjacent to the appropriate target map. A viewer could then compare the burst photos with the target map and assess miss distances and damage information. (The reader is urged to try his hand at the former, using the photographs and maps in Appendix G, Set 1. Either distance or angle scaling techniques can be used.) If the inputs are the miss distance, yield, height of burst, and target number, including vulnerability number, the computer can calculate the probability of kill. This procedure would allow the rapid scanning of the photographs and target maps so that two such display consoles would permit processing of the strike within minutes. As misses become known, missiles can be targeted (or the missile selected with this target stored) and the second wave prepared.

The signal from the relay would be sent out on a broad beam and therefore could be intercepted at a number of locations, such as intelligence centers, airborne or ground command posts, and at any other desired location in the United States. Note that this information feedback can advise the SAC commander of the effectiveness of his missile force without the existence of other communication media, and may permit better coordination of missile-aircraft strike forces.

As an example: let us assume that a portion of the missile force is allocated to knocking out air defenses to aid bomber penetration. After each wave the command structure is aware of which air defense installations have been destroyed and which defenses remain. Even if as many as three waves (assuming one hour required for each shot) are used and communication with the bomber force exists, the command center could possibly reroute the bomber force to avoid the remaining defenses. This aspect could magnify bomber effectiveness.

COSTS

The five-year costs for equipping 1000 Minuteman and 54 Titan II missiles with AIDE and providing relays, ground stations, etc., is estimated to be approximately $625 million (including R&D costs). This overall cost is comparable with the five-year cost of 100 pre-wing VI Minuteman missiles (Appendix J).

ENEMY COUNTERMEASURES

The enemy could destroy the AIDE system by:

1. Jamming the relay. The proposed system is highly susceptible to enemy jamming. A repeater located near the target area looks particularly attractive. Counter-countermeasures appear to also be possible. This area warrants further study.
2. Using the advance notice given by the camera as a warning of the following warhead. The 50-sec time differential affords some advance warning. If the camera appears to be a decoy, this warning may not be significant. Again, further study is suggested.
3. Shooting down each camera when it is reentering. (The camera here is a decoy.) This method would also be effective, but of course would attract defensive fire away from the warhead.
4. A high-altitude blast could provide attenuation between camera and relay or between relay and ground station. This effect lasts for minutes out to ranges of 50 mi and may be a good counter against communication near known target areas.
5. Destroying communications within the ZI. This is the command control problem, but the proposed system is limited to the links between the missile commander to missiles and to the ground station antennas.

IV. CONCLUSIONS

A sizable gain in missile force effectiveness during war-fighting periods appears attainable with the proposed AIDE system over much of the spectrum of possible nuclear wars. Combined use of IBDA techniques, of missile-away signals, good guidance signals at the end of boost, the proposed AIDE system, and later post-attack reconnaissance appear to offer the elements of a good system mix.

The proposed AIDE system described here consists of a piggyback TV camera package for each missile, a specially launched relay package for each wave of missiles, and augmented command installations that can receive, sort, match with target maps, and then display the TV pictures and maps together. Use of Appendix G maps and photographs and crude graphical techniques provides location accuracies within 1000 ft. Appropriately designed techniques could offer large improvements in accuracy.

The proposed AIDE system would provide a technique for real-time damage assessment and for "shoot-look-shoot" employment of ICBMs. The entire missile force could be equipped and operated for five years at a cost of about $600 million. Operationally, the system would permit:

- killing more targets with a given missile force
- obtaining very high confidence kills with fewer missiles
- coping better with errors in estimation of missile kill probability, and
- improving the effectiveness of a mixed strategic force.

Appendix A

COMPARISON OF SALVO AND SHOOT-LOOK-SHOOT TECHNIQUES

CASE I

Desire: At least 90 per cent of the targets to be killed with probability 0.9.

A. No-information (Salvo) Situation

No damage assessment. Salvo nT missiles. How many missiles are required to satisfy the condition $P(x > 0.9T) = 0.9$?

Where x	number targets killed, x has a binominal probability density function $f(x) = \binom{T}{x} p^{x} \cdot (1 - p)^{T-x} \quad x=0,1,2\ldots T$
T	number of targets
P_{kss}	single-shot kill probability (includes missile reliability, penetration, and target damage)
n	number missiles per target
p	multiple-shot kill probability $p = 1 - (1 - P_{kss})^{n}$
$p(1-p)T$	variance of number of targets killed

If one uses the normal probability density function as an approximation to the binominal, the value of p that satisfied the condition $P(x > 0.9T) = 0.9$ can be found from the equation

$$0.9T = pT - 1.28 \sqrt{p(1-p)T}$$

If $T = 100$; $p = 0.932$

If $P_{kss} = 0.5$; $n = 4$. If $P_{kss} = 0.25$; $n = 10$.

Thus, 400 and 1000 missiles are required when $p_{kss} = 0.5$ and 0.25 respectively.

B. Shoot-look-shoot Situation

Perfect damage assessment. How many missiles are required to satisfy the condition $P(n < N; 0.9T) = 0.9$?

Where N total number of missiles required

n shot on which the $(0.9T)^{th}$ target is killed, has the following probability density function

$$f(n;0.9T) = \binom{n-1}{0.9T-1} p_{kss}^{\,0.9T} (1-p_{kss})^{n-0.9T} \quad n=0.9T, 0.9T+1, \ldots$$

$\frac{0.9T}{p_{kss}}$ average number of shots needed to kill 0.9T targets

$\frac{0.9T(1-p_{kss})}{p_{kss}^2}$ variance of n

If one uses the normal probability density function as an approximation to $f(n;0.9T)$, the value of N that satisfies the condition $P(n<N;0.9T) = 0.9$ can be found from the equation

$$N = \frac{0.9T}{p_{kss}} + 1.28\sqrt{\frac{0.9T(1-p_{kss})}{p_{kss}^2}}$$

If $T = 100$ and $p_{kss} = 0.5$; $N \approx 200$

If $T = 100$ and $p_{kss} = 0.25$; $N \approx 400$

Thus, 200 and 400 missiles are required when $p_{kss} = 0.5$ and 0.25, respectively.

The number of salvos required to kill in the shoot-look-shoot situation is equal to the number of missiles per target in the no-information situation.

CASE II

Desire: At least 99 per cent of the targets to be killed with probability 0.99.

A. No-information (Salvo) Situation

With no damage assessment, how many missiles are needed to satisfy the condition $P(x \geq 0.99T) = 0.99$?

Using the binominal probability distribution (where $T = 100$), the value of p that satisfies the condition $P(x = 99 \text{ or } 100) = 0.99$ can be found from the equation

$$100\, p^{99}\,(1 - p) + p^{100} = 0.99$$

In this case

$p \approx 0.9985$

If $p_{kss} = 0.5$; $n = 10$.

Thus, 1000 missiles are required.

B. Shoot-look-shoot Situation

With perfect damage assessment, how many missiles are required to satisfy the condition $P(n < N; 0.99T) = 0.99$? Again, if one uses the normal approximation to $f(N;0.99T)$, the value of N can be found from the equation

$$N = \frac{0.99T}{p_{kss}} + 2.33\sqrt{\frac{0.99T(1-p_{kss})}{p_{kss}^2}}$$

If $T = 100$ and $p_{kss} = 0.5$; $N \approx 230$

Thus about 230 missiles are required.

Appendix B

WARHEAD BURST EFFECTS

LIGHT ENERGY AND RANGE CALCULATION FOR A ONE-MEGATON WARHEAD

A 1-MT bomb releases energy equivalent to approximately 10^{15} calories,(5) of which from 35 per cent to as much as 49 per cent(5,9) is thermal energy. The thermal radiation is located mostly in visible and infrared wavelength regions. The visible light region contains conservatively 30 per cent of the thermal energy. The effective rate of thermal energy(5) for a 1-MT detonation is 127 KT/sec maximum, or 127×10^{12} calories/sec, or 38×10^{12} calories of visible light. Over the region of 1 to 10 seconds, the rate varies from 100 to 5 per cent of the maximum,(5) giving a minimum rate of 1.9×10^{12} calories of visible light per second. The sun provides .033 calories/cm^2/sec(10) above the atmosphere when overhead. If one computes the range in clear air for lighting equivalent to direct sunlight overhead,

$$.033 \text{ cal/cm}^2\text{/sec} = \frac{1.9 \times 10^{12}}{4\pi R^2} \text{ cal/sec}$$

$$R^2 = \frac{1.9 \times 10^{12}}{.424}$$

$$R = \sqrt{4.49 \times 10^{12}} = \text{approx. } 2.1 \times 10^6 \text{ cm}$$

$$R > 68{,}800 \text{ ft or approximately 11 n mi.}$$

Appendix C

EVAPORATION OF CLOUD AND FOG BY NUCLEAR DETONATION

Reference 9[*] is a detailed discussion of the amount of radiant energy delivered to a target at a distance, d, from ground zero and a height, H, above the surface. As a first approximation, however, the amount of energy available to evaporate cloud and fog droplets may be expressed as

$$Q_a = f\,F_t\,W\,\tau \tag{1}$$

where Q_a is the available energy for the evaporation of cloud droplets,

f is the fraction of the thermal energy that can be absorbed by water drops and is not seriously attenuated by water vapor,

F_t is the fraction of the bomb energy available for thermal radiation,

W is the yield of the weapon expressed in calories, and

τ is the transmission of the atmosphere.

The energy required to evaporate the clouds will be given by

$$Q_r = k\,\ell\left(\frac{4}{3}\pi R^3 - \frac{4}{3}\pi R_{fb}^3\right) \tag{2}$$

where Q_r is the energy required to evaporate a cloud of thickness, R,

ℓ is the latent heat of vaporization of water,

k is the liquid water content per unit volume of air, and

R is the radial distance from the center of the fireball in meters,

R_{fb} is the radius of the fireball in meters.

---

[*] Reference 9 assumes that the detonation of the bomb does not change atmospheric transmission. This discussion shows that the atmosphere will be changed in the immediate vicinity of the burst.

If it is assumed that the cloud is uniform in the space about the detonation, the energy reaching a distance, say R', from the detonation will be given by the radiant energy minus the energy absorbed by the water. Thus, at some distance R, where the energy has been reduced to zero, no further evaporation will be possible (no atmospheric heating is assumed from the energy spectrum used for evaporation). Setting $Q_a = Q_r$ and solving for R we find

$$R = \sqrt[3]{R_{fb}^3 + \frac{3\ fF_t W}{4\pi k \ell}} \tag{3}$$

The wavelength region in which water droplets are good absorbers is in the infrared beyond about 1.5μ. The fraction of the thermal pulse(5) in this region is about 10 per cent. We will assume, therefore, that f = 0.1. According to Ref. 9, F_t is about one-third. If a 1-MT device is to be considered, W = 10^{15} calories. For a first approximation it will be assumed that $\tau = 1$. The constant ℓ will be of the order of 600 cal/gram. When these values are substituted into the equation for R

$$R = 3.5 \text{ km}^* \text{ for } k = .3 \text{ gm/m}^3$$

$$R = 1.7 \text{ km for } k = 2.5 \text{ gm/m}^3.$$

Next, we will look at the weather characteristics over European Russia. The area of interest is clear (less than 20 per cent cloud cover over a location) below 15,000 ft approximately 15 per cent of the time.(6) The remaining 85 per cent of the time there is cloud cover at some altitude within this range.

---

*There is experimental evidence of an increase in this evaporation during the first 2-4 sec (for a 1-MT burst) due to air heating by the shock front. The negative portion of the blast wave, which follows in 4 to 7 sec, causes a cooling and condensation that may obscure the fireball at later times.

These clouds are not solid but rather in layers of varying thickness, surrounded by clear air. Over a given location, the total thickness of cloud cover on a cloudy day is usually less than two kilometers. In general, the liquid moisture concentrated in clouds decreases rapidly with altitude.(11) The cloud evaporation capability decreases as the third power of the distance. The probability of the bomb's energy penetrating clouds up to an altitude of 2 to 3 kilometers is therefore quite high. Horizontal clearing will also occur, but the area will be less since the moisture content cannot be expected to reduce with distance from the fireball, as is likely in the vertical direction.

Now let us examine some "worst case" conditions, to clarify the minimum extent of clearing likely. In general, the <u>average</u> liquid water content of clouds in the lower 3 km over European Russia can be expected to be less than 0.30 gm/m^3 more than 95 per cent of the time, with clouds containing 2.5 gm/m^3 (a thunderstorm) or more for considerably less than 1/2 per cent of the time.(6) Assuming (worst case) these clouds are continuous in all directions at these densities, for 0.3 gm/m^3 the cleared distance is approximately 3.5 km or about 11,000 ft and for 2.5 gm/m^3 the cleared distance is 6000 ft. Of these cleared radii, the inside 3000 to 3600 ft is occupied by the fireball.

This analysis is a conservative approximation of the conditions; for more exact evaluation a detailed analysis must be conducted considering the environments of specific targets at particular times of the day and month. Since the weather varies in an irregular cyclic manner, this would result in a probabilistic statement. With knowledge of the weather conditions on a given day, the nature of the statement could be improved in its accuracy and clarity, and this approach might be used to advantage on the specific days of system employment. Appendix G photography shows cloud evaporation in the vicinity of the burst. The second set (Flathead) clearly shows cloud evaporation ahead of the shock wave in frames 23, 30, 37, and 44 (upper right of frame).

In the event of snow on the ground in the target vicinity, most of the time the bomb will melt the snow for two or more thousand ft beyond the fireball. This will enhance the photographic contrast during the melting process. The following calculations show this effect, using likely values.

Assume a maximum melting radius and fireball location such that the line between the maximum melting radius and the mean fireball height is 30 deg above the horizontal. The thickness of snow rarely exceeds 35 cm, which contains 3.5 cm of water.(6) The quantity of energy per cm^2, q_r, to melt the snow is

$$q_r = k\ell = 3.5 \times 80 = 280 \text{ cal}$$

where ℓ = latent heat of melting

k = thickness of equivalent water.

The energy incident on this cm^2 useful for melting snow, q_a, is given by

$$q_a = \frac{(1-a)\ F_t\ W\ \tau\ \sin\alpha}{4\pi R^2}$$

where a = the albedo of snow

α = the angle of incidence of the energy (30°), and

R, τ, F_t, W as previously defined for the cloud case.

Setting $q_a = q_r$, and solving for R

$R \approx 5000$ ft for

$\tau = 1$, $F_t = 0.33$, and $a = 0.5$

The albedo of snow varies between 0.4 for snow that has been on the ground for a while to 0.8 for freshly fallen snow. It is assumed that the former is the more likely case.

Appendix D

POST-BURST DUST CLOUDS

A surface burst of a large nuclear explosion generates a dust cloud by the surface shock wave wind and the heat energy released. The dust cloud appears to form within 10-15 seconds and grows in size and density for the first several minutes. Initially, the dust-laden air is drawn into the stem, but after a few minutes this air is too heavy for the stem to support, and the air flow reverses, with the dust cloud speading out to the 5 to 10 psi region.(12) This is 15,000 to 10,000 ft for a 1-MT surface burst. After spreading out over the area, the dust-laden air moves in accordance with normal gravitational-climatological forces.

For twelve typical locations in European Russia, the smallest wind rose for any quarter of the year is at Strigino. At this location there is at least a 6-knot wind 80 per cent of the time.(13)* This means that for 80 per cent of the time, after one-half hour, the dust cloud will have moved at least 3 n mi, completely clearing the burst point. Observation of the dust cloud in movie films taken in a desert location show the cloud is not opaque, but semi-transparent and observation of major topographical features is possible, except perhaps for a few minutes shortly after the burst. These considerations and observations permit the conclusion that the post-burst dust cloud will not be a serious problem (if a problem at all) in observing nuclear detonations near the same point if there is a one-half hour separation in time between successive shots.

---

*Lesser speed winds are shown in the Caucasus area and much higher speed winds are common to the other parts of USSR.(13)

Appendix E

DELIVERY CALCULATIONS

The amount and direction of the thrust required to place the camera into the proper location has been computed for 3 target ranges, using a minimum energy trajectory.

CAMERA PACKAGE

Target Range	Angle of Thrust with Respect to Line of Flight at Burnout	Δ Velocity
4100 n mi	- 75°	861.00 fps
4800 n mi	- 80°	723.00 fps
5500 n mi	- 84°	605.74 fps

These incremental velocities computed for a 50-lb package represent 4 to 6 lb of 250 I_{sp} propellant and a total 5-to 7-lb propulsion system.

$$\frac{m_p}{m_o} = 1 - e^{\frac{-\Delta V}{gI_{sp}}} = 1 - e^{-.1} = 1 - .905 = .095 \approx .1$$

$$\frac{\text{Mass of propellant}}{\text{Initial mass of object}} = \frac{\Delta V}{gI_{sp}} = \frac{800}{32 \times 250} = .1,$$

or 5.0 lb of propellant.

Since the camera must travel 10 miles farther before reentry, a 10 per cent error in propulsion amount, by simple ratio, represents a change of approximately 10 x .1 = 1 n mi in range. Again, the camera must arrive 50 seconds early; a 10 per cent error in propulsion amount again by simple ratios represents 50 x .1 or 5 sec in timing. Five seconds in time represents 3,000 to 5,000 ft in camera warhead burst range at time of burst.

Since the initial angle of the velocity increment is to be controlled by the missile guidance system, better than one-hundredth of one degree accuracy could reasonably be expected for that portion of the trajectory. This potential initial error would represent approximately 0.1 mi in range or 300 to 500 ft in altitude. Other errors in the angle of the velocity vector are considered to be second-order effects and are not examined further here.

RELAY PACKAGE

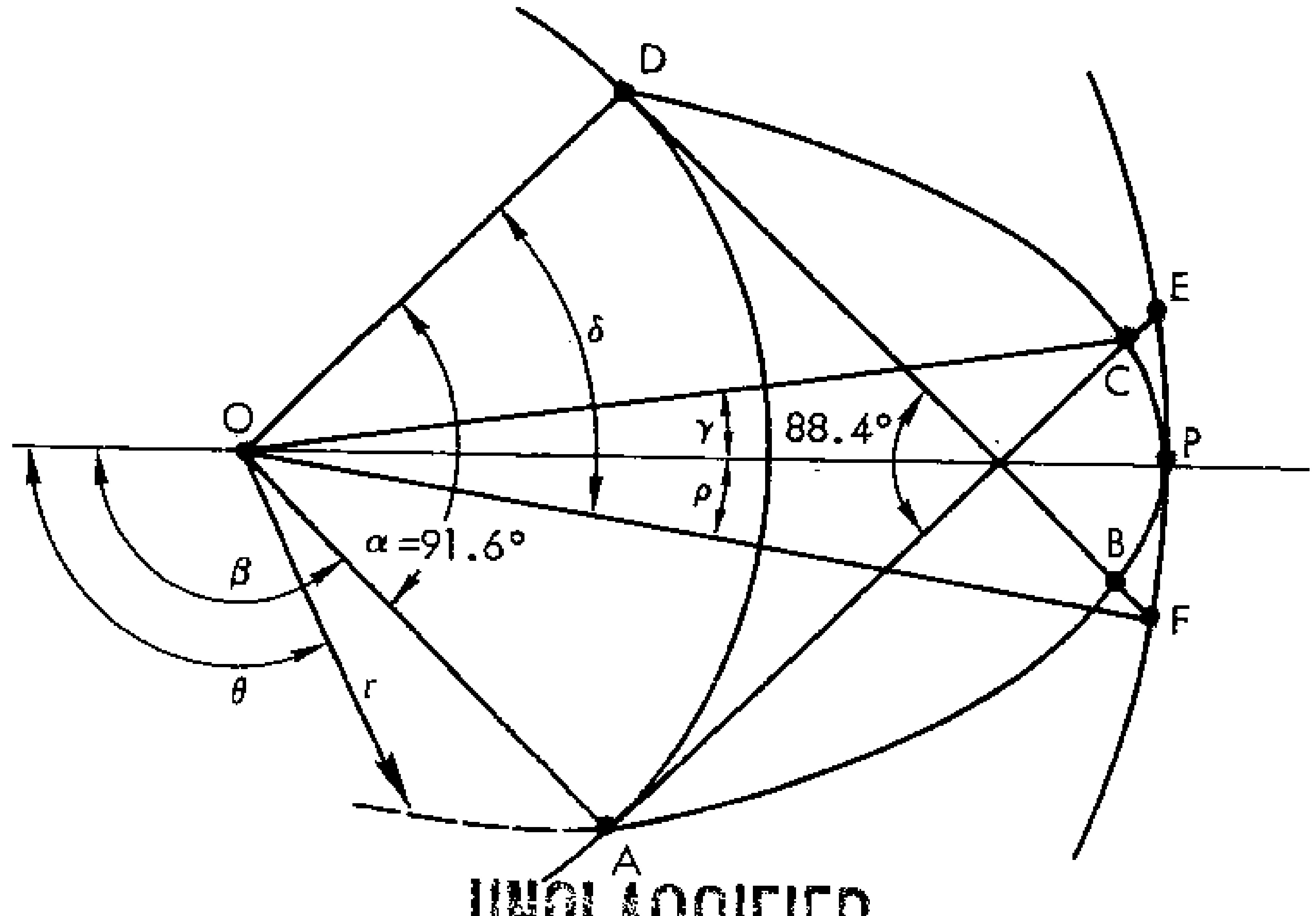
Given:

A. The range of a ballistic trajectory is 5500 n mi and the apogee of the trajectory is 2500 n mi above the earth's surface.

B. A satellite is in orbit 2500 n mi above the earth's surface.

To find:

1. For what interval of time will the launch site and the target both be visible from a point along the trajectory near the apogee?
2. For what interval of time would the same two points be visible from a satellite in a circular orbit of radius (2500 n mi altitude)?



$$\alpha = \frac{5500}{3438} \times 57.3 = 91.6^{\circ} \qquad (1)$$

$$\beta = 180^{\circ} - \frac{\alpha}{2} = 180^{\circ} - 45.8^{\circ} = 134.2^{\circ} \qquad (2)$$

At point A on the ellipse, using the standard polar coordinate ellipse equation, we write

$$r = 3438 = \frac{a(1 - e^2)}{1+e \cos 134.2^{\circ}} \qquad (3)$$

where a is the semi-major axis and e is the eccentricity; and at point P on the ellispe we write

$$r = 3438 + 2500 = \frac{a(1 - e^2)}{1+e \cos (180^{\circ})} \qquad (4)$$

Dividing (3) by (4), we obtain

$$\frac{3438}{5938} = \frac{1 - e}{1 - .696\ e}$$

$$3438 - (.696)(3438)\ e = 5938 - 5938e$$

$$[5938 - (.696)(3438)]e = 5938 - 3438 = 2500$$

$$e = \frac{2500}{3545} \approx .708 \qquad (5)$$

From (4), we write

$$a = \frac{(1 - .708)\ 5938}{1 - (.708)^2} \approx 3450 \text{ n mi or } 6390 \text{ km} \qquad (6)$$

In Δ OAC we can write

$$\cos\left(\frac{\alpha}{2} + \gamma\right) = \frac{R}{r} \qquad (7)$$

and from the equation of the ellipse we write

$$r = \frac{a(1-e^2)}{1 + e \cos (\pi + \gamma)} \qquad (8)$$

Substitute (8) into (7) and get

$$\cos\frac{\alpha}{2}\cos v - \sin\frac{\alpha}{2}\sin\gamma = \frac{R}{a(1-e^2)}\left[1 - e\cos\gamma\right]$$

$$\left[\cos\frac{\alpha}{2} + \frac{R\ e}{a(1-e^2)}\right]\cos\gamma - \sin\frac{\alpha}{2}\sin\gamma = \frac{R}{a(1-e^2)} \qquad (9)$$

$$\left[.696 + \frac{3438\ (.708)}{3450\ (1-.5)}\right]\cos\gamma - .716\sin\gamma = \frac{3438}{3450\ (1-.5)}$$

$$2.11\cos\gamma - .716\sin\gamma = 1.992.$$

Hence $\gamma \approx 8^\circ$.

Now get the period for the satellite in elliptical orbit:

$$P_e = 3.147^{*} \times 10^{-7}\ (a)^{3/2} = 3.147 \times 10^{-7}\ [6.390 \times 10^6]^{3/2}$$
$$= 3.147 \times 10^{-7} \times 16.15 \times 10^9 = 5080 \text{ sec} = 84.7 \text{ min.}$$

From Ref. 14 we can read fraction of period to get from perigee to point B. This is 0.415 P. So time to go from B to C will be 2(0.5 - 0.415) = 2(0.085) = 0.17P, or 0.17 (84.7) = 14.4 min for the ICBM trajectory.

For a satellite in circular orbit of radius 3438 + 2500 n mi = 5938 n mi = 10,980 km, the period will be

$$P = 3.147 \times 10^{-7}\ [10.98 \times 10^6]^{3/2}$$
$$= 3.147 \times 10^{-7}\ (36.4 \times 10^9) = 11{,}410 \text{ sec} = 190 \text{ min.}$$

---

[*] $3.147 \times 10^{-7} = \frac{2\pi}{\sqrt{K}}$ where K is the earth's gravitational constant and is $3.9862 \times 10^{14}\ \frac{M^3}{\sec^2}$.

$$\text{In } \Delta\ ODF,\ \cos\delta = \frac{R}{R+h} = \frac{3438}{5938} = 0.579$$

$$\delta = 54.6^{\circ}$$

$$\rho = \delta - \frac{\alpha}{2} = 54.6 - 45.8 = 8.8^{\circ}.$$

Time to go from E to F in circular orbit will be

$$\frac{2(8.8)}{360} \times 190 = 9.3 \text{ min for satellite trajectory.}$$

Appendix F

COMMUNICATION CALCULATIONS

The two communication links, each 5000 n mi in length, are illustrated on p. 2. The links are assumed to operate at a frequency of 1200 Mc ($\lambda = 1$ ft) on the camera-to-relay leg, at a frequency of 4800 Mc ($\lambda = 0.25$ ft) on the relay-to-ground leg, and to employ wide-band FM with frequency feedback detection. Antenna gains of 10 db are assumed at the camera capsule and in both directions from the relay. The ground receiving antenna is taken as a parabolic dish with a gain of 24 db.

The system noise temperature is assumed to be 600°K at the relay and 200° to 300°K at the ground station. Most communication relay designs use a simple heterodyne repeater. In this case, the FM signal is demodulated at the relay in order to realize the feedback improvement on the up-link and thus reduce the power requirement at the camera capsule. The television video signal is assumed to be of the conventional broadcast type with a reduction of one-third in picture frequency (a bandwidth of 1.33 Mc).

Assume that feedback demodulation can reduce the threshold by 6 db. The required power at the relay then becomes

$$P_{req} = \frac{\left(\frac{C}{N}\right)_{thresh} \times KTB \times L}{I} = 0.88 \times 10^{-12} \text{ watts} \qquad (1)$$

where

$\left(\frac{C}{N}\right)_{thresh}$ = carrier-to-noise ratio at threshold = 12 db

I = feedback improvement = 6 db

K = Boltzmann's constant = 1.38 x 10^{-23} joules/^{o}K

T = effective noise temperature = 600^{o}K

B^{*} = RF bandwidth = 10 x 1.33 Mc = 13.3 Mc

L = losses = 2 (3 db).

The transmitter power required at the camera capsule is

$$P_T = \frac{16\pi^2 R^2 P_{req}}{G_T G_R \lambda^2} = 1286 \text{ watts} \qquad (2)$$

where

R = range = 5000 n mi

P_{req} = power required at relay = 0.88 x 10^{-12} watts

G_T = camera capsule transmitting antenna gain = 10 (10 db)

G_R = relay receiving antenna gain = 10 (10 db)

λ = wavelength = 1 ft.

However, 2500 watts is used since it offers an additional safety factor. The received power required at the ground station is just half that required at the relay because of the lower system noise temperature assumed. The transmitter power required at the relay is given by Eq. (2) but with

P_{req} = power required at ground station = 0.22 x 10^{-12} watts

G_T = relay transmitting antenna gain = 10 (10 db)

G_R = ground station receiving antenna gain = 250 (24 db)

λ = wavelength = 0.25 (frequency = 4800 mc)

---

[*] A modulation index of 4 is used. This results in an FM improvement of 3 (4^2) = 48 (17 db), thus yielding a picture signal-to-noise ratio of 17 + 6 + 7 = 30 db where the sum of 6 + 7 = 13 db represents the feedback-reduced threshold (12 db threshold-6 db reduction) referred to twice the baseband (13.33 Mc to 2.67 Mc, which corresponds to 7 db).

so that

$$P_T = 205.9 \text{ watts}$$

In this case, 500 watts is used since it offers an additional safety factor.

Appendix G

NUCLEAR TEST PHOTOGRAPHS

The Redwing series(15) of nuclear test shots provides some excellent photographs of nuclear detonations for indicating the usefulness of TV photography to locate the point of burst of a nuclear device. The examples in this Appendix were selected to illustrate the potential for this quality of photography.

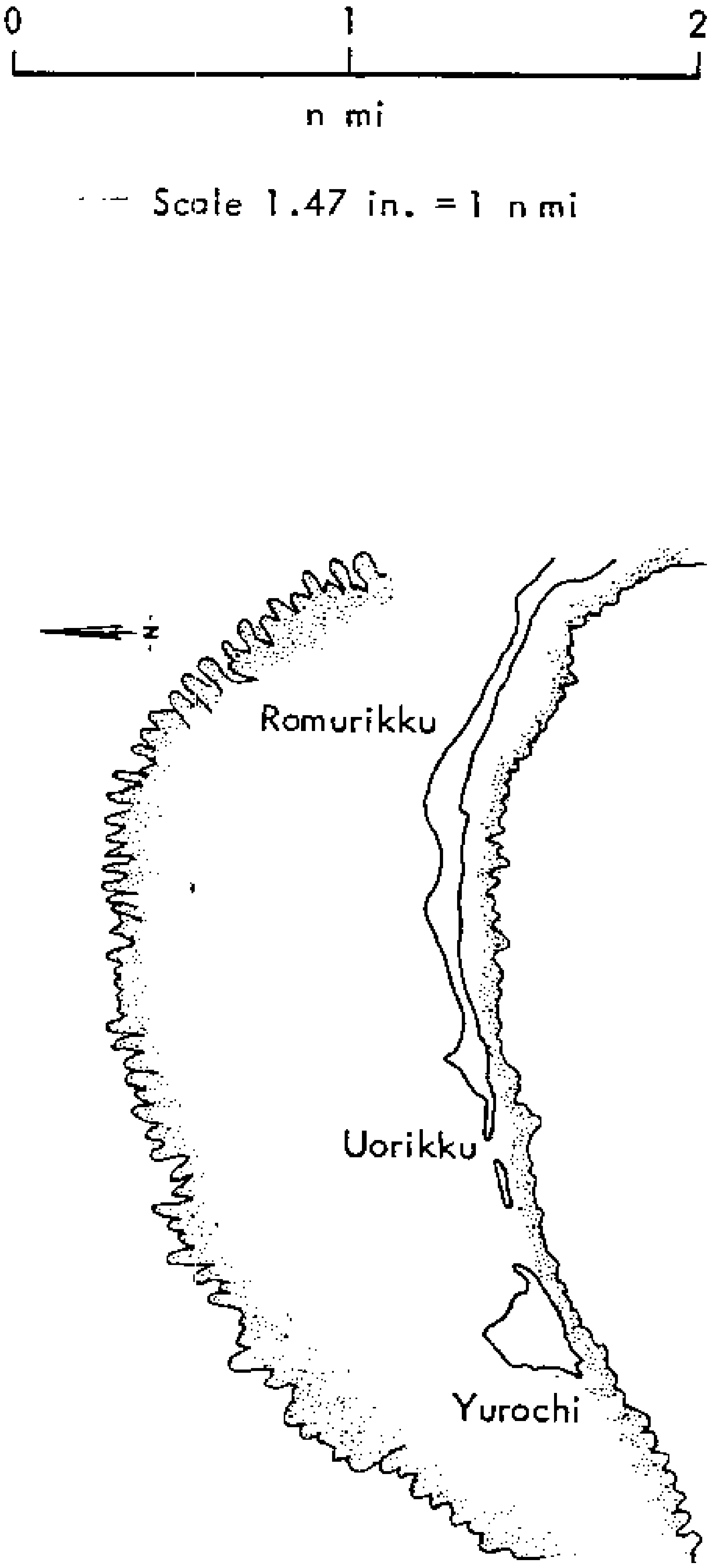
The series was conducted at the Eniwetok Proving Grounds (Eniwetok and Bikini atolls) where the bulk of the surface is ocean, with small islands and reefs as essentially the only points of visual reference. The film was taken in 1956; the maps are dated 1962,

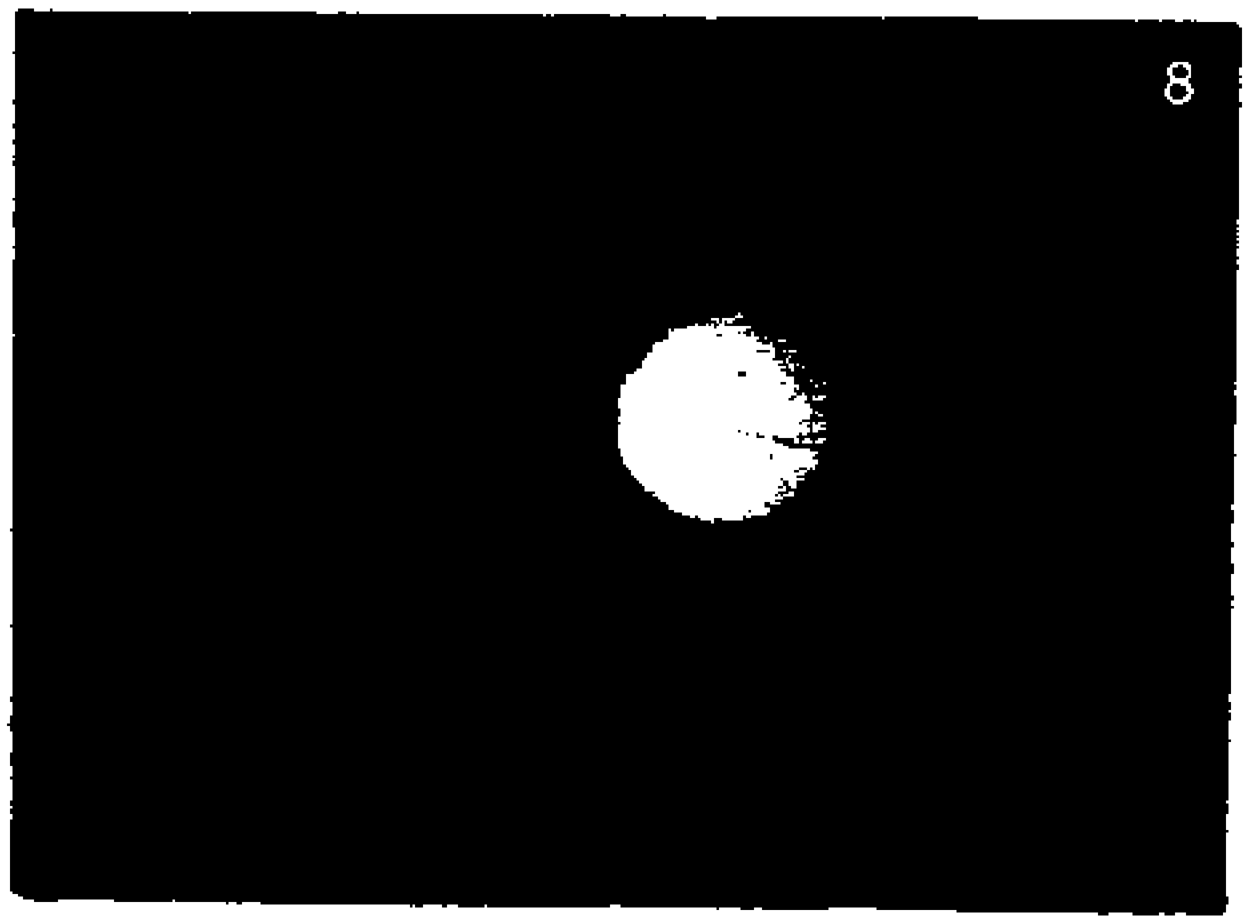
The first and fourth sets of photographs are of the Dakota shot,(16) a 1.1-MT barge-mounted detonation. The first set is made up of approximately every seventh frame of a 64-frame-per-second film. The fourth set shows the first 16 frames in uncut 64-frame-per-second sequence.

The second set illustrates the Flathead shot,(17) a 380-KT detonation at the same location but photographed from a different angle.

The reader is encouraged to use the photographs and maps to estimate the point of burst, and then to compare that with the point marked on the maps. Even using crude measures, one can locate the burst point with an error of less than 1000 ft.

If the camera were so mislocated or misaligned that it covered only some of the lighting and the later shockwave, the burst point could still be located with reasonable accuracy. The third set of photographs illustrates this point, using Huron, a 265-KT shot.

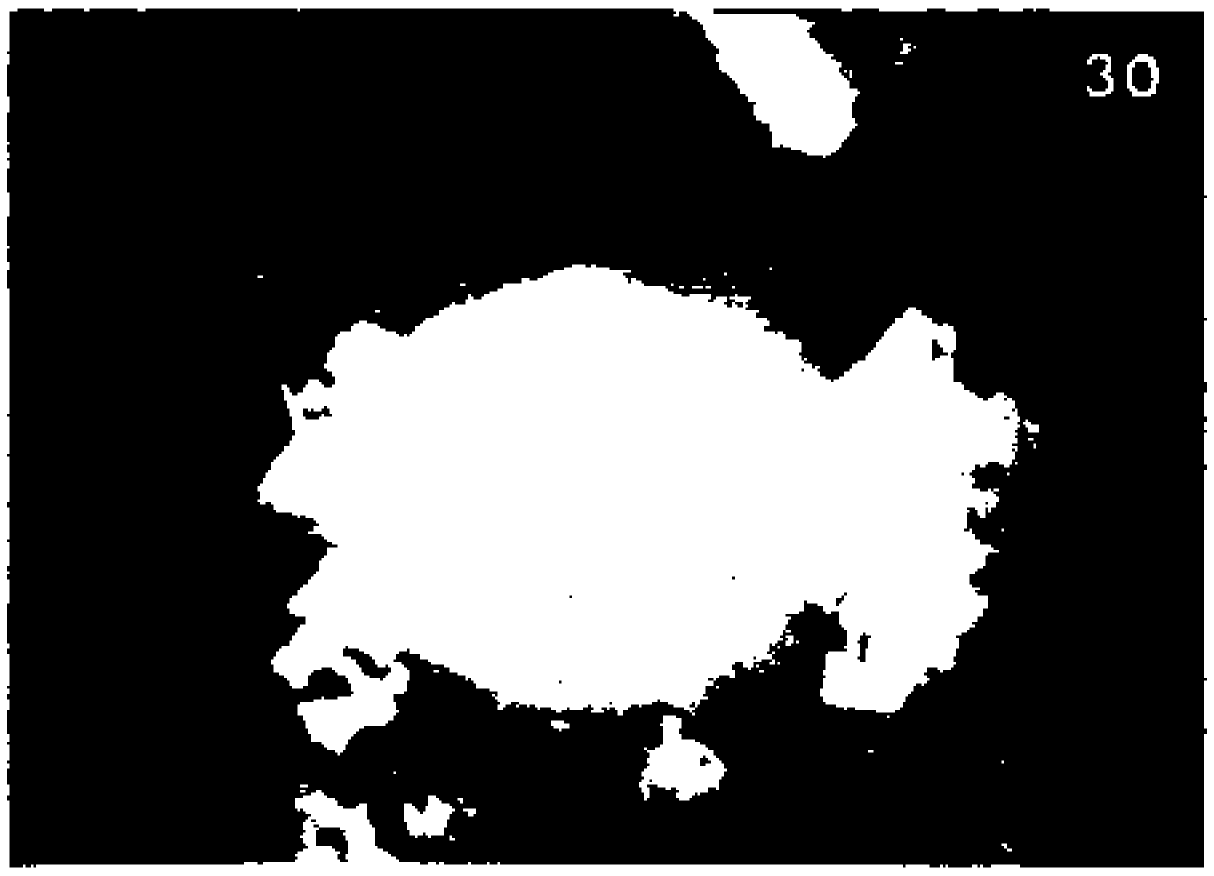




×
Recorded point of burst

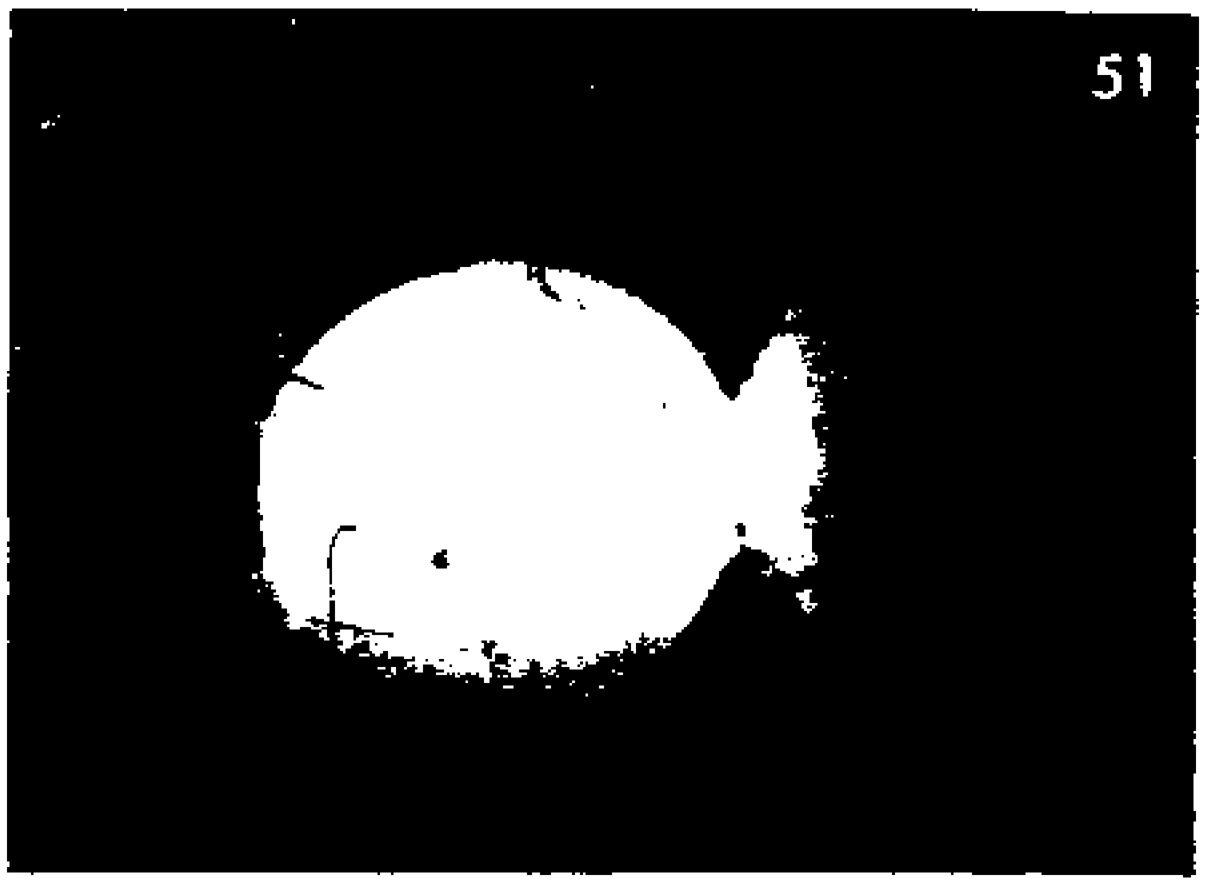
Set 1

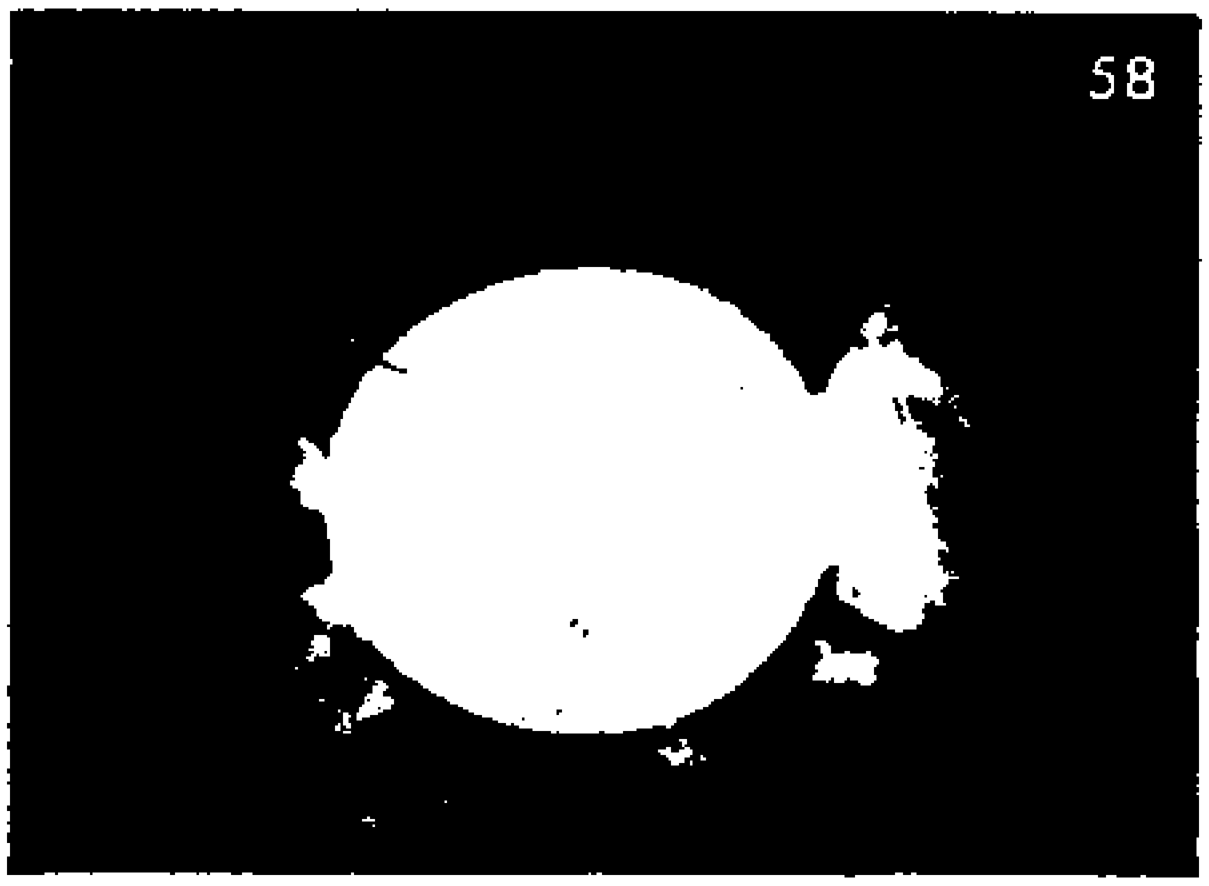

23

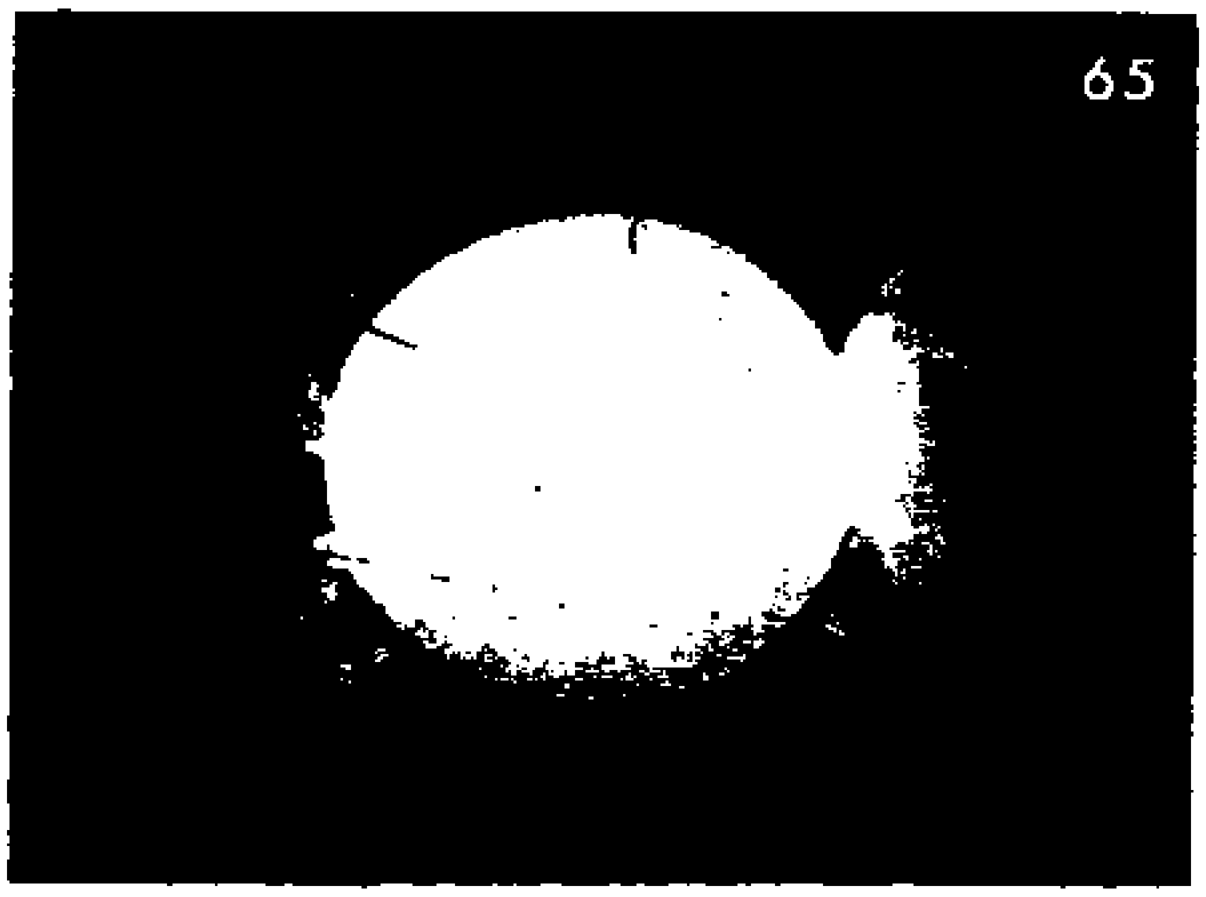

30

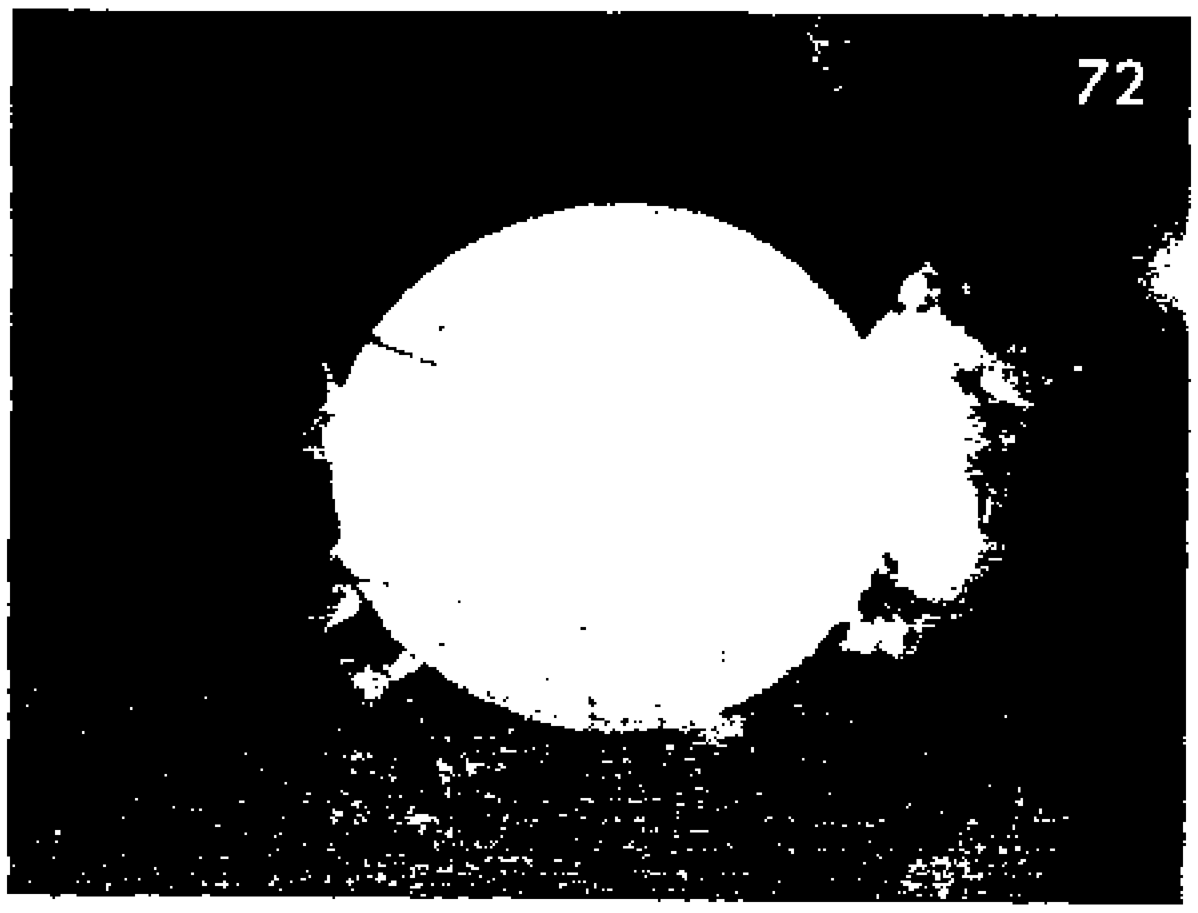

37


44

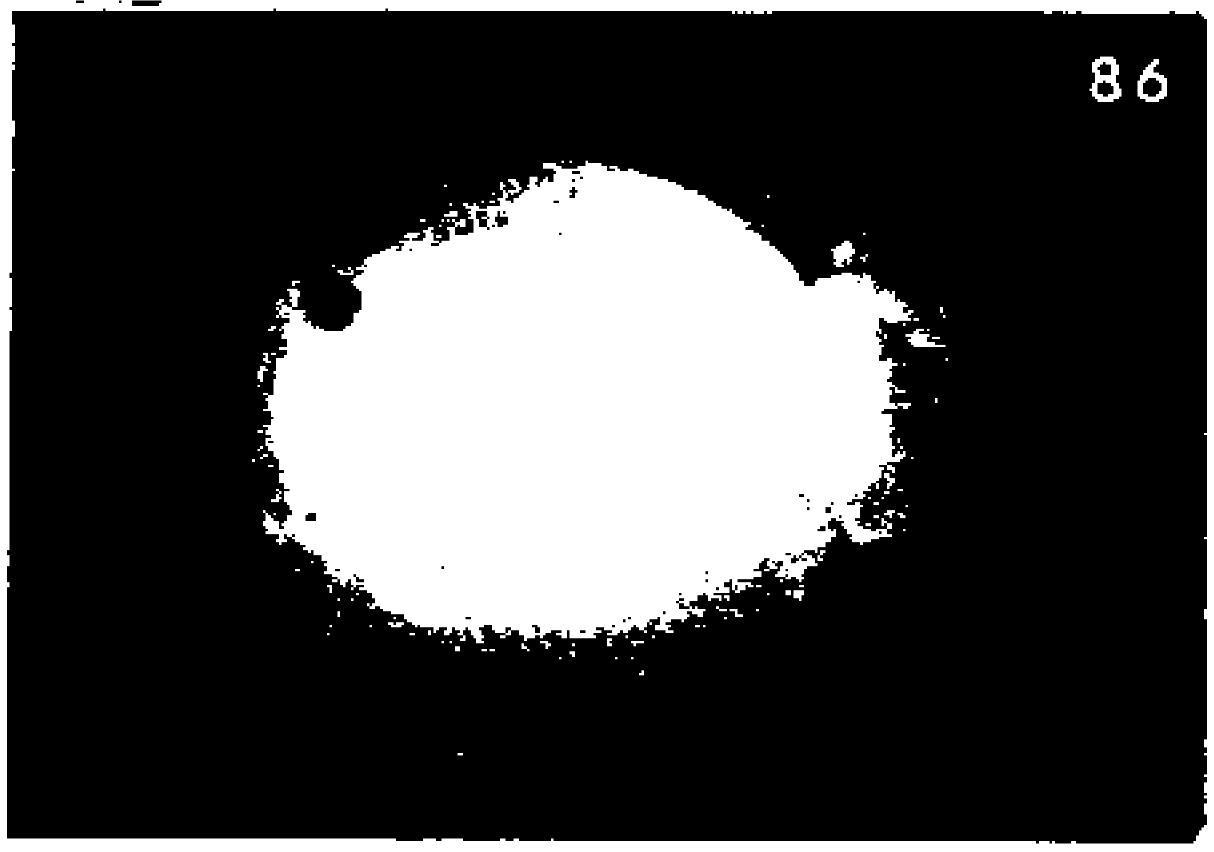

51

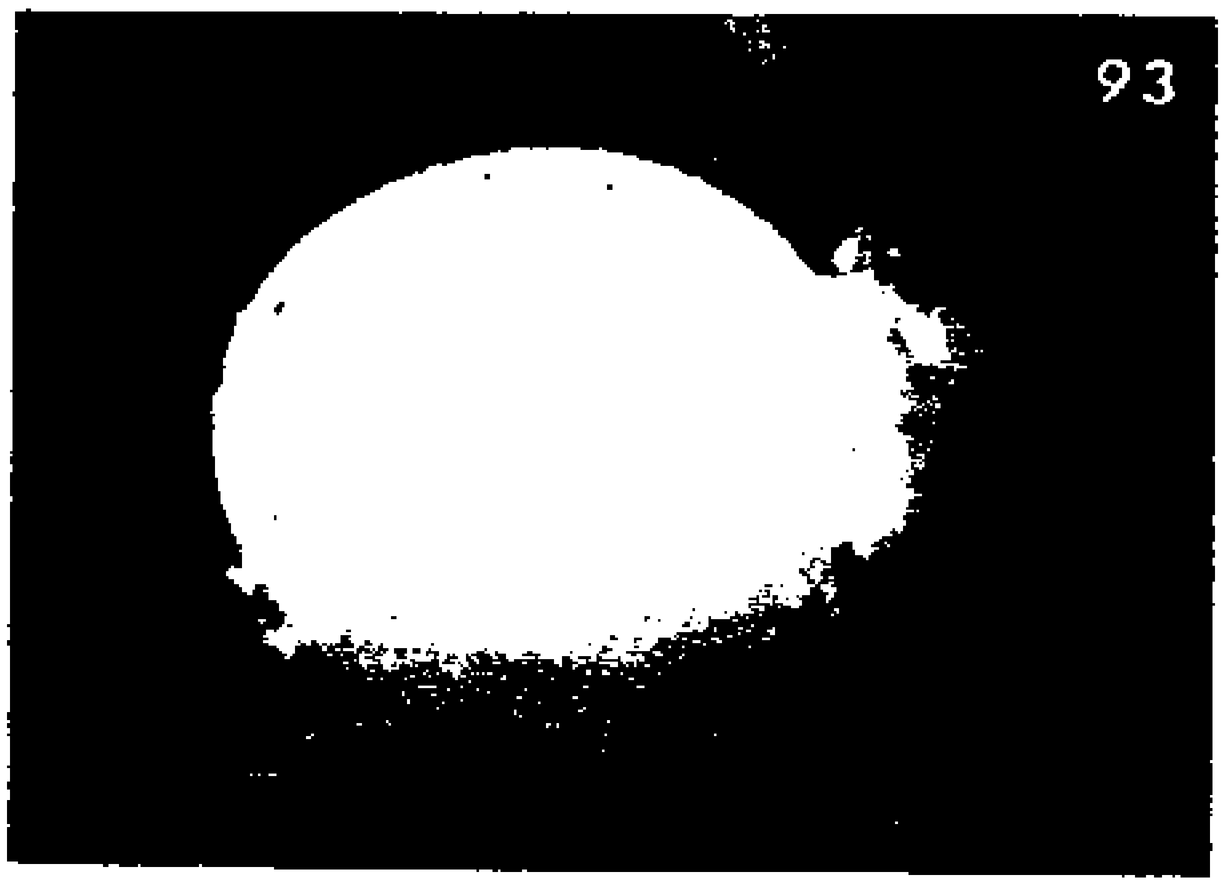

58

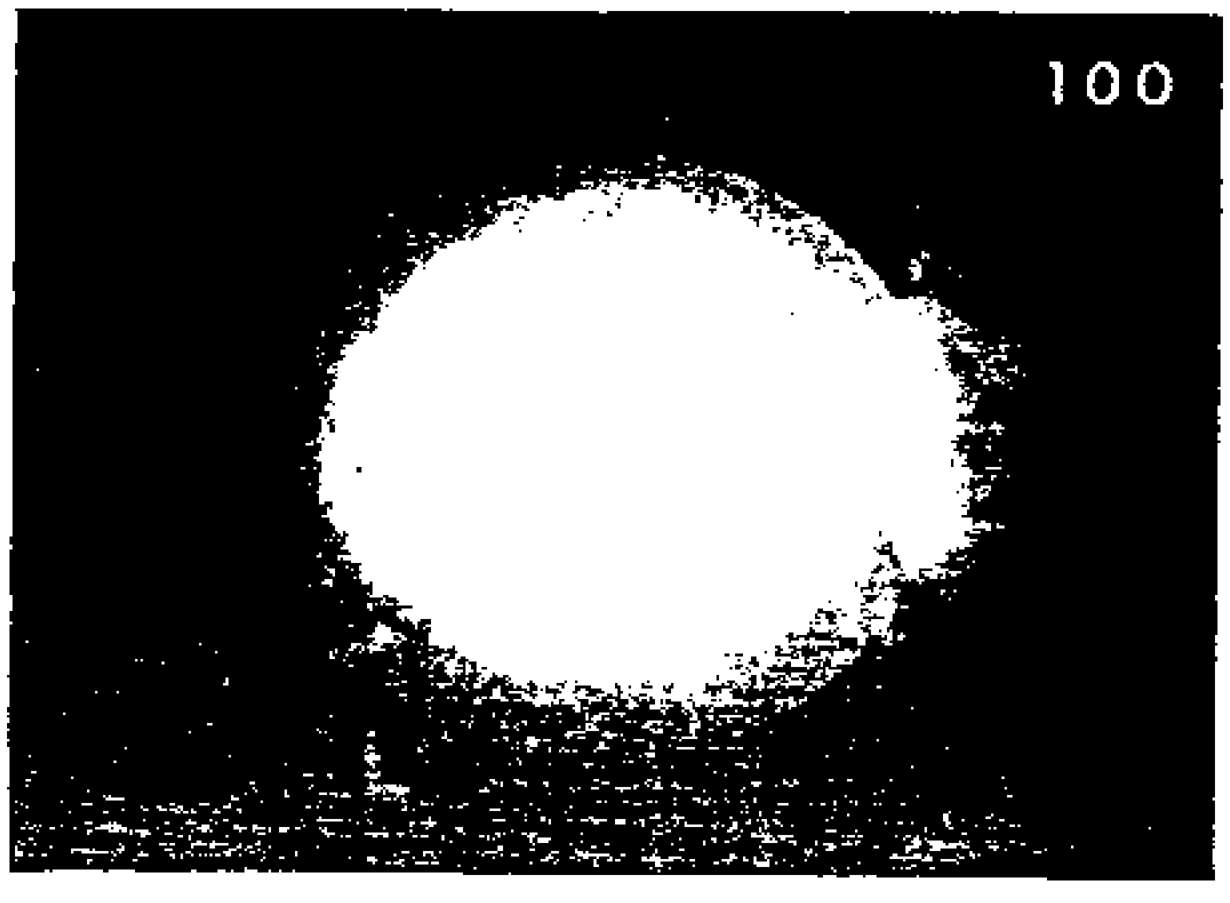

65


72

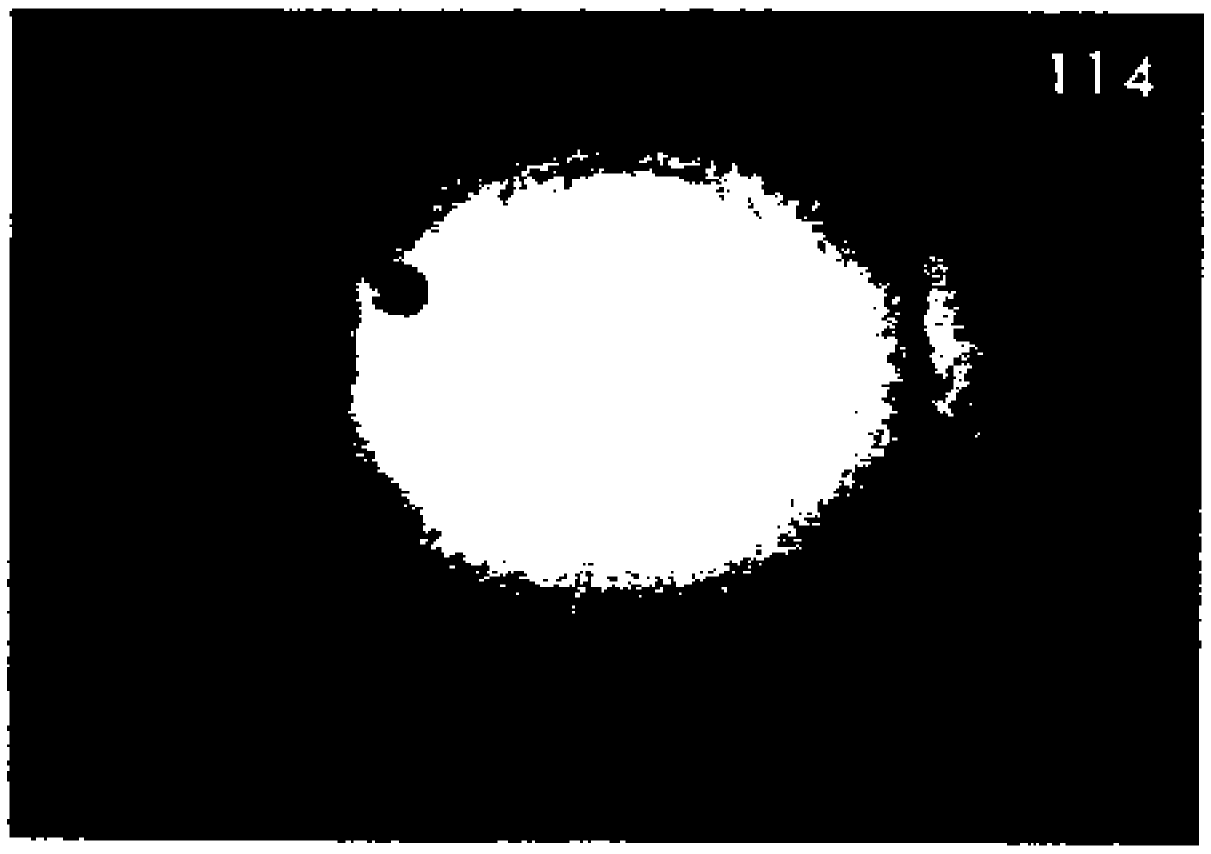

79

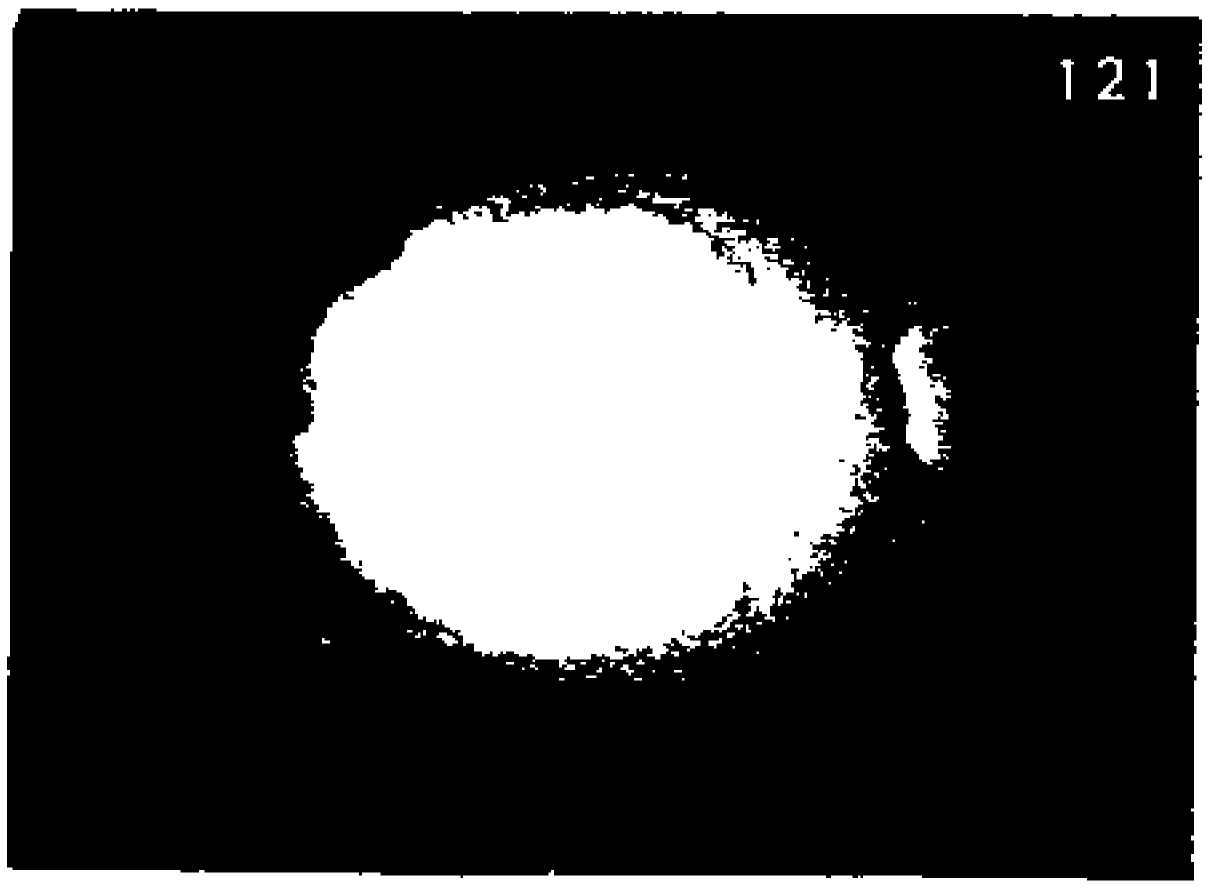

86

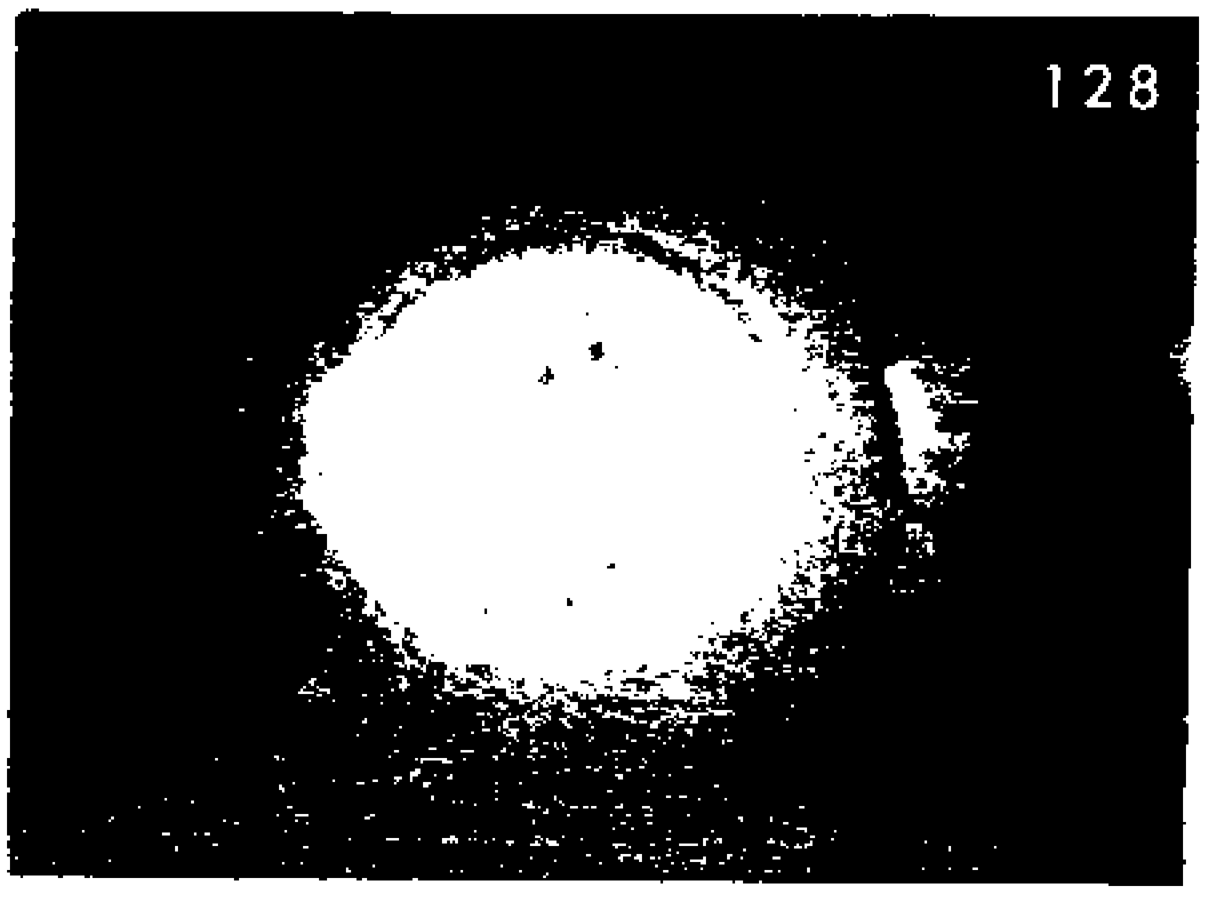

93


100


107


114

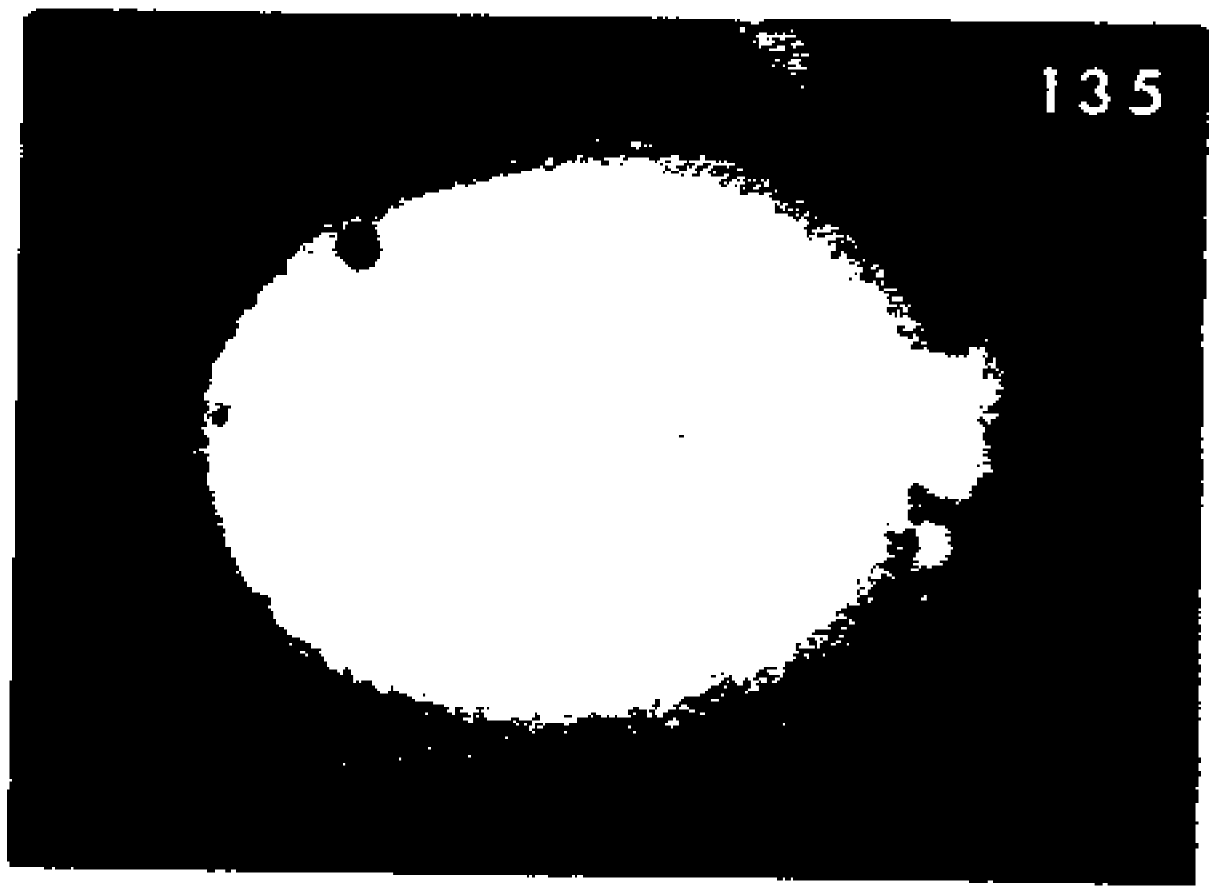

121


128

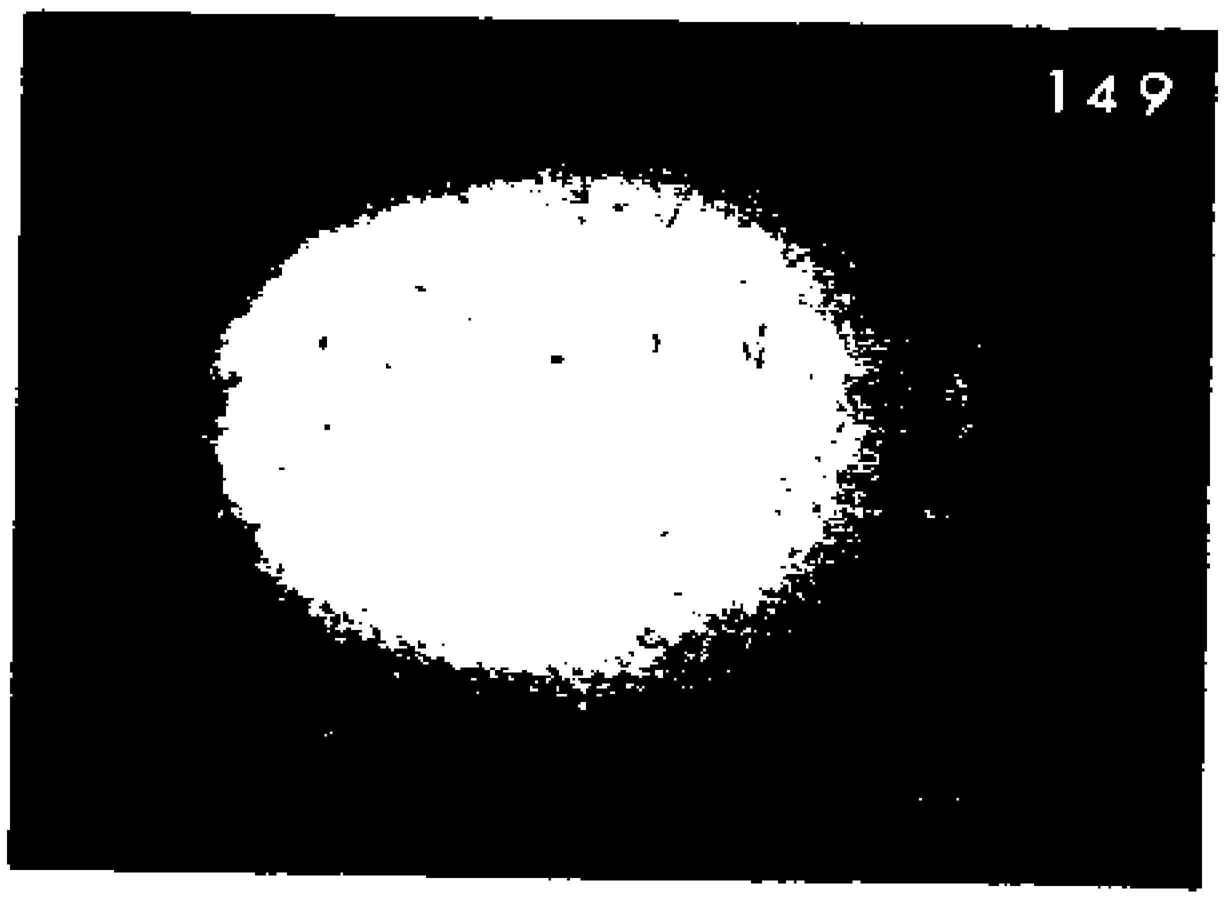
~~SECRET~~

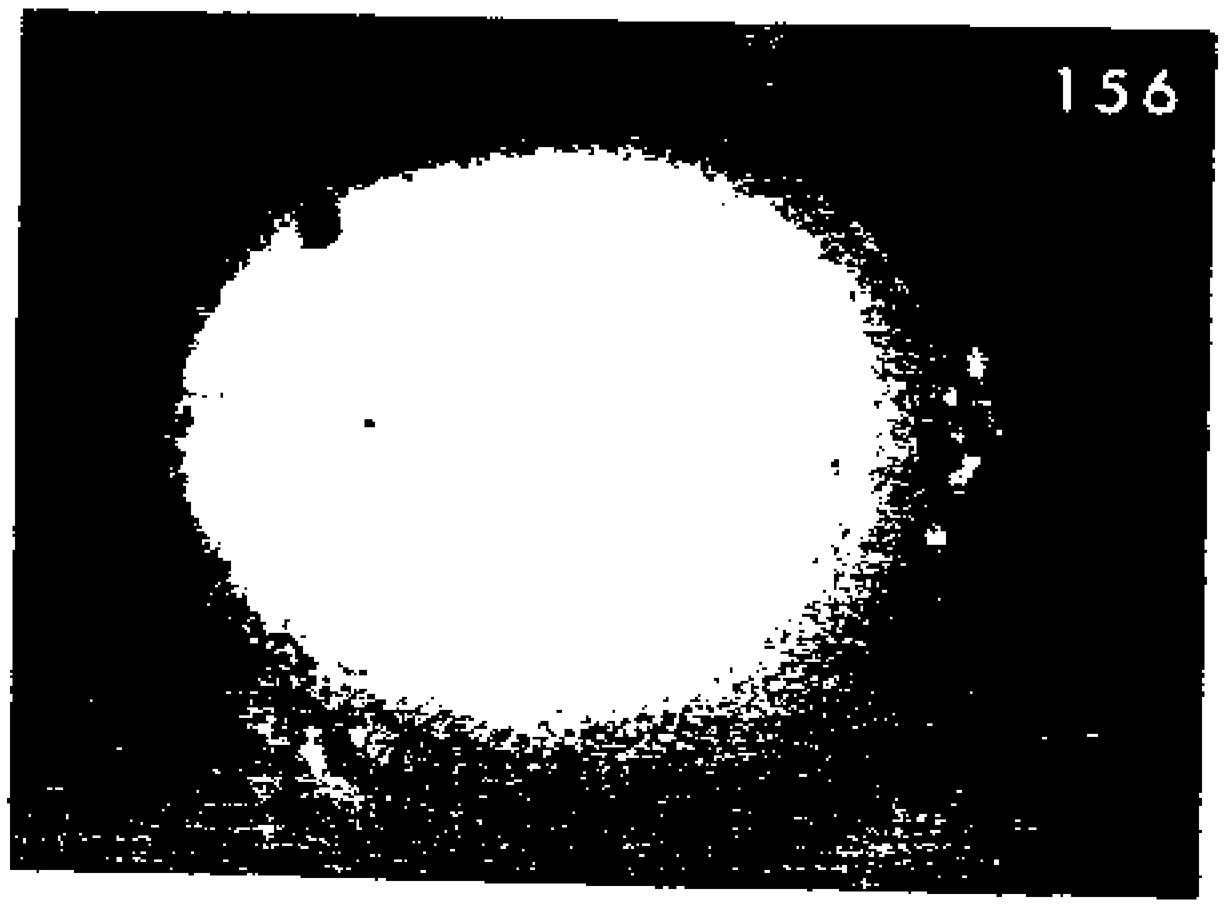
~~RESTRICTED DATA~~

~~ATOMIC ENERGY ACT—1954~~

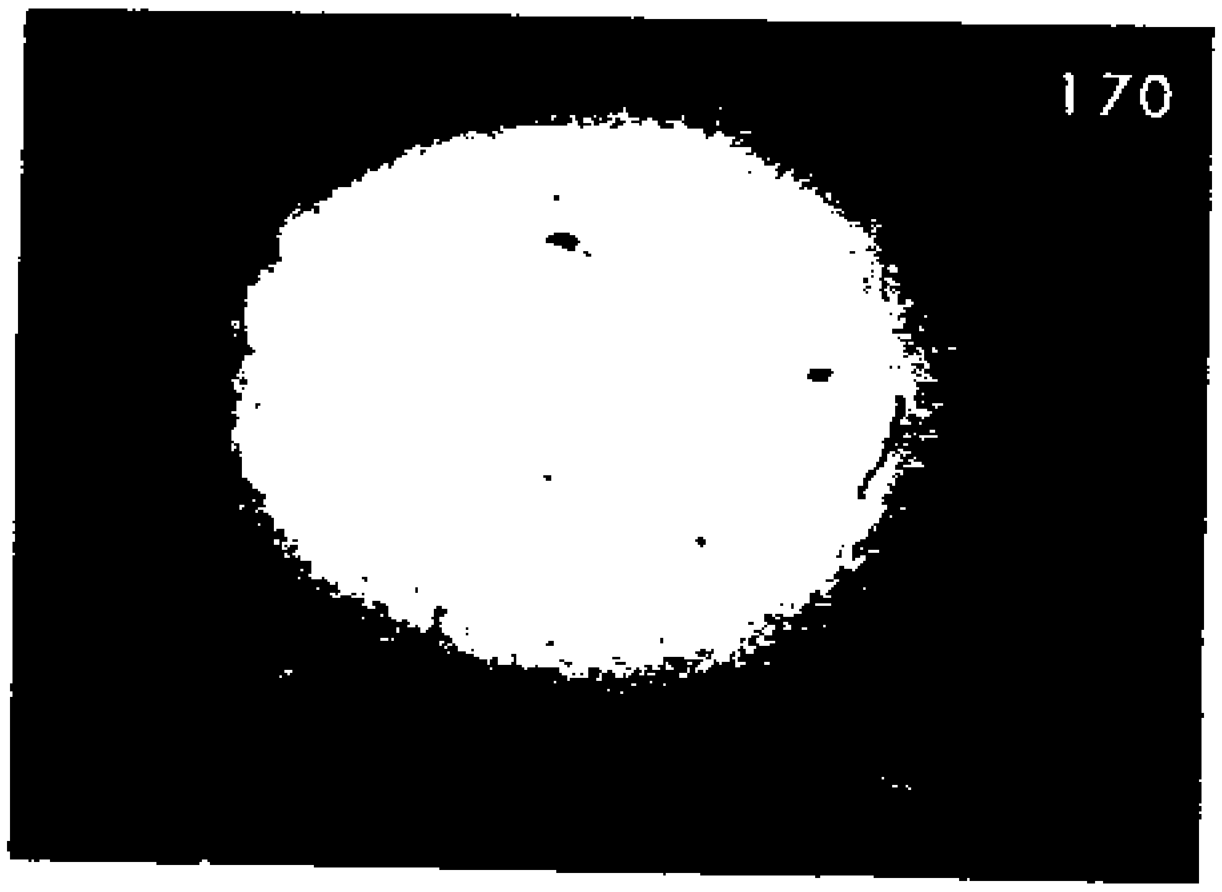

135

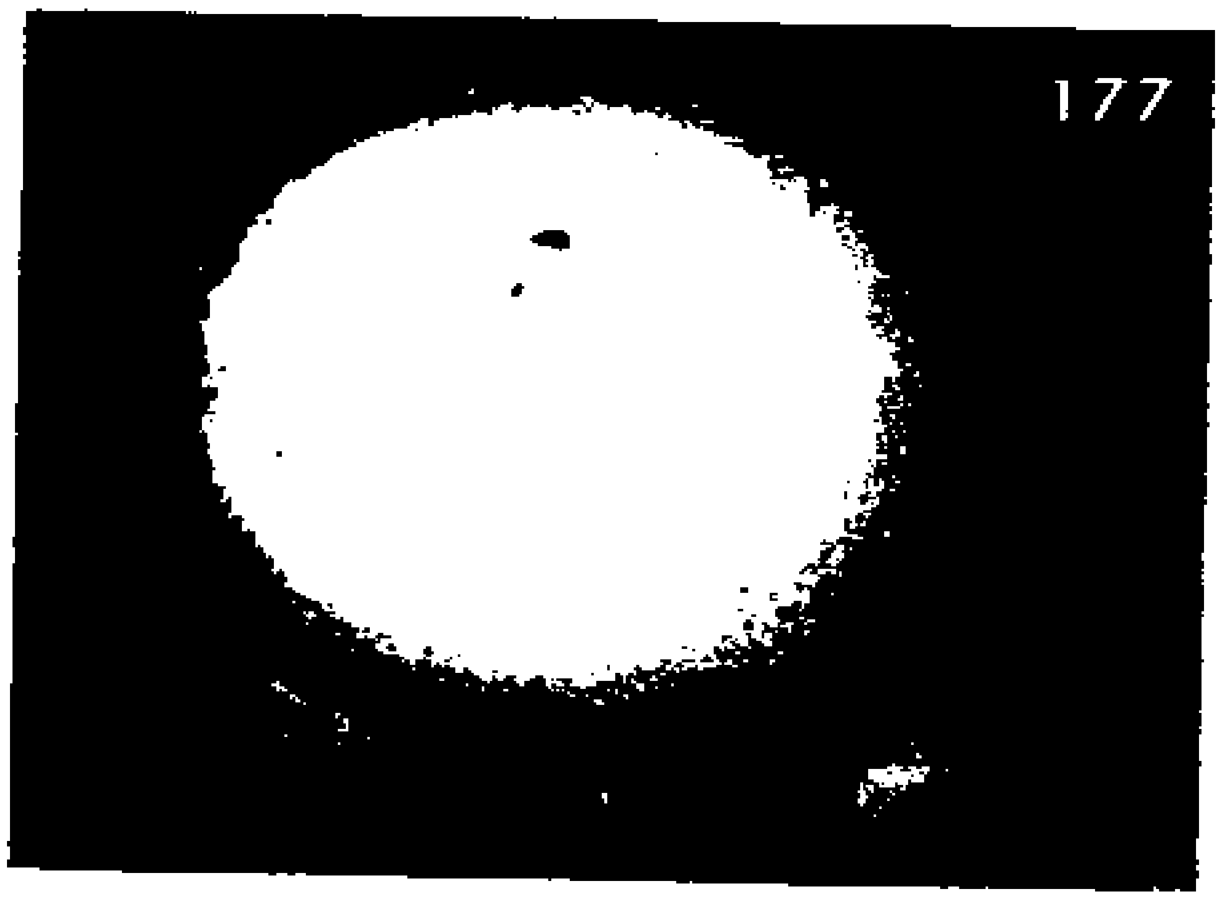

142

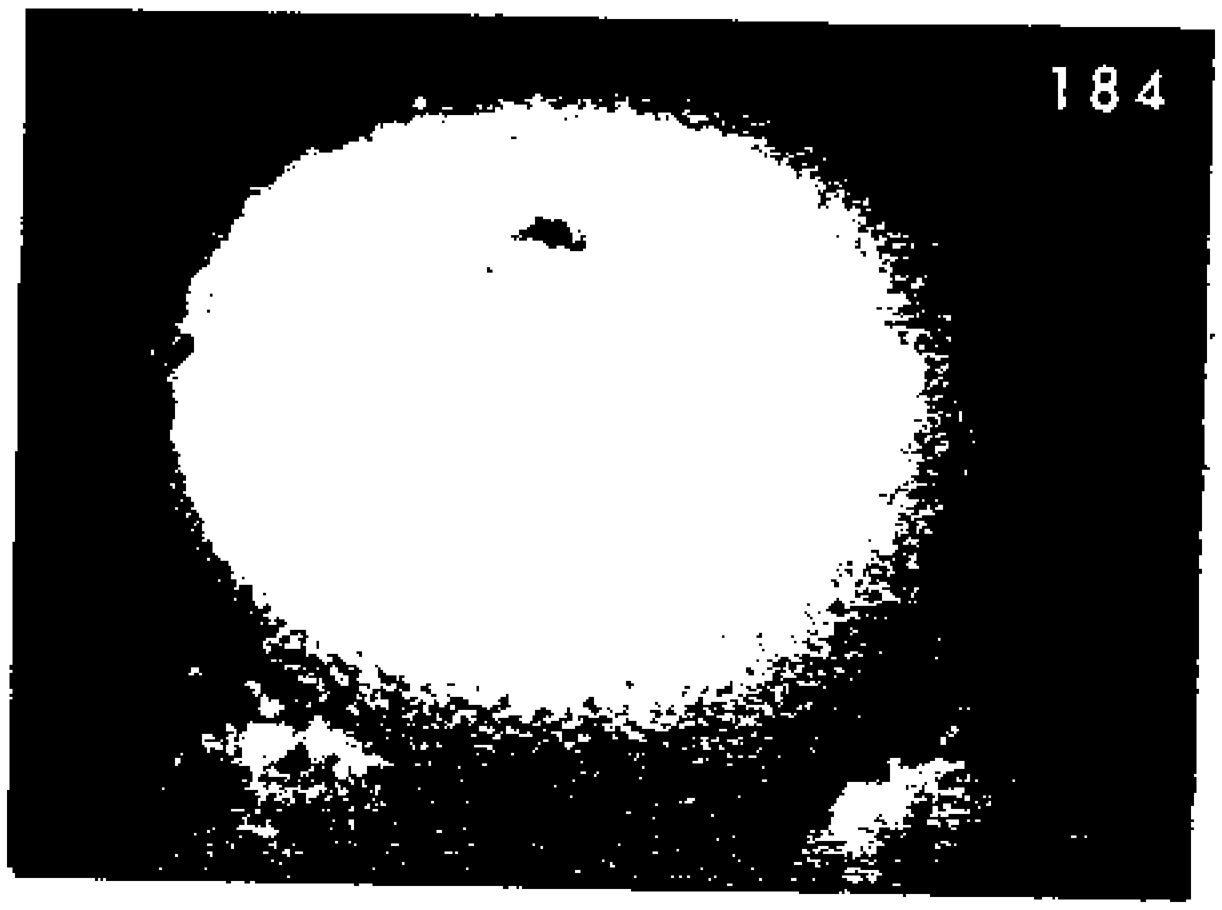

149


156

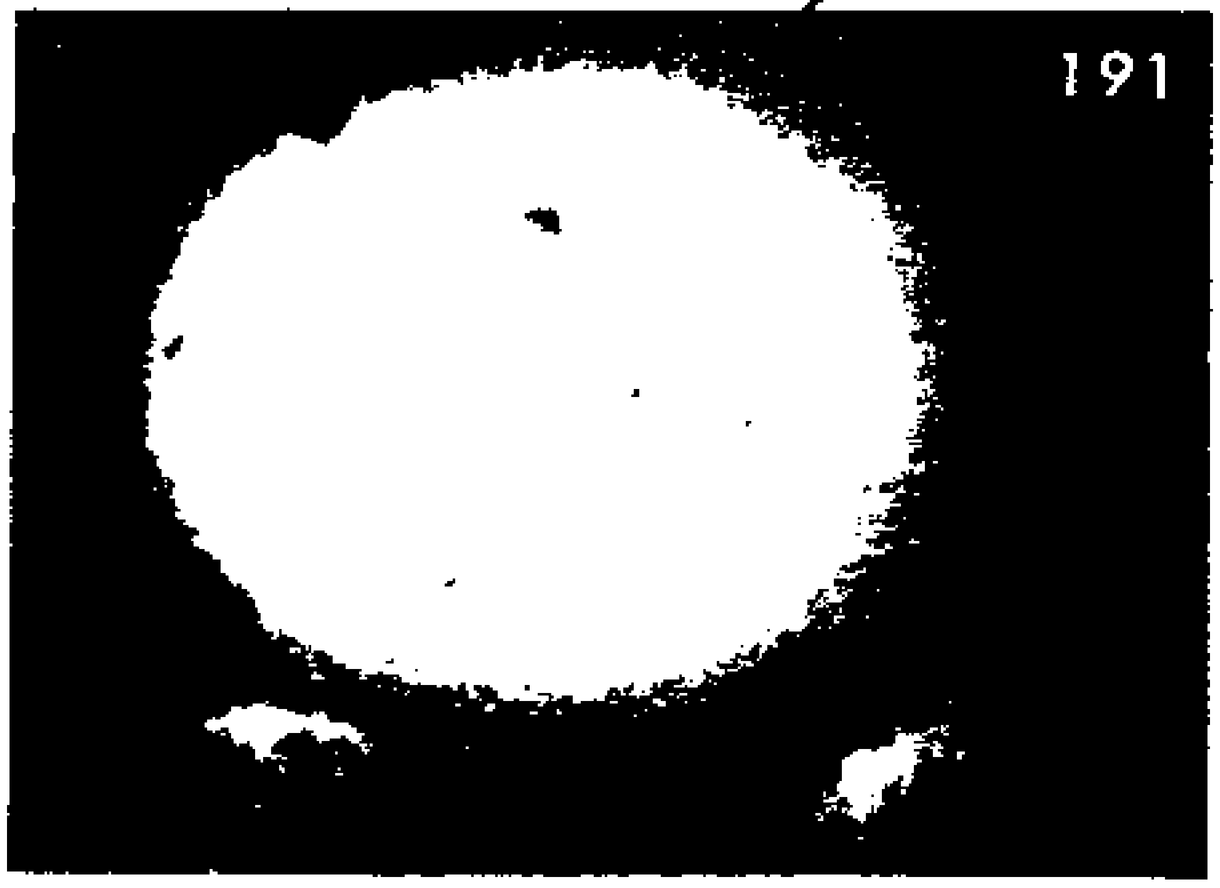

163


170

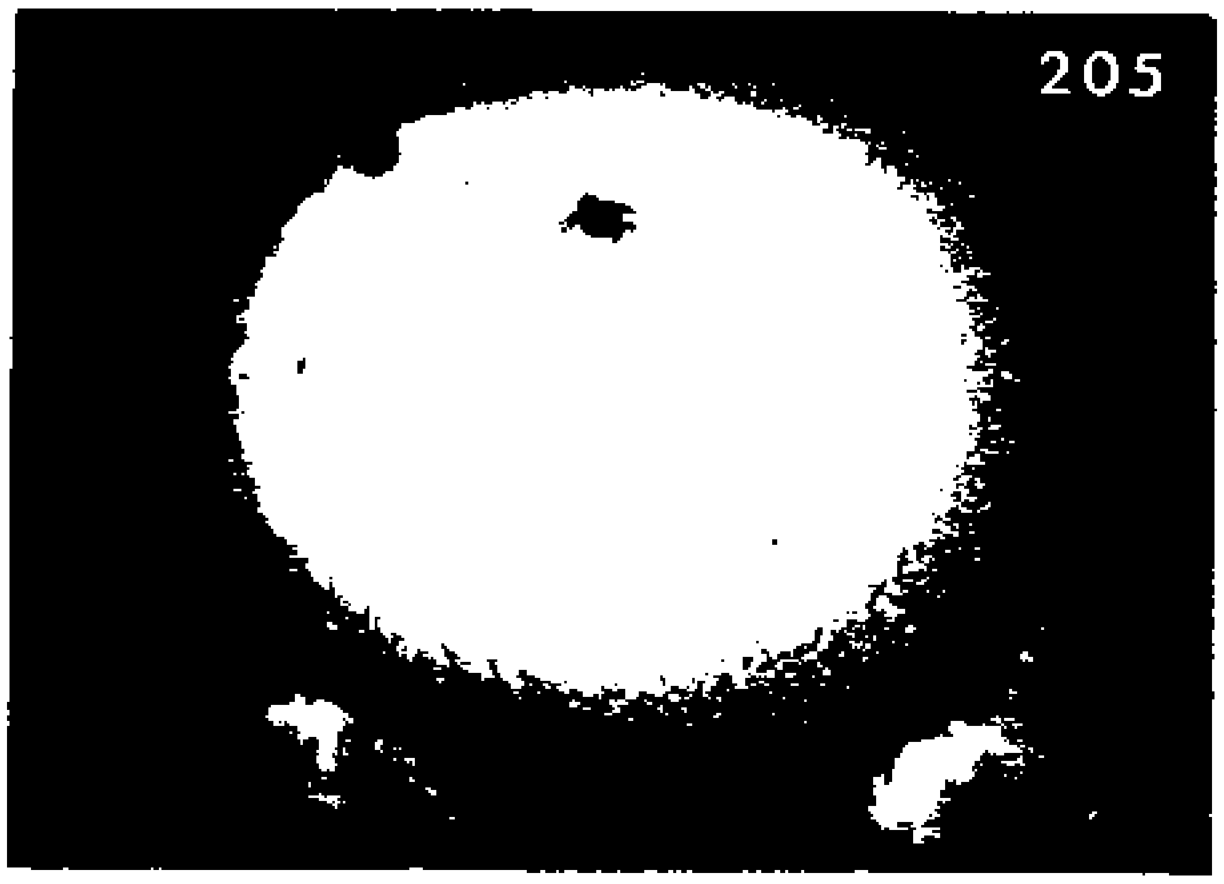

177

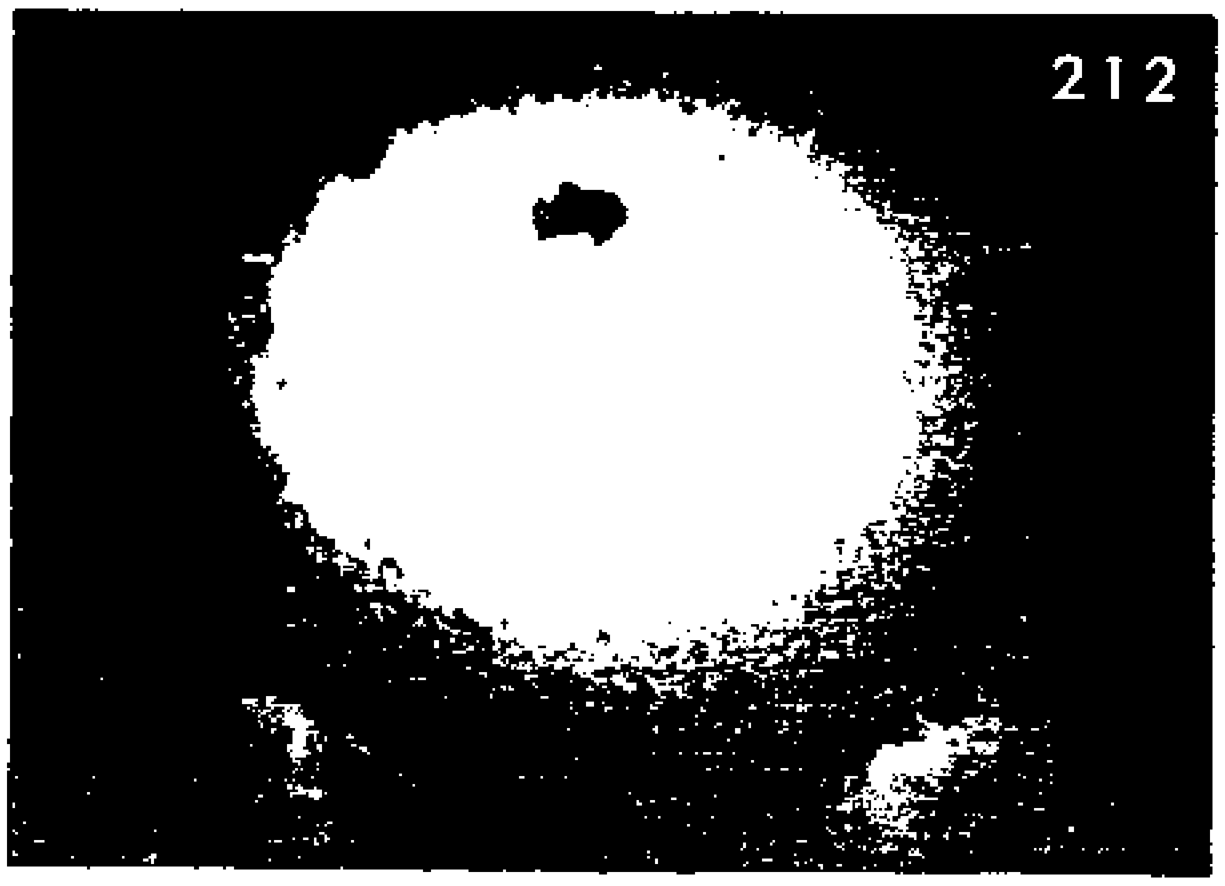

184

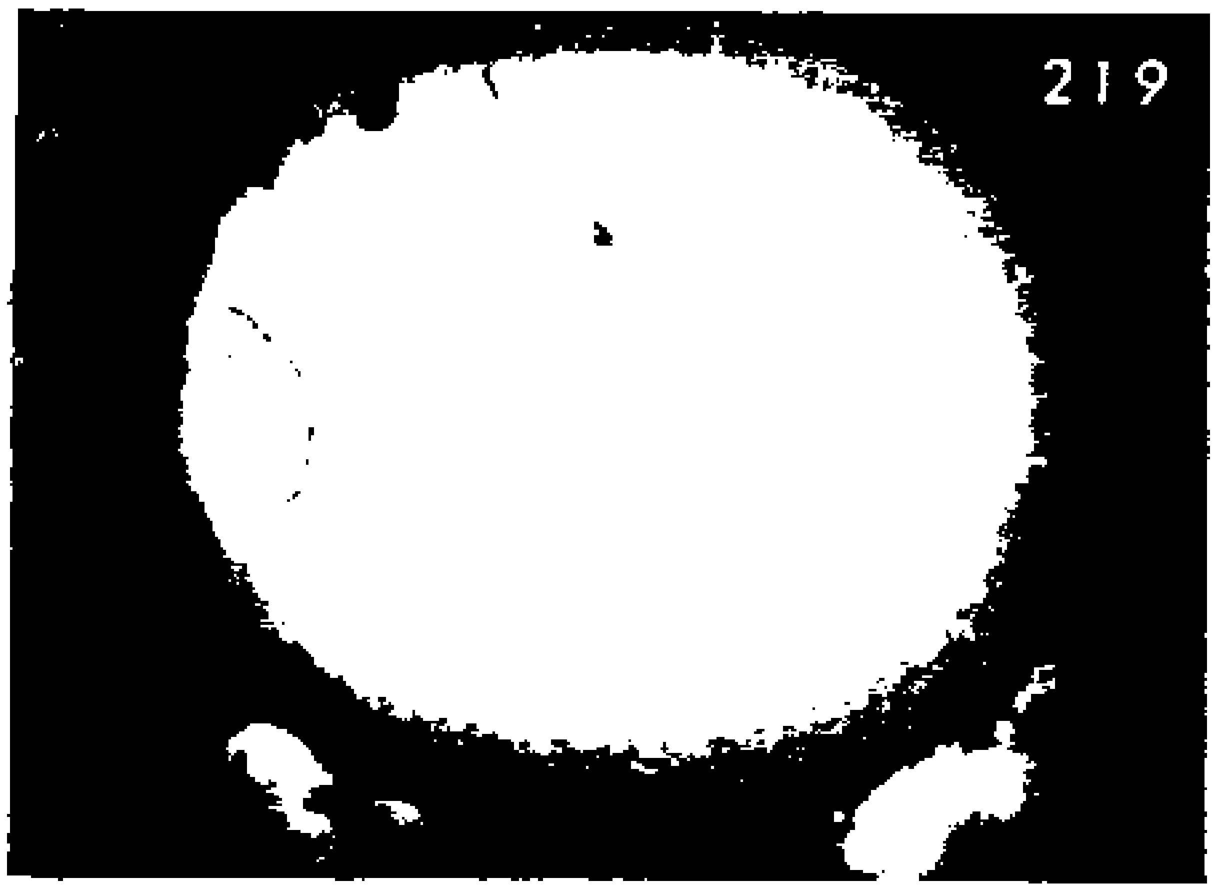
UNCLASSIFIED

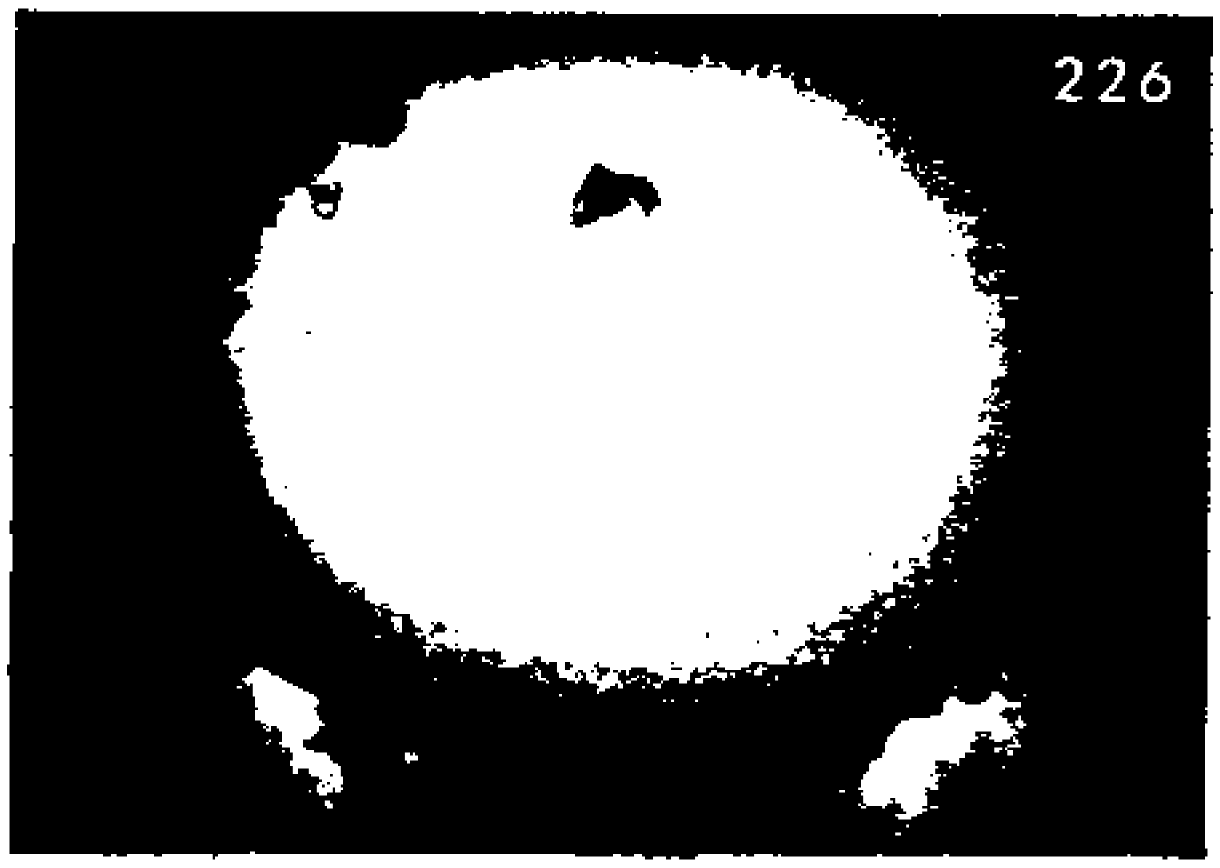

191

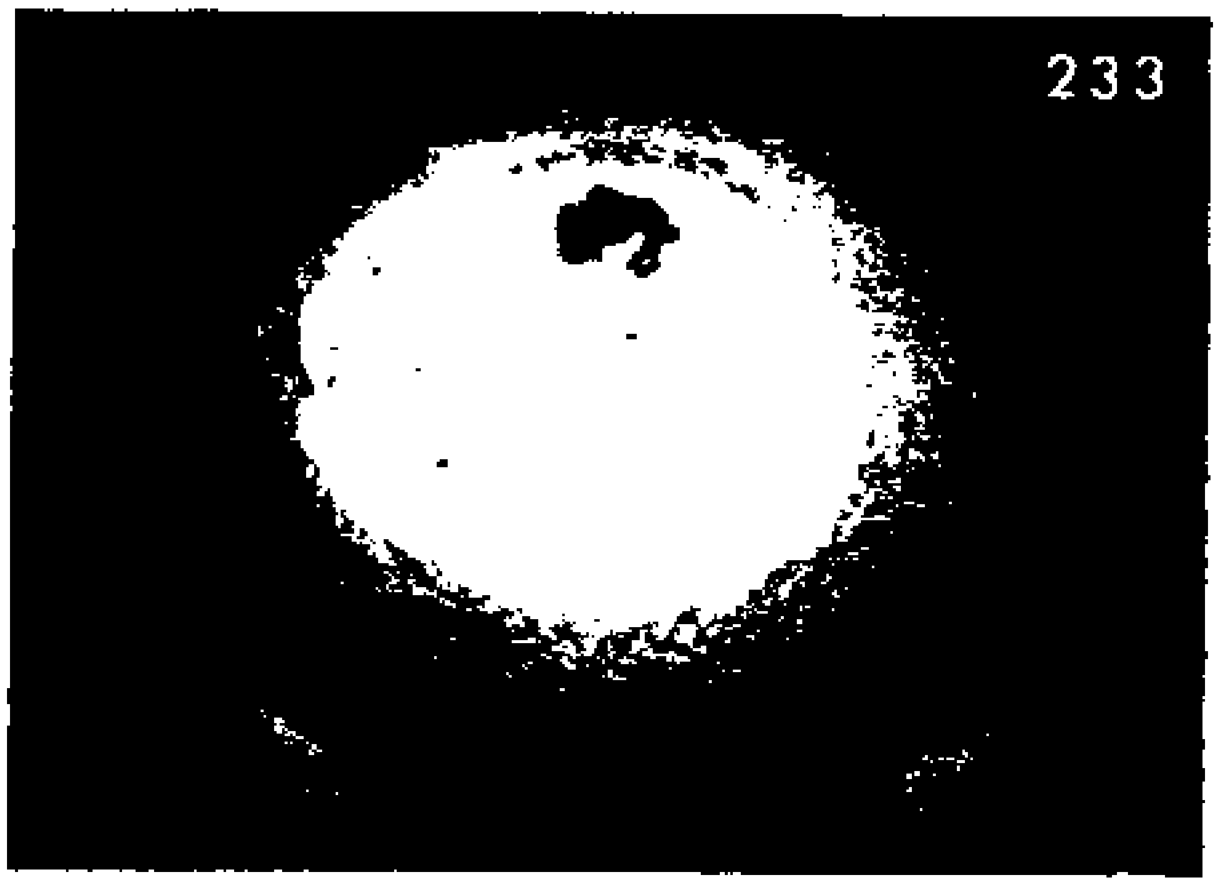

198

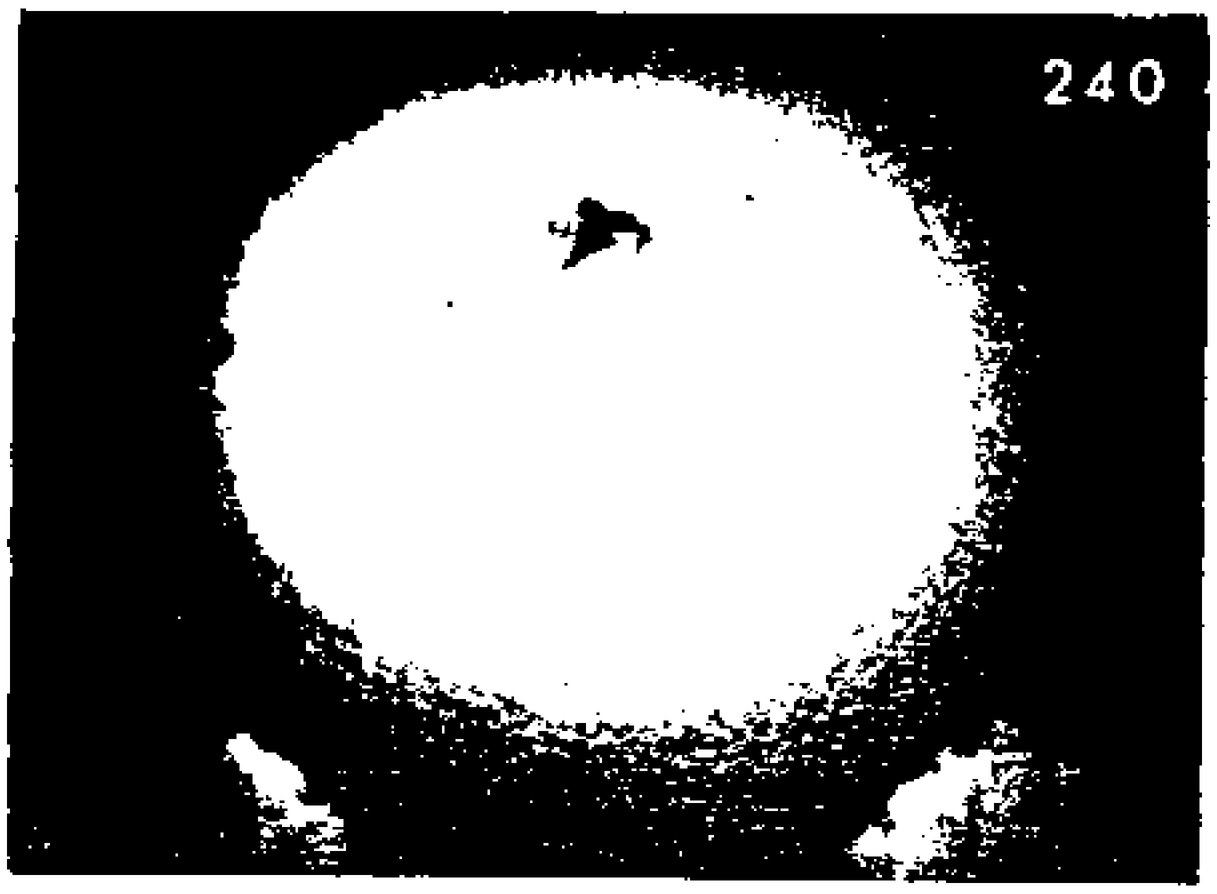

205


212

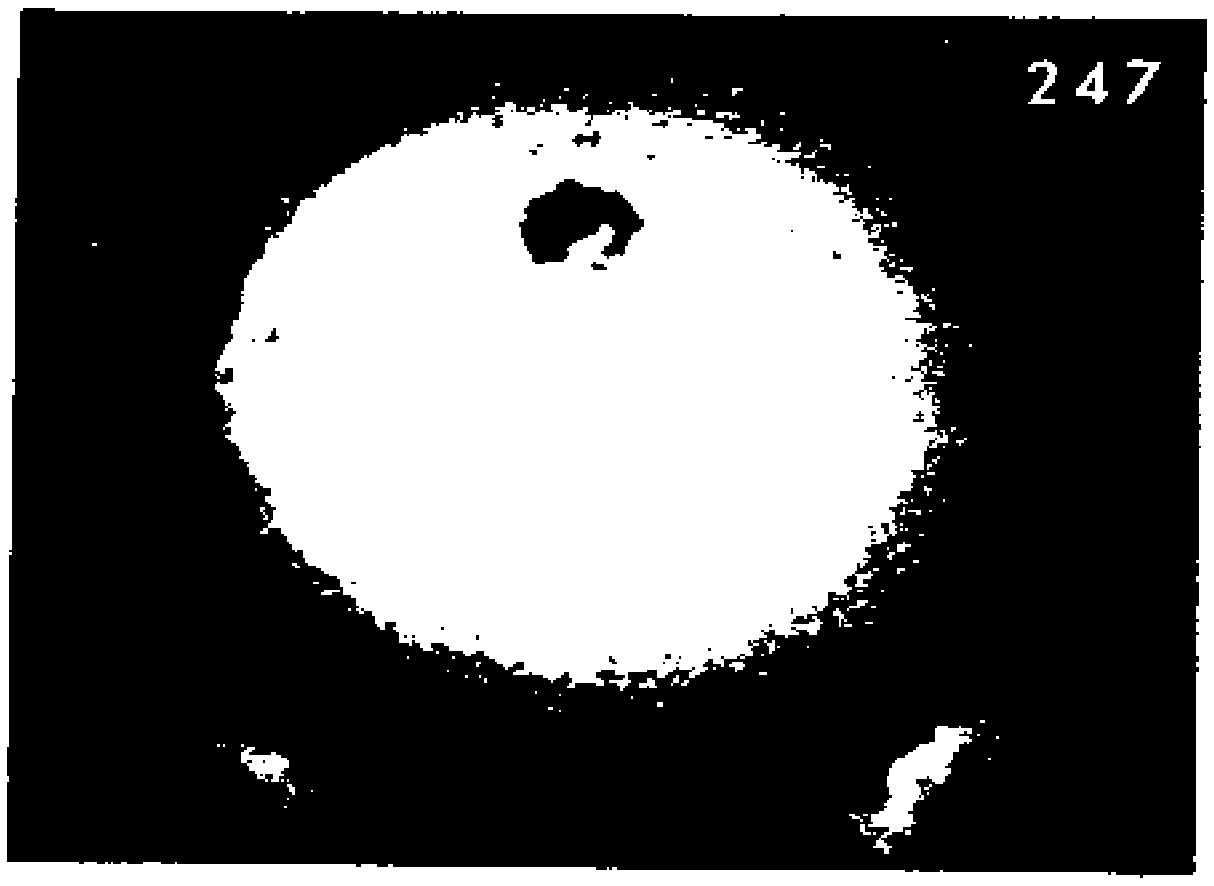

219


226


233

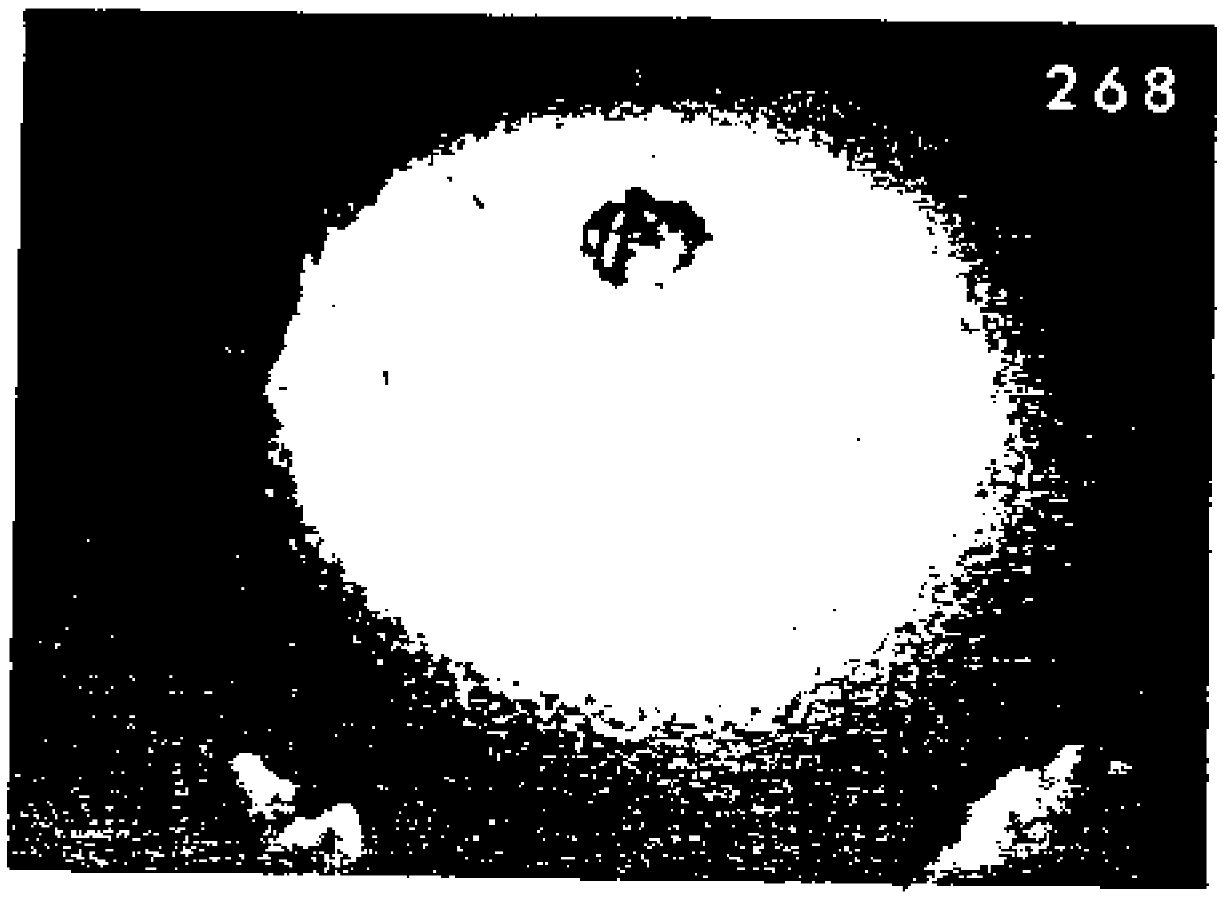

240

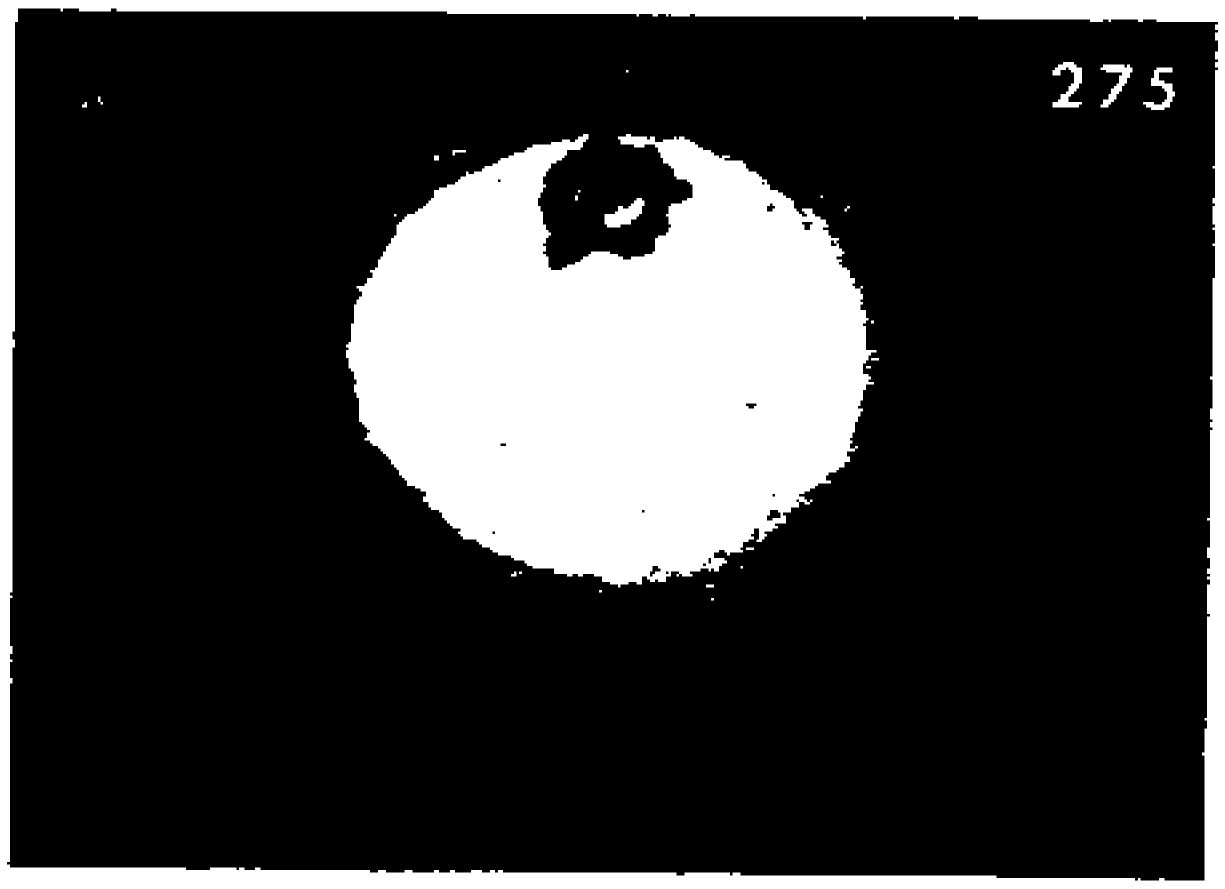
~~SECRET~~
~~RESTRICTED DATA~~
~~ATOMIC ENERGY ACT—1954~~


247


254

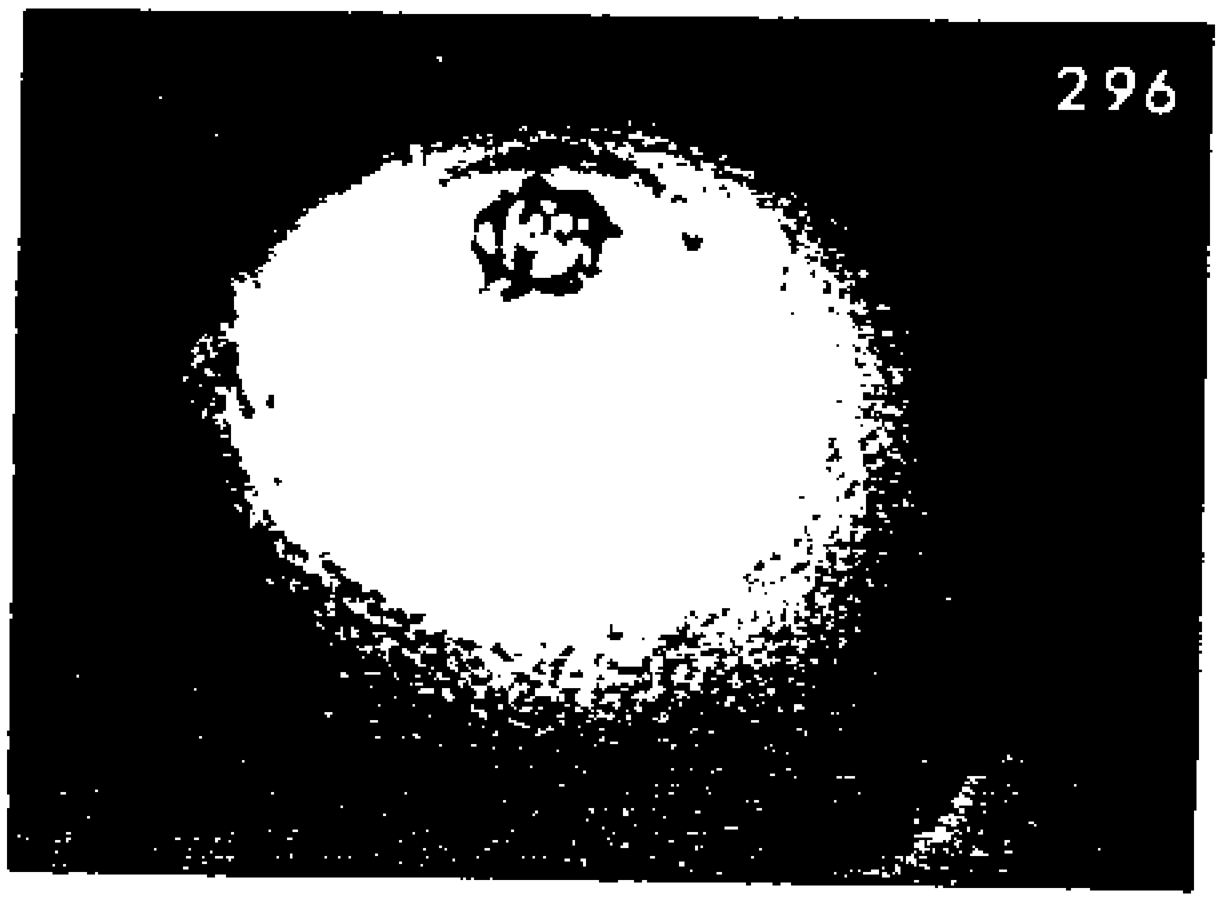

261


268


275


282


289

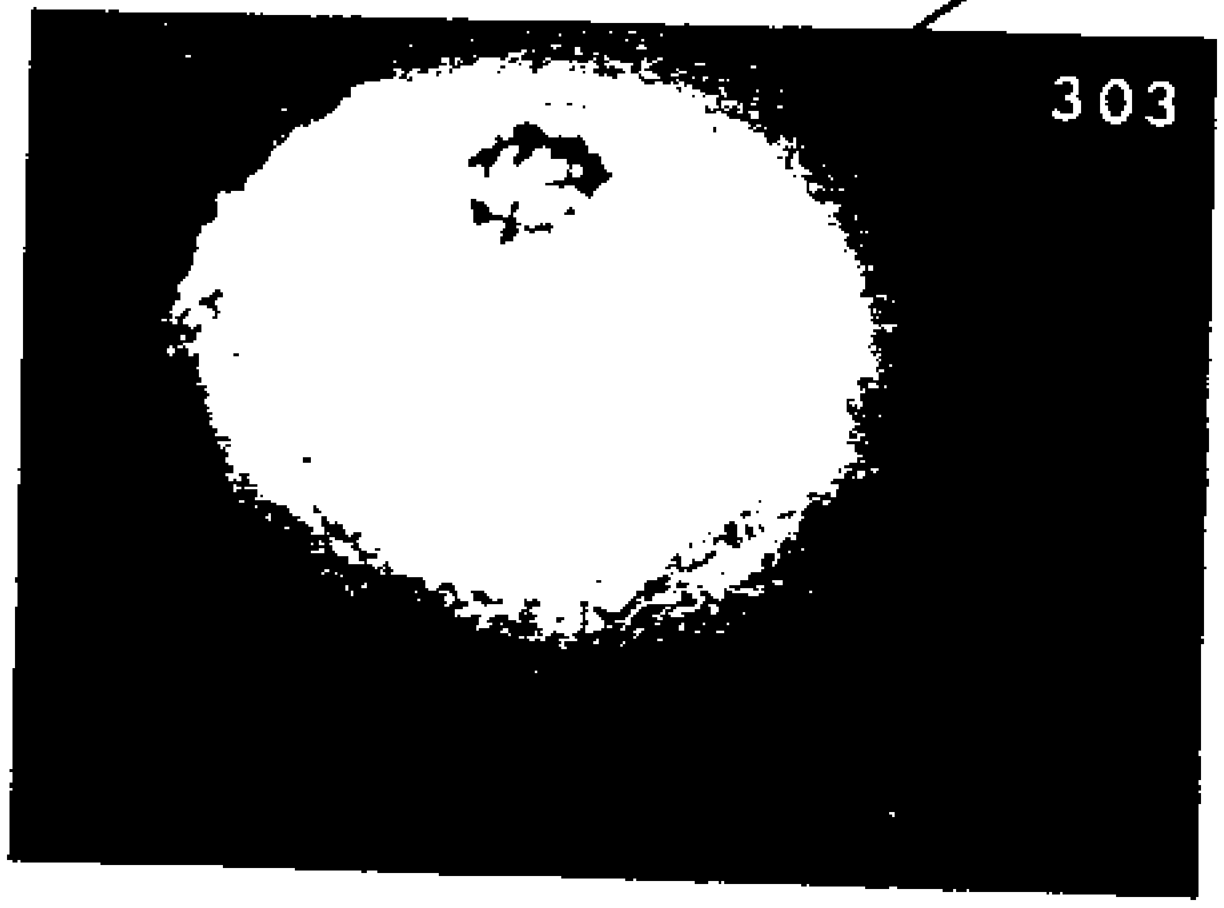

296

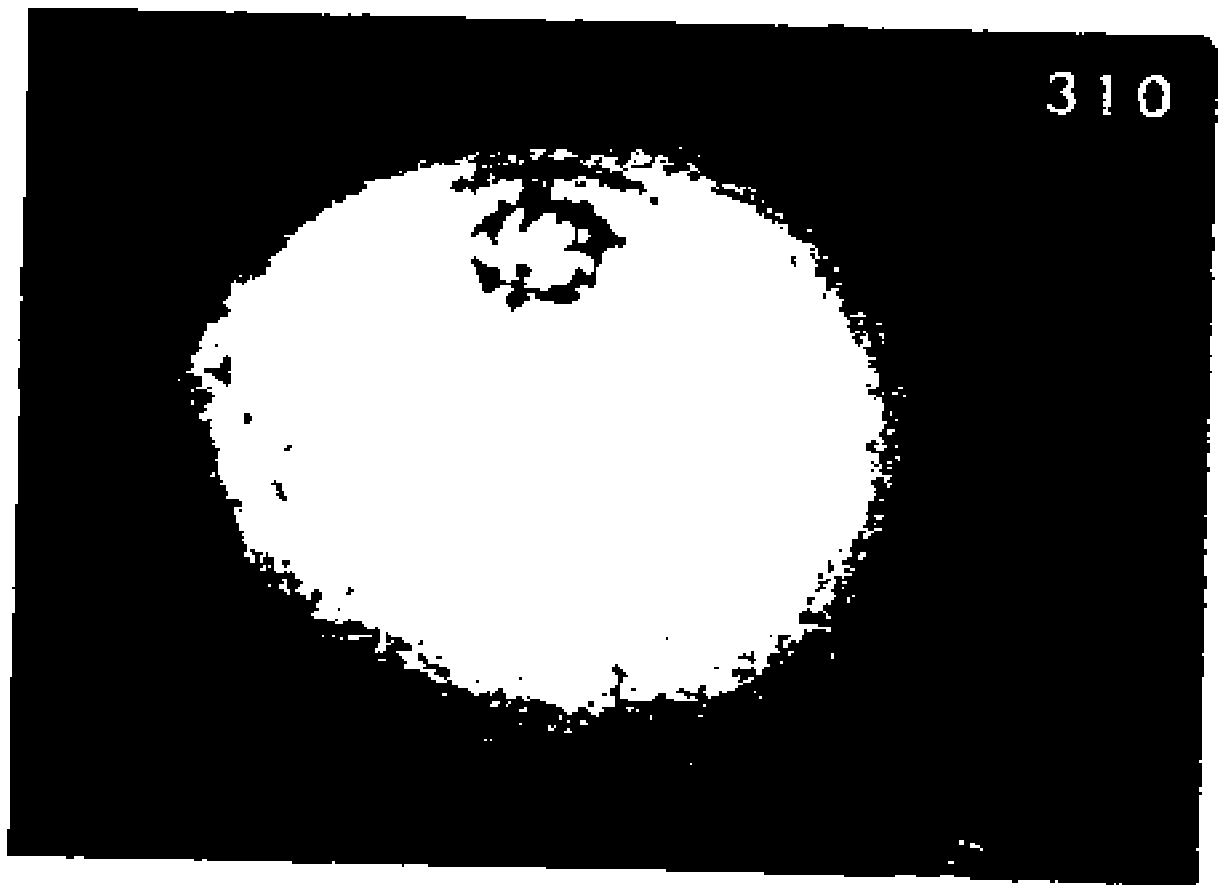
~~SECRET~~

~~SECRET~~

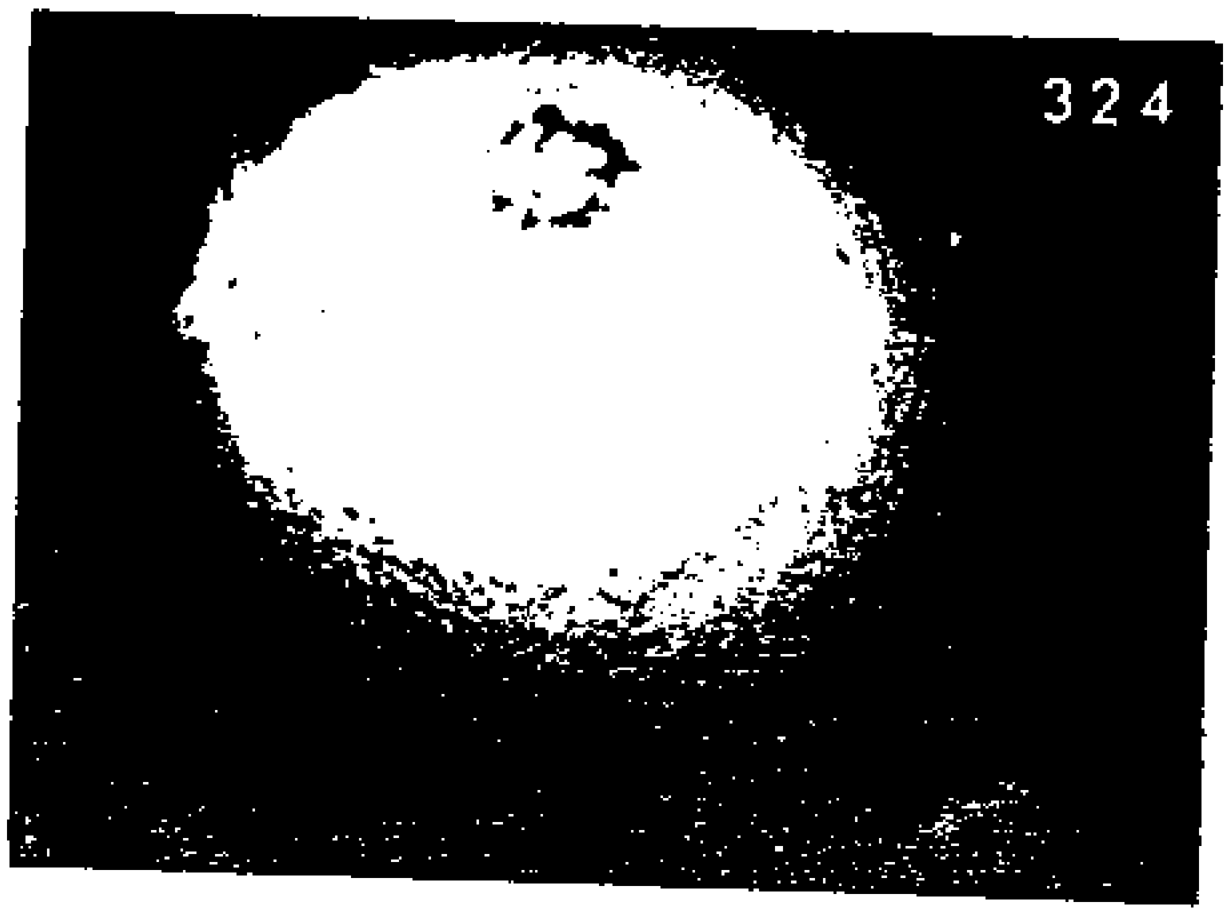
~~RESTRICTED DATA~~

~~ATOMIC ENERGY ACT—1954~~

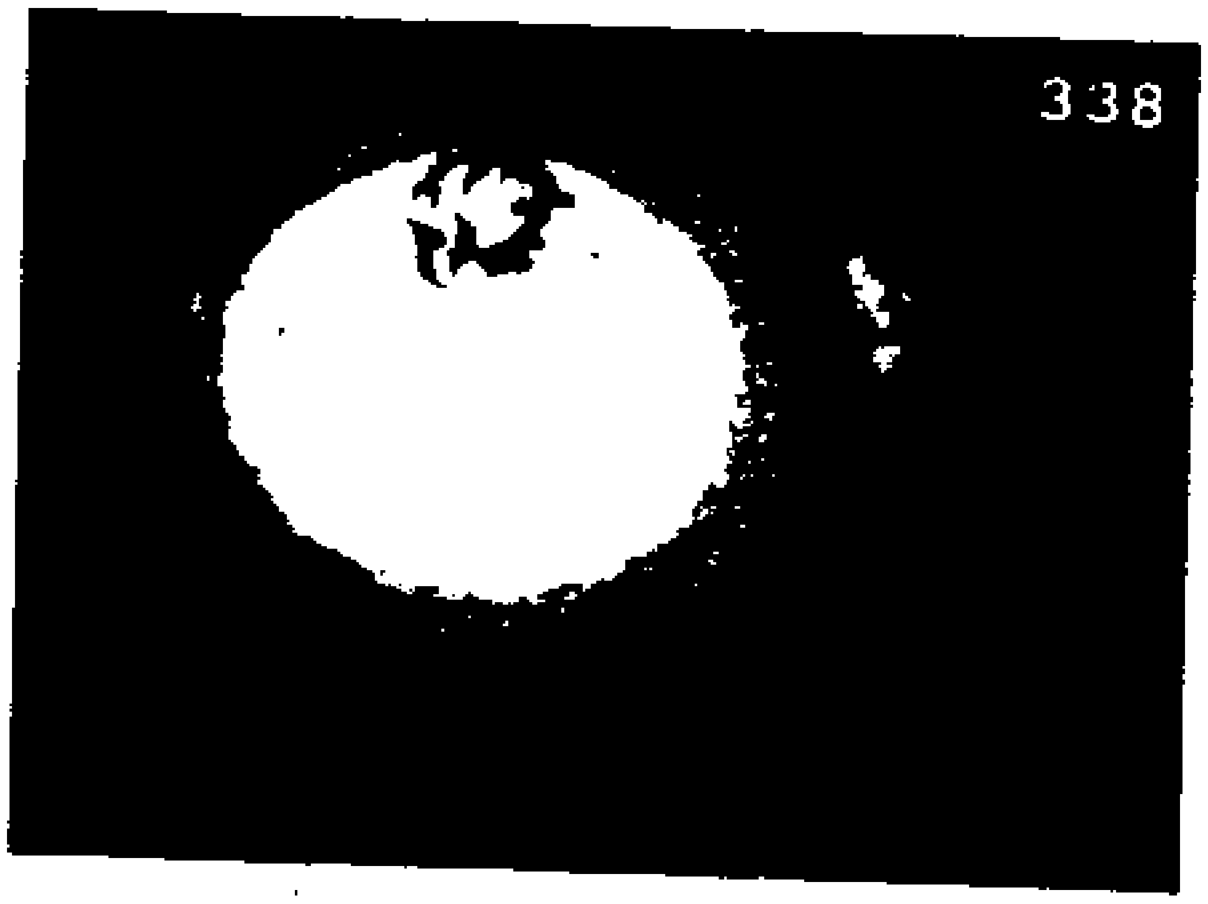

303

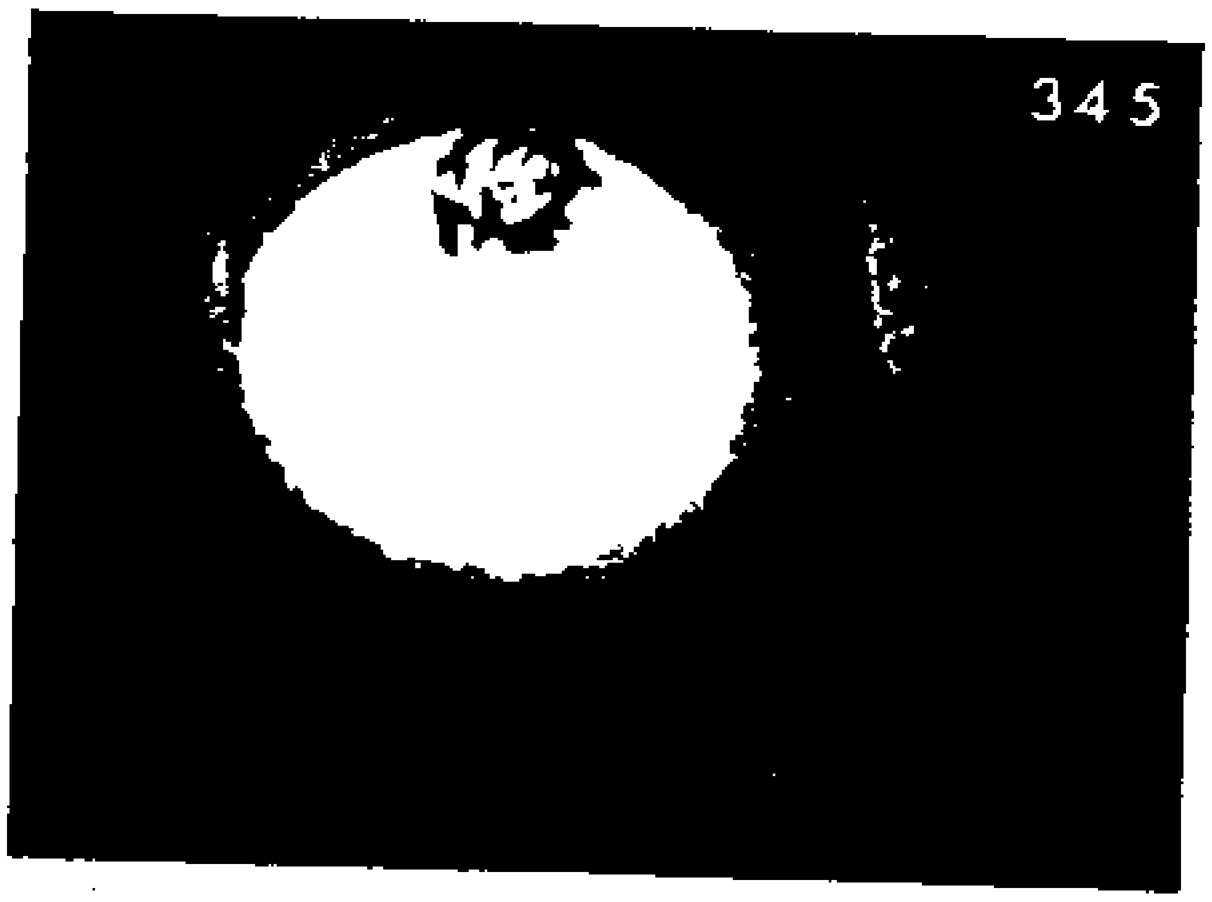

310

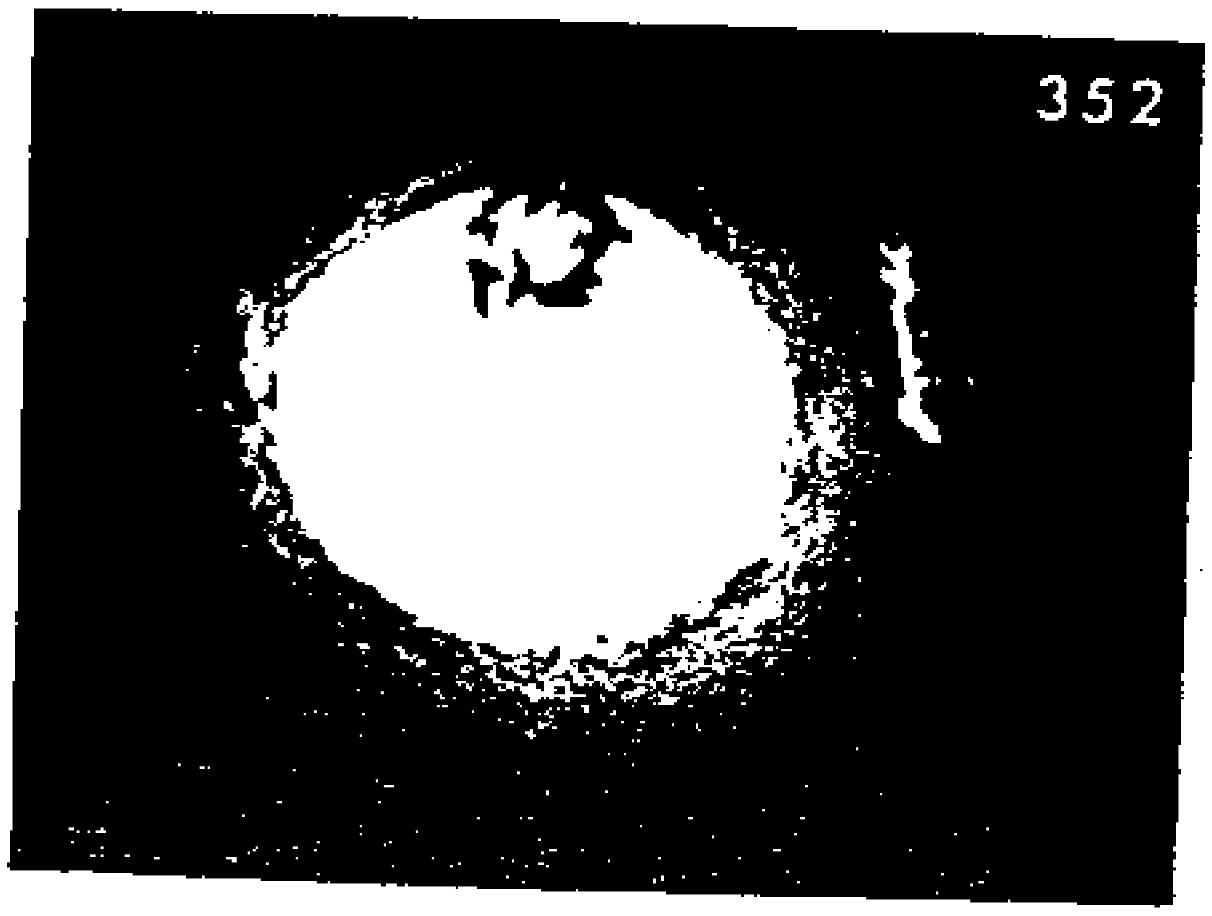

317

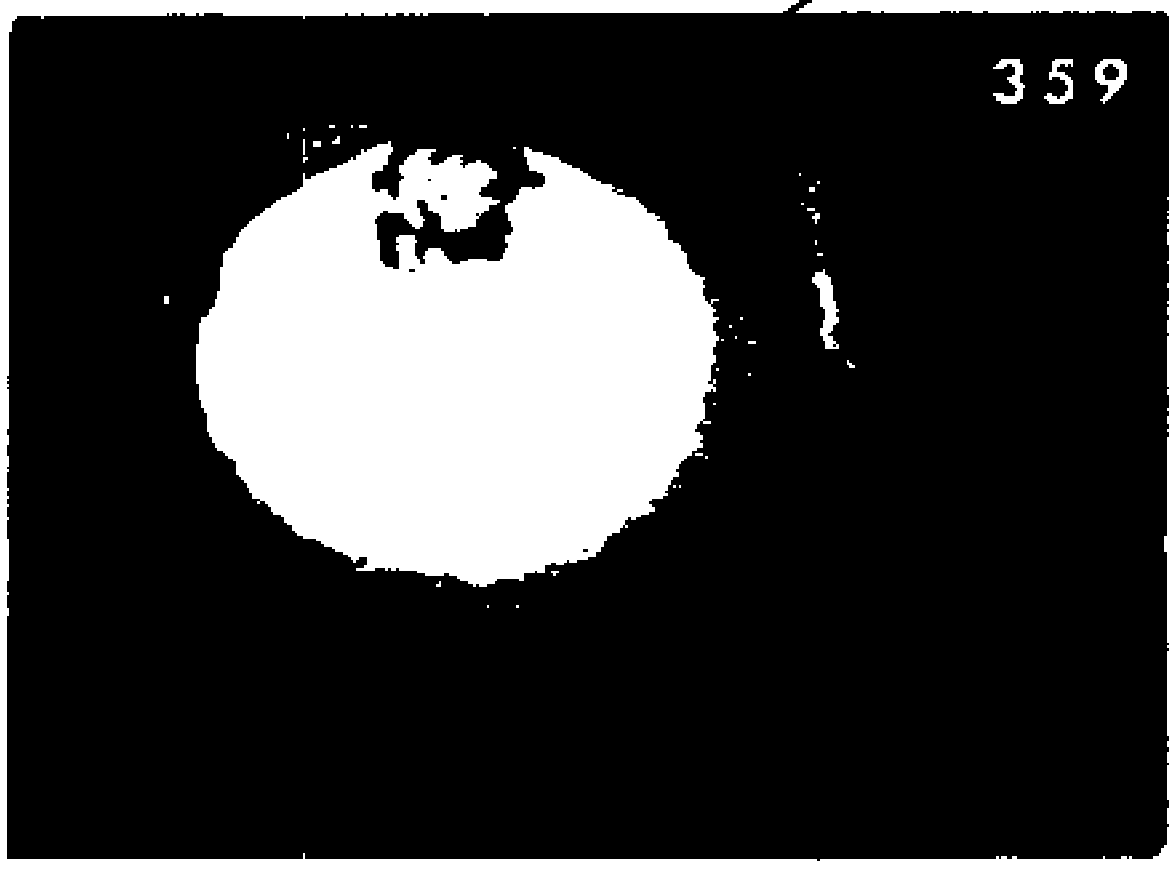

324


331


338

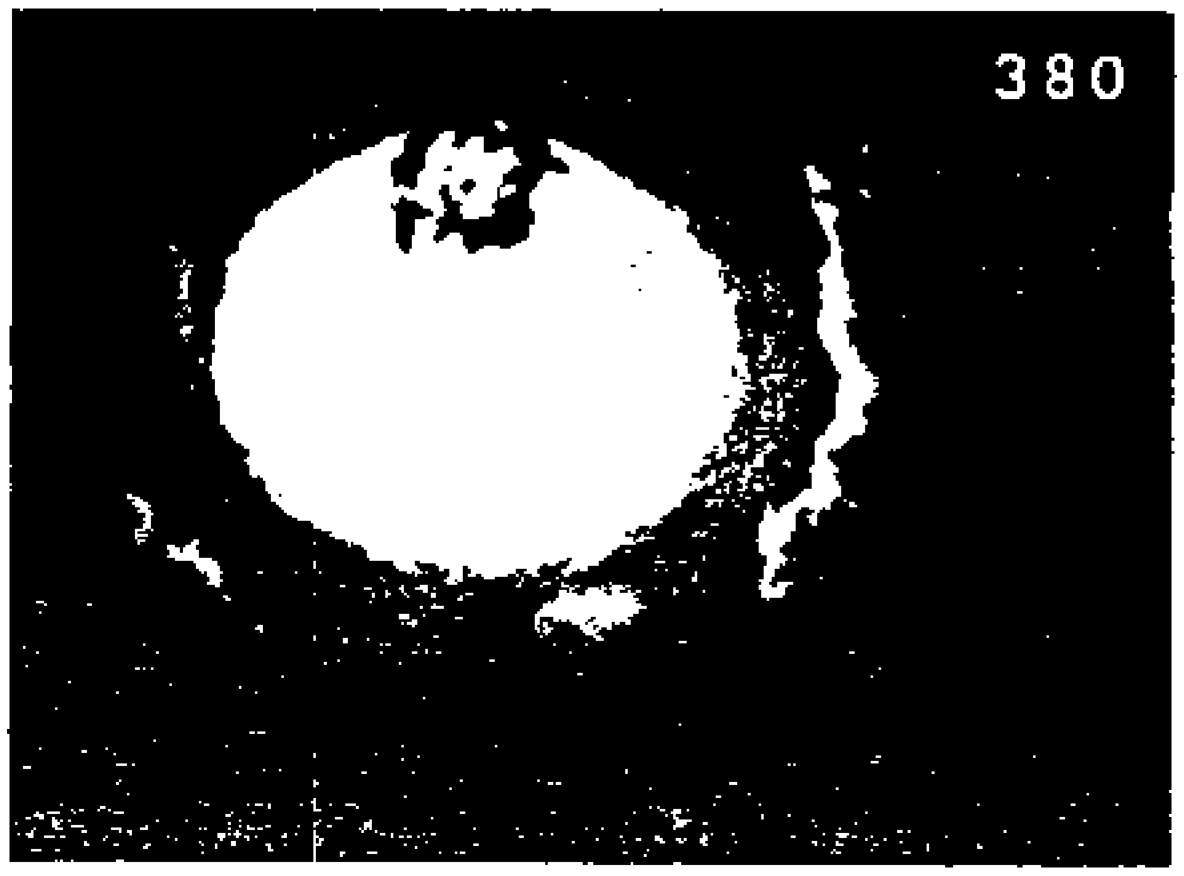

345

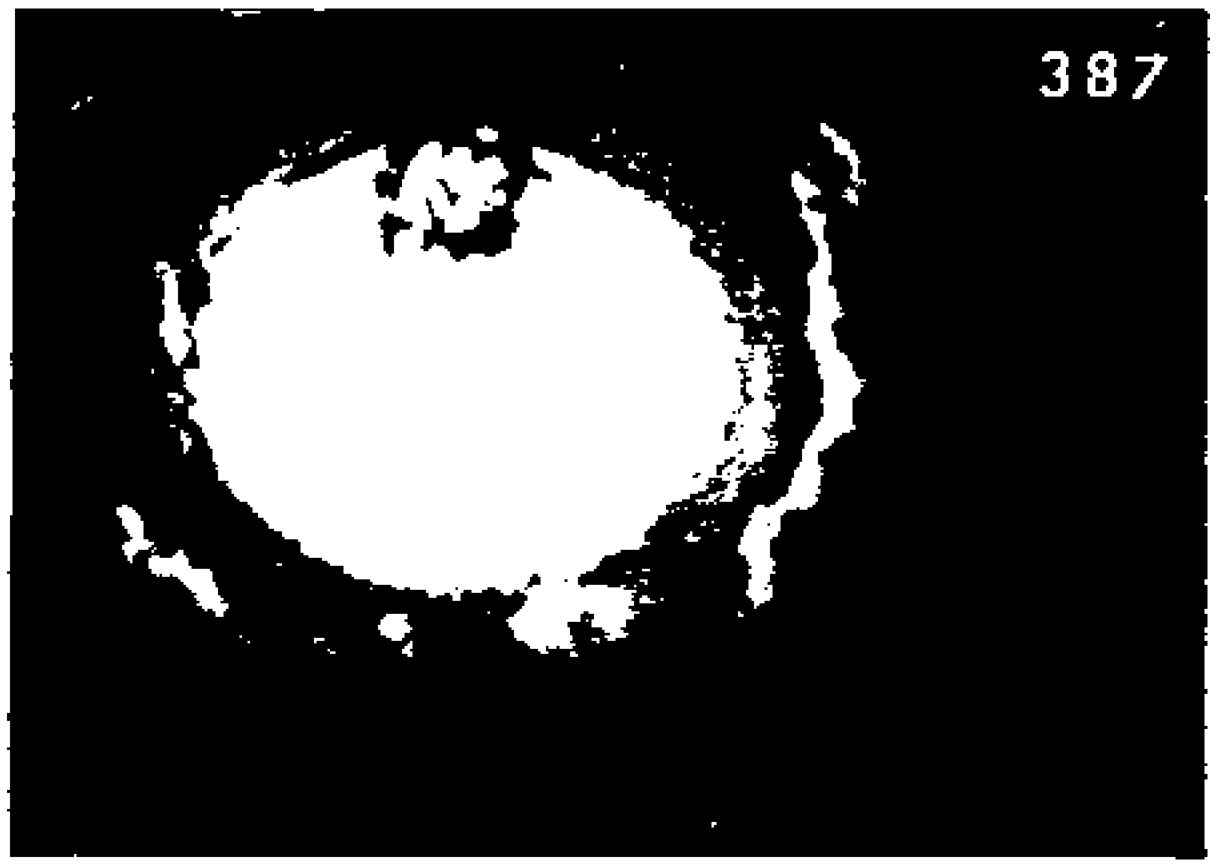

352

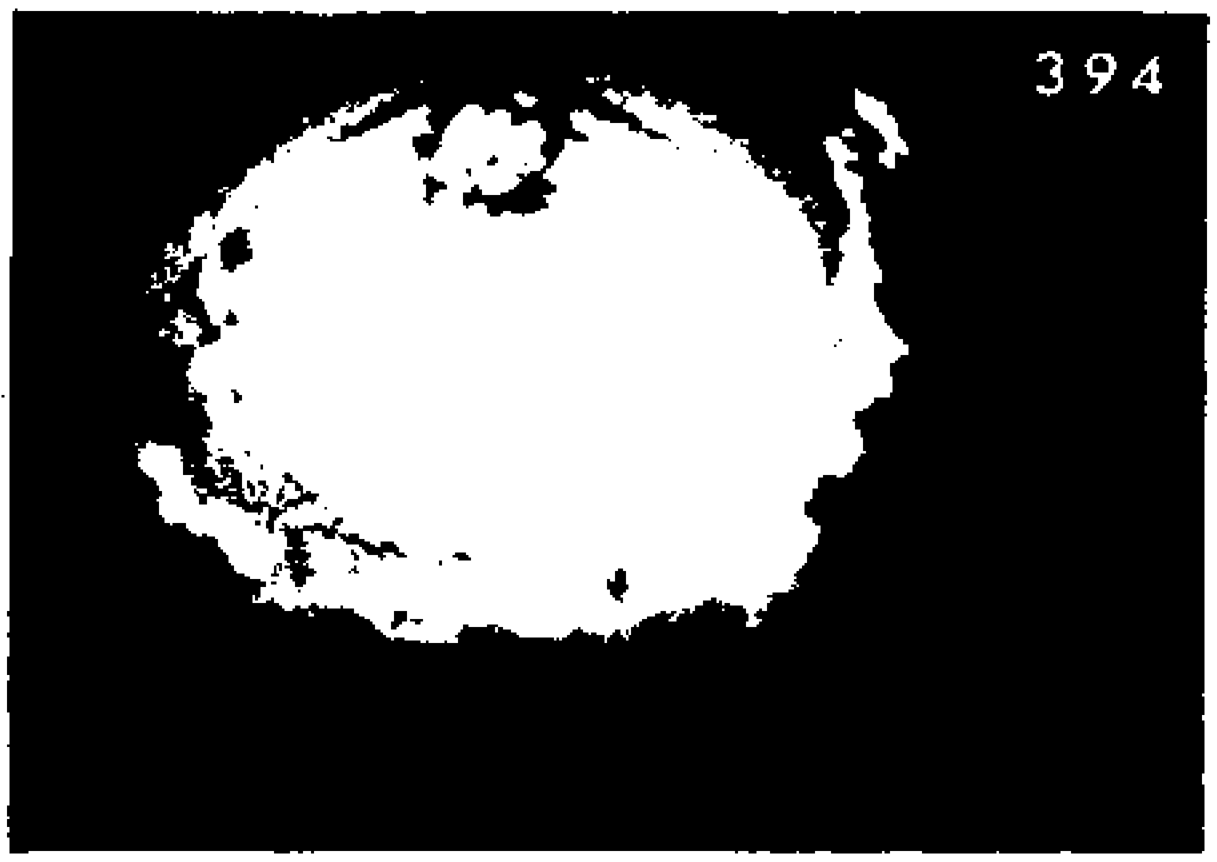

359

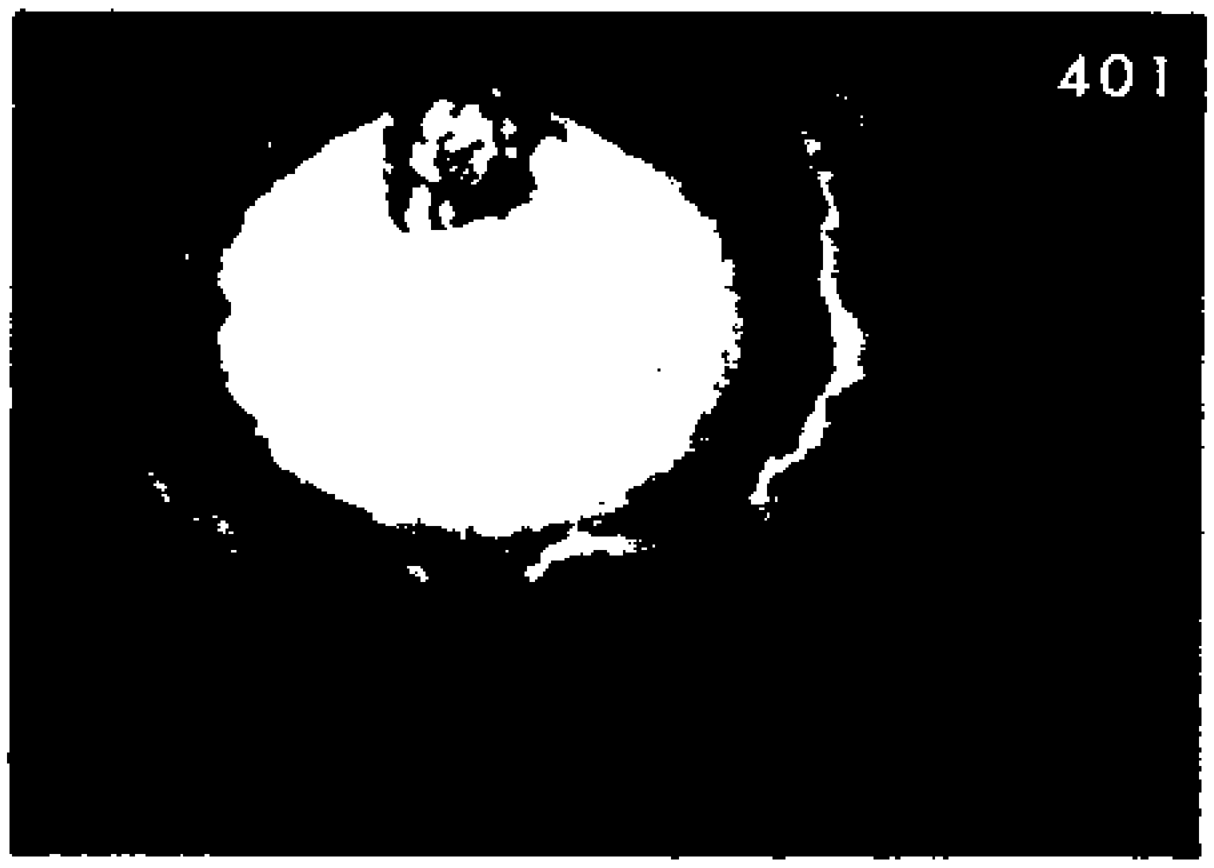

366

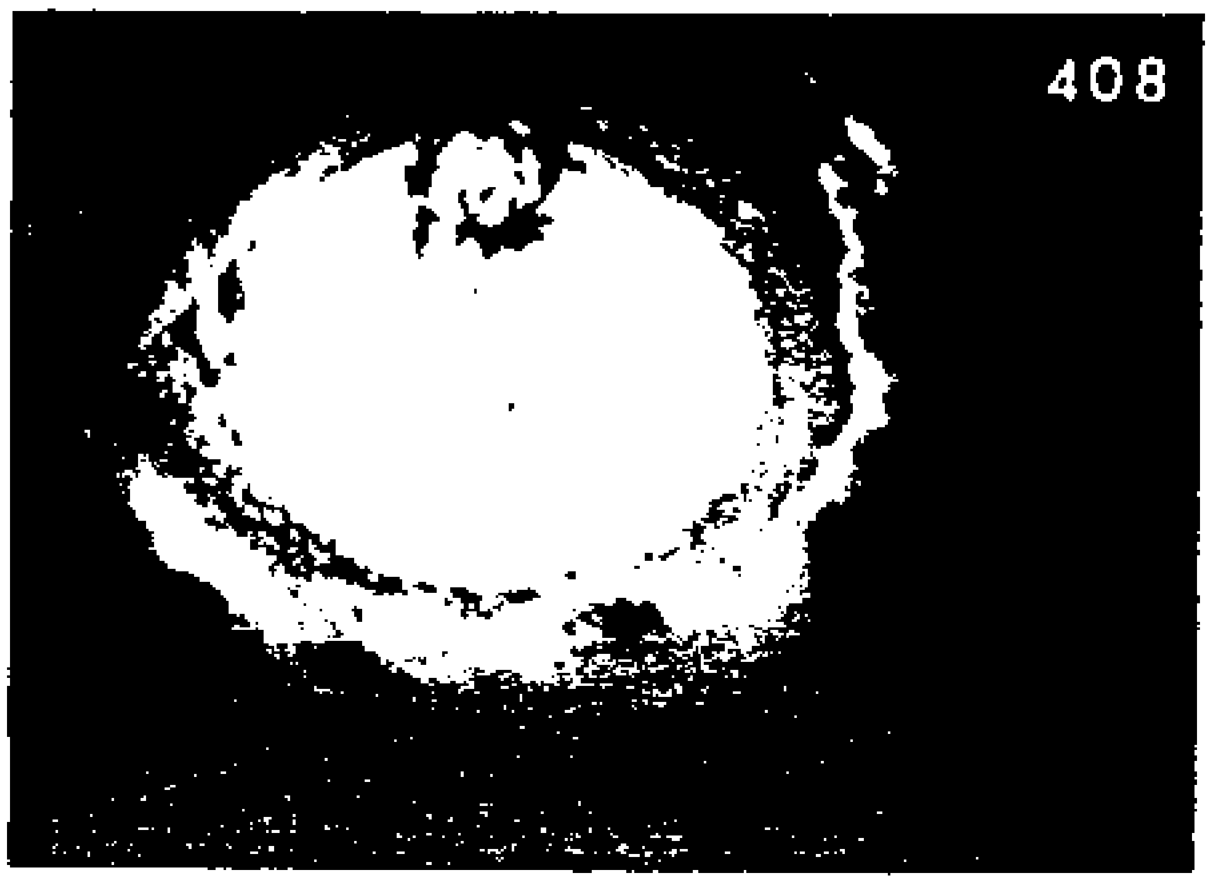

373

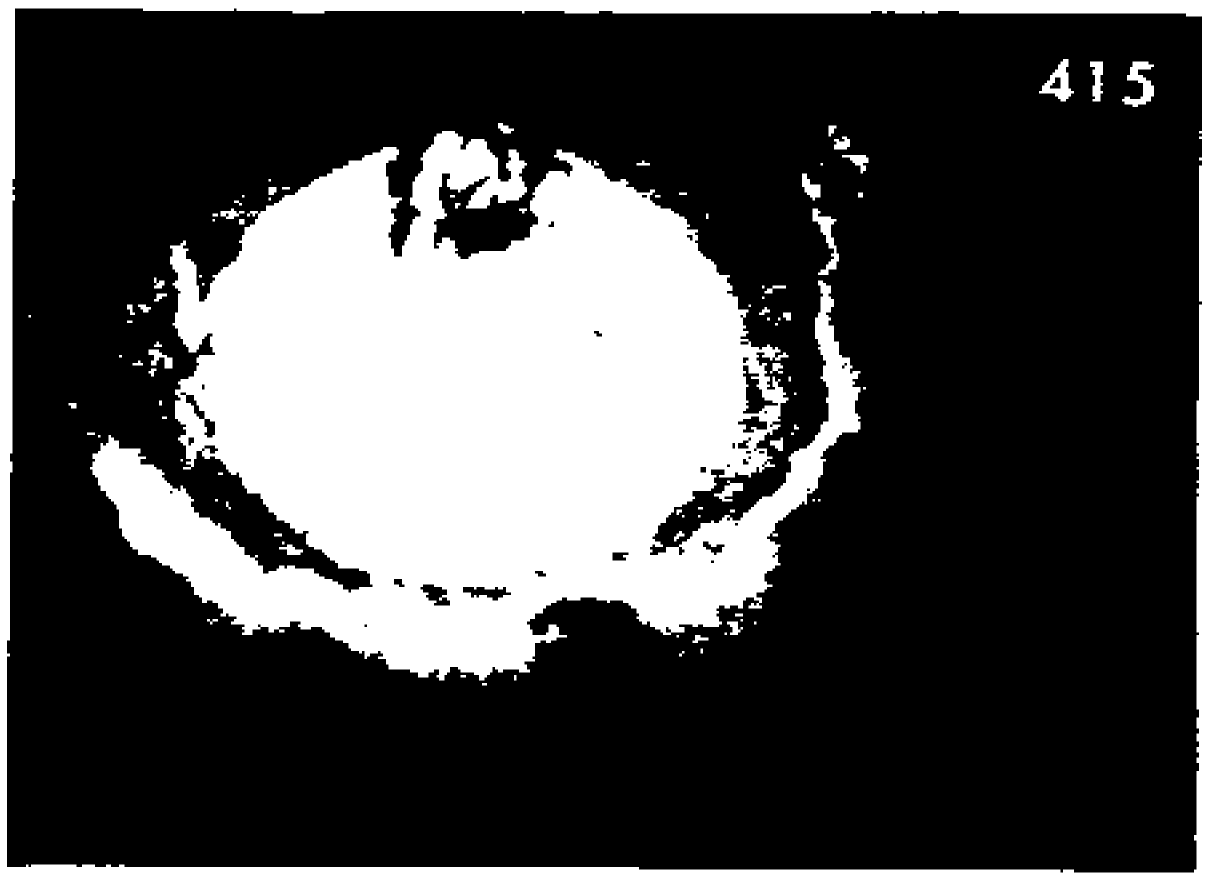

380

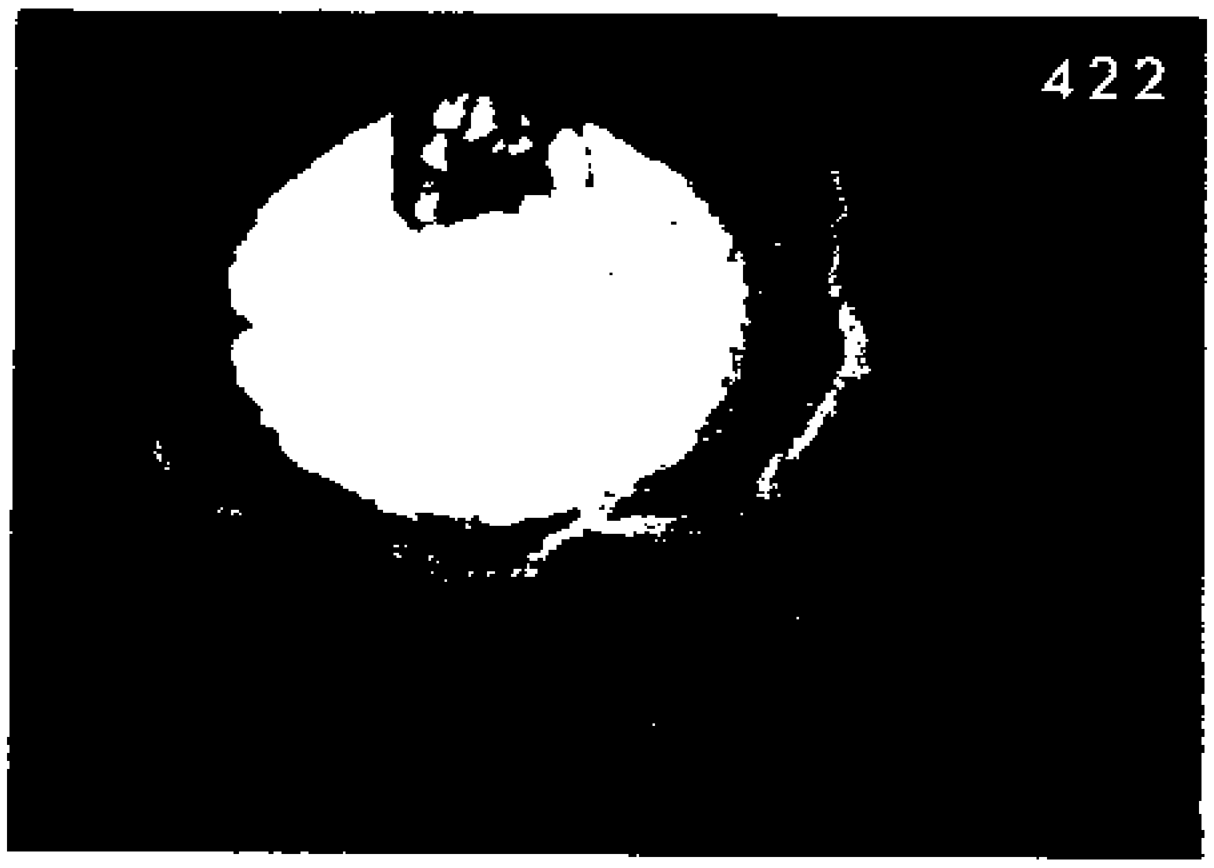

387


394

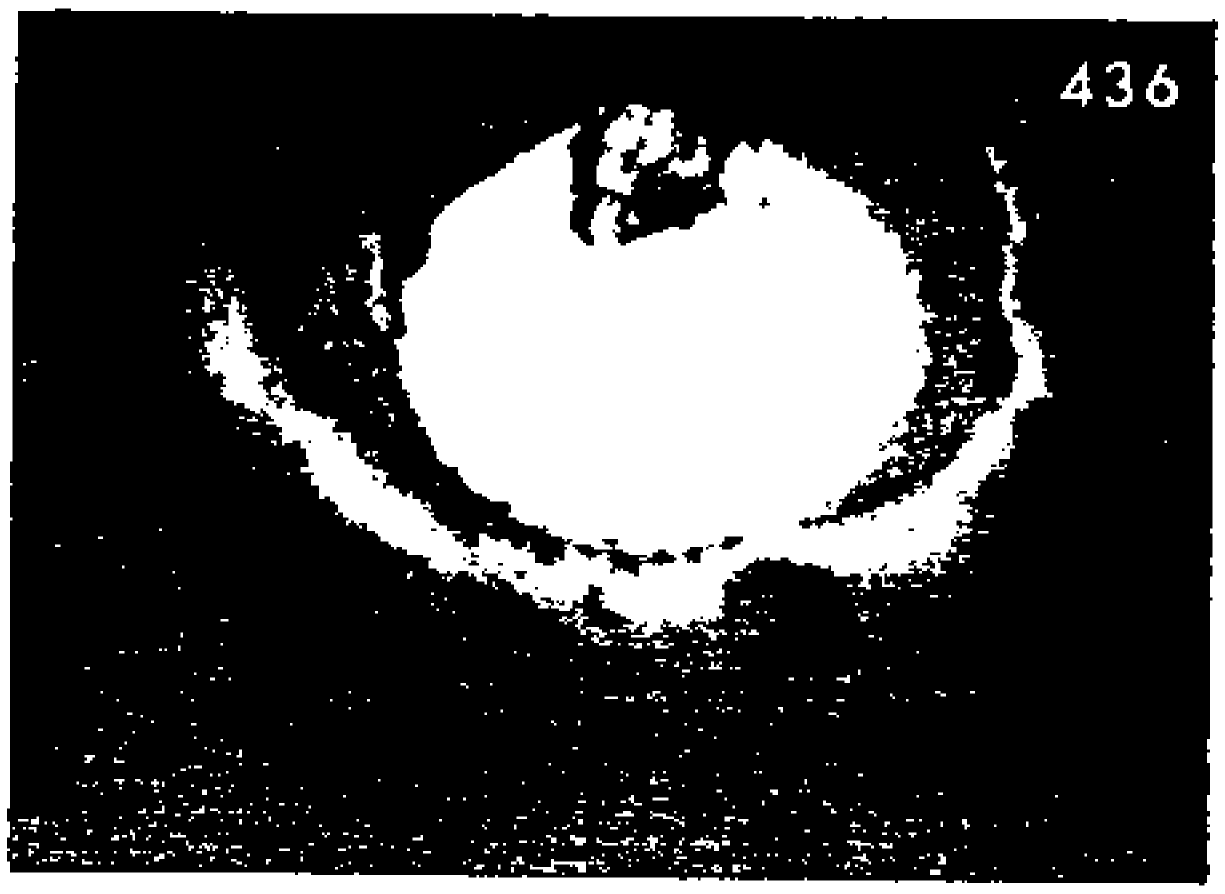

401

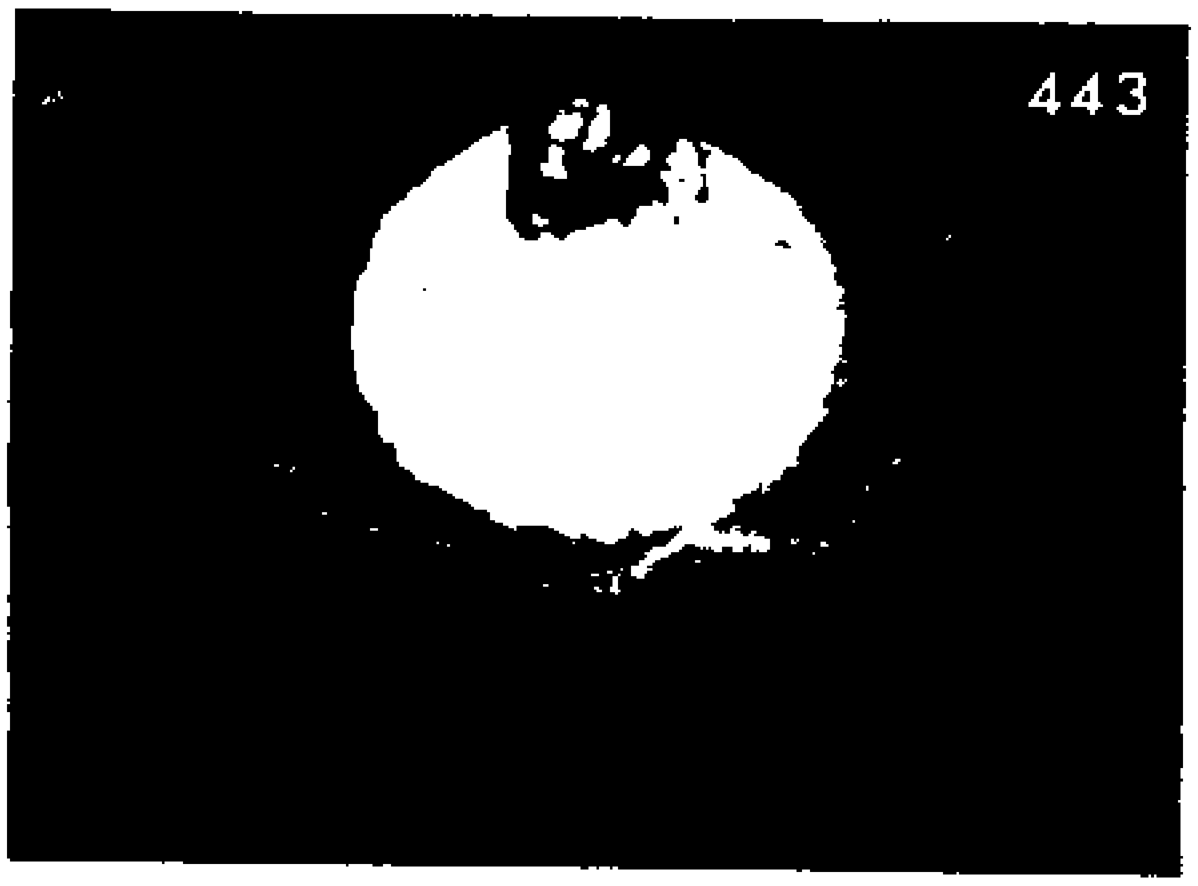

408

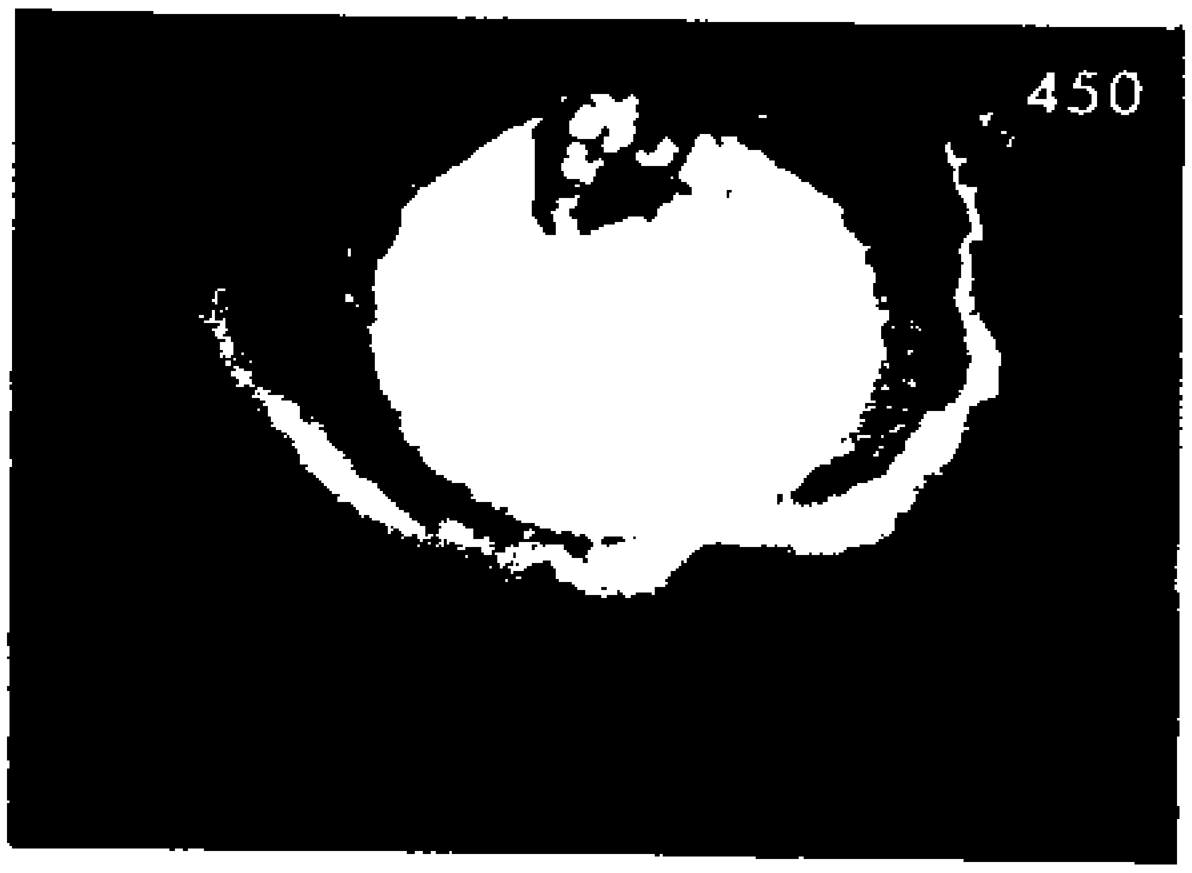

415

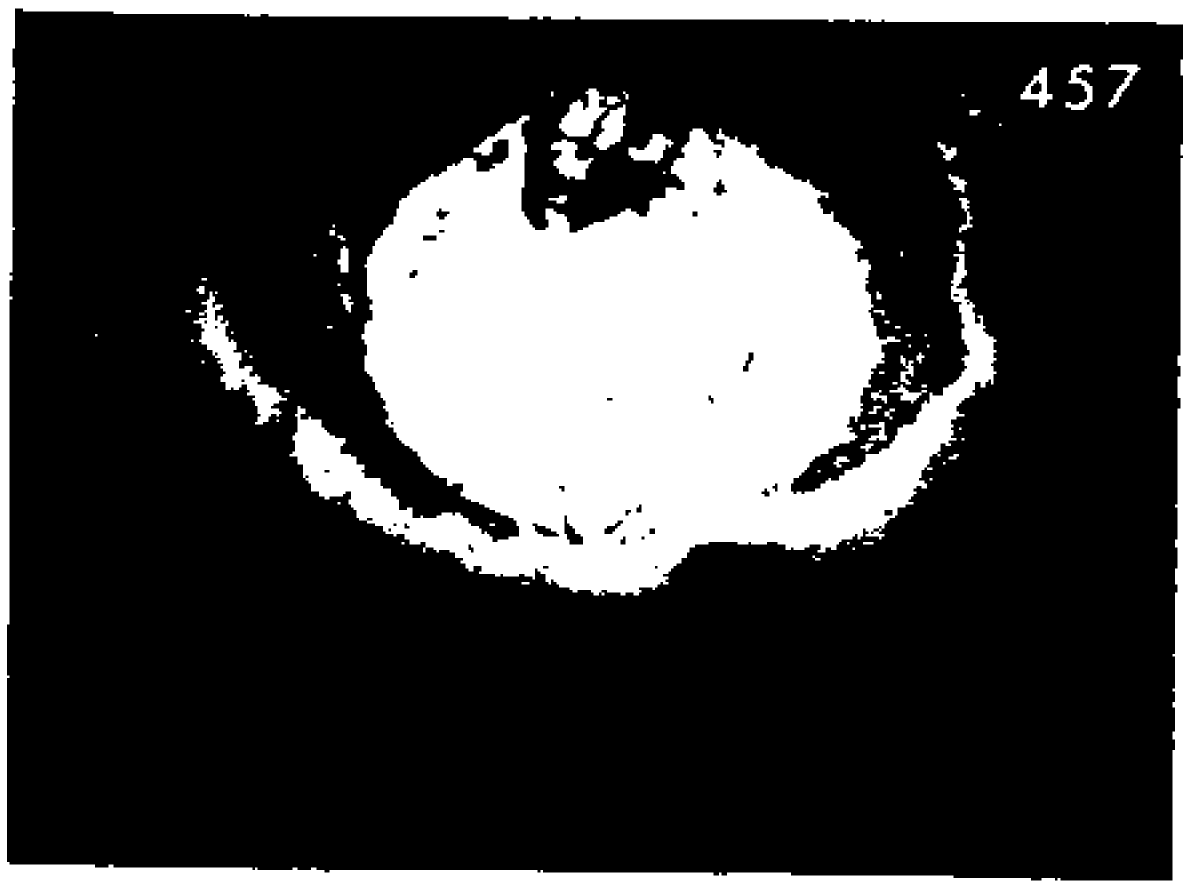

422


429


436


443


450

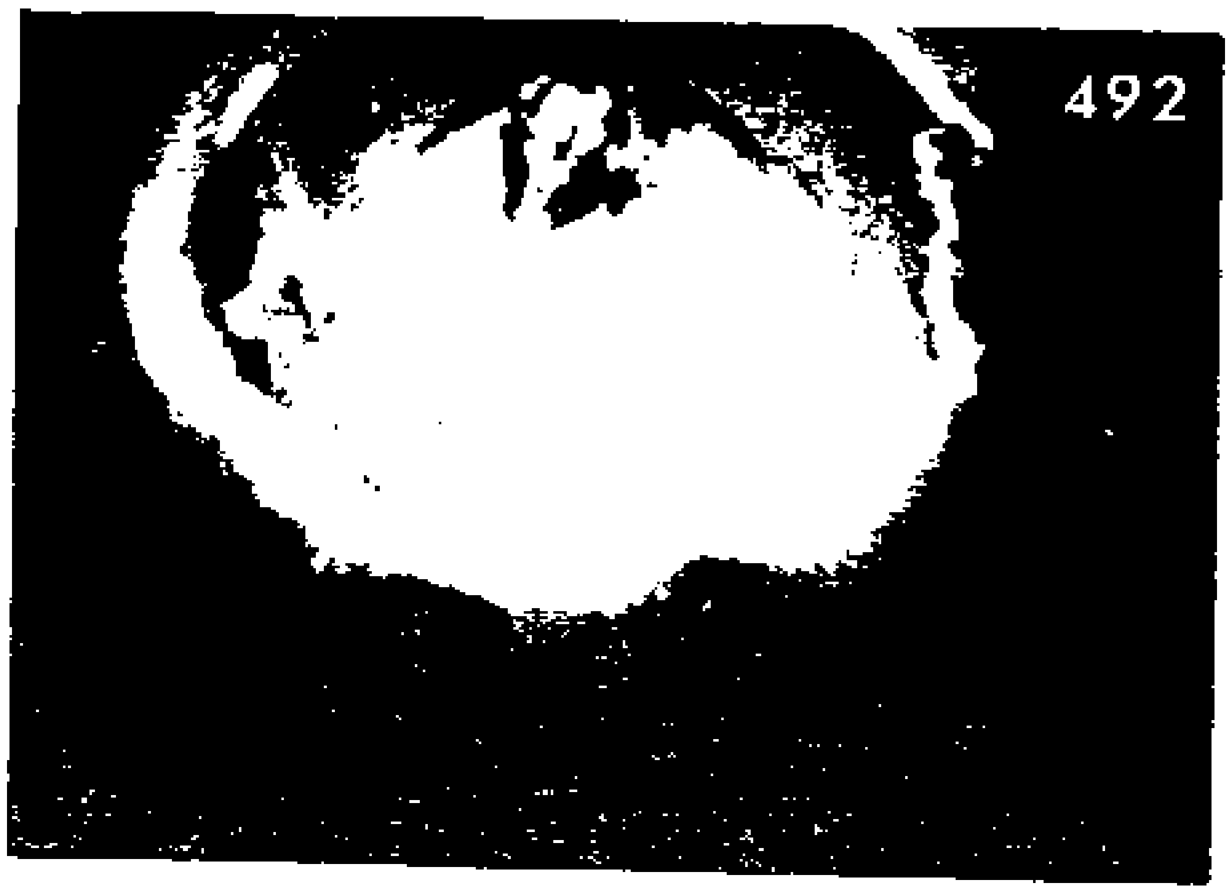

457

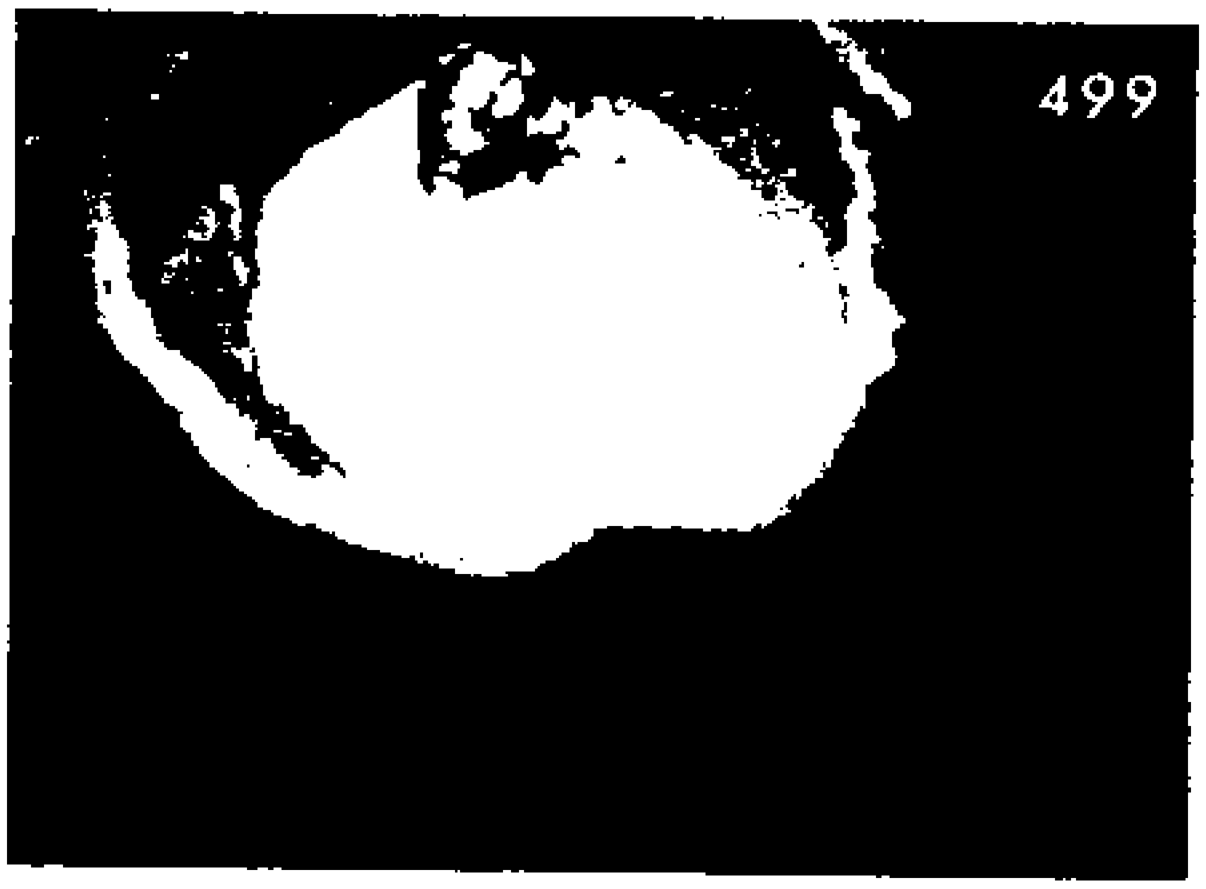

462


469


476


485


492


499

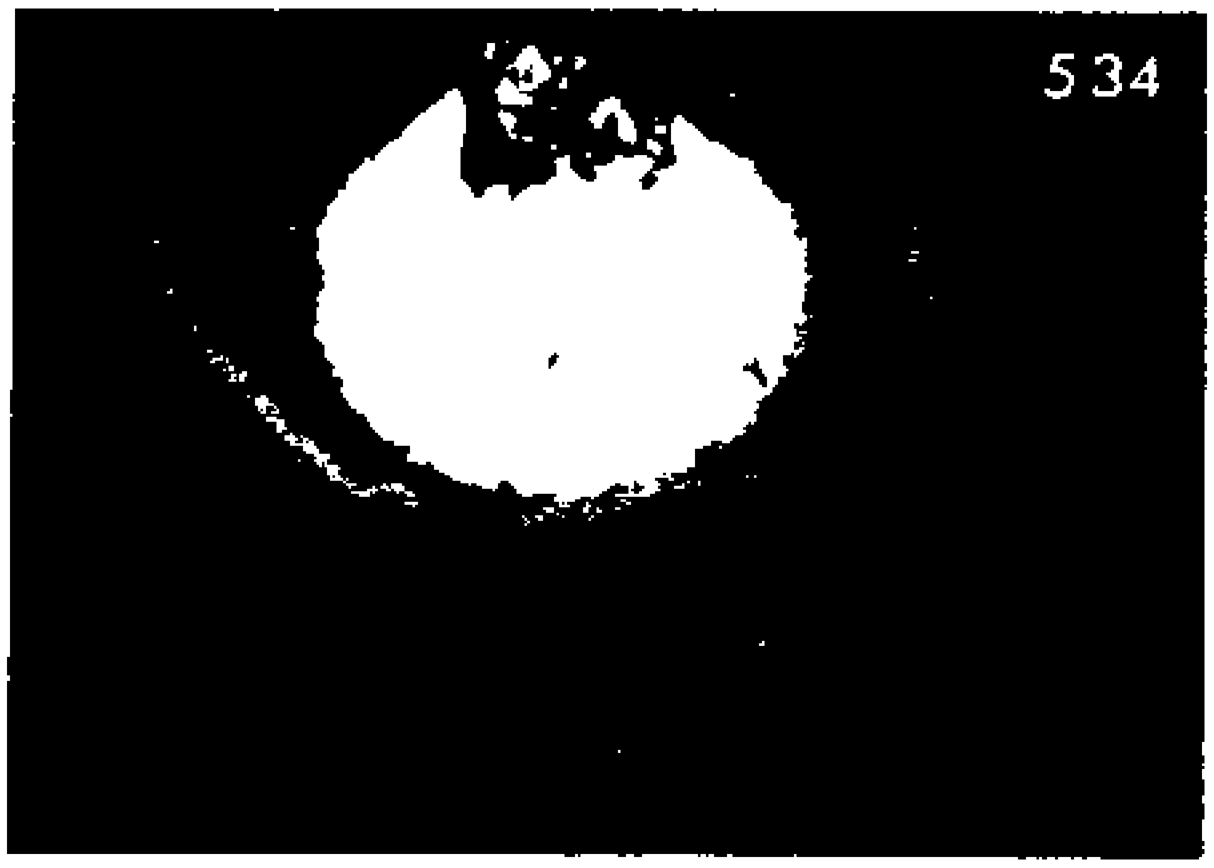

506


513

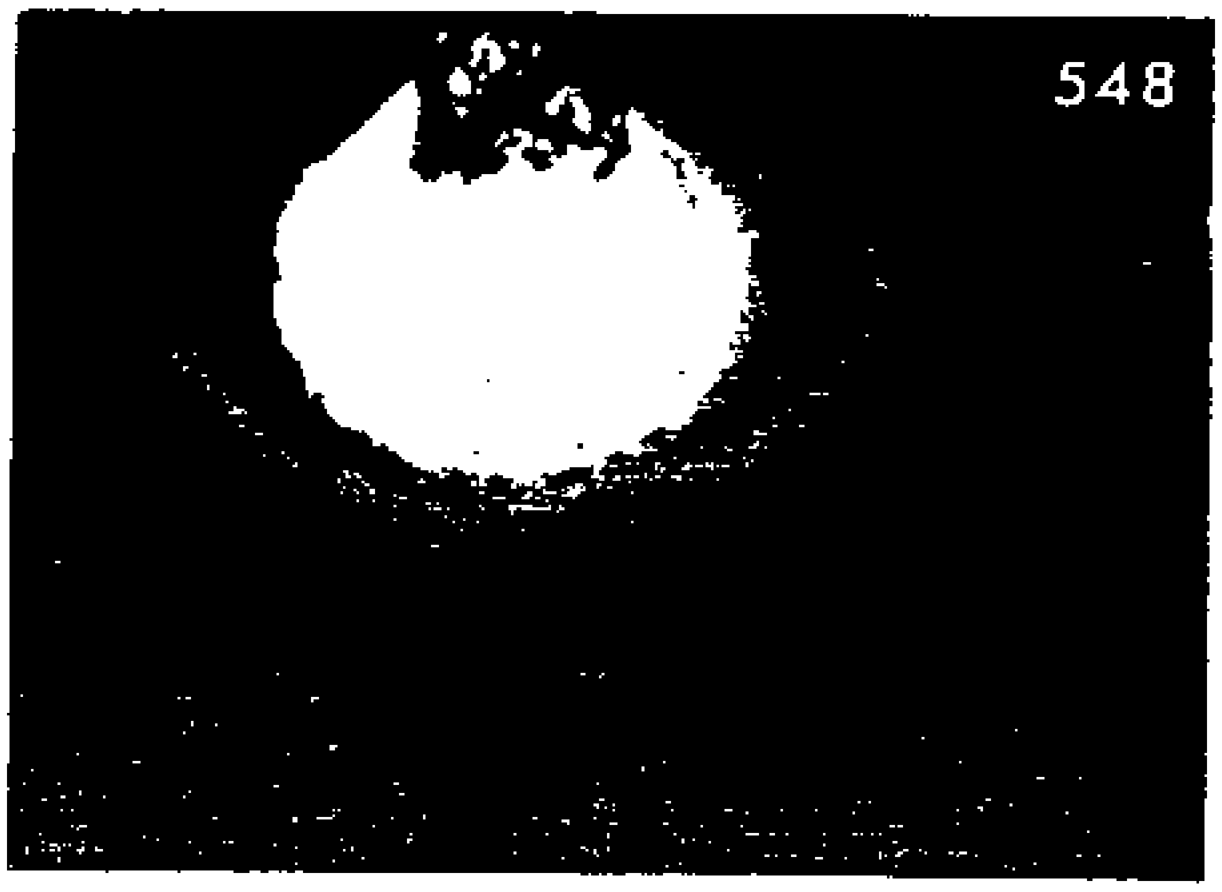

520

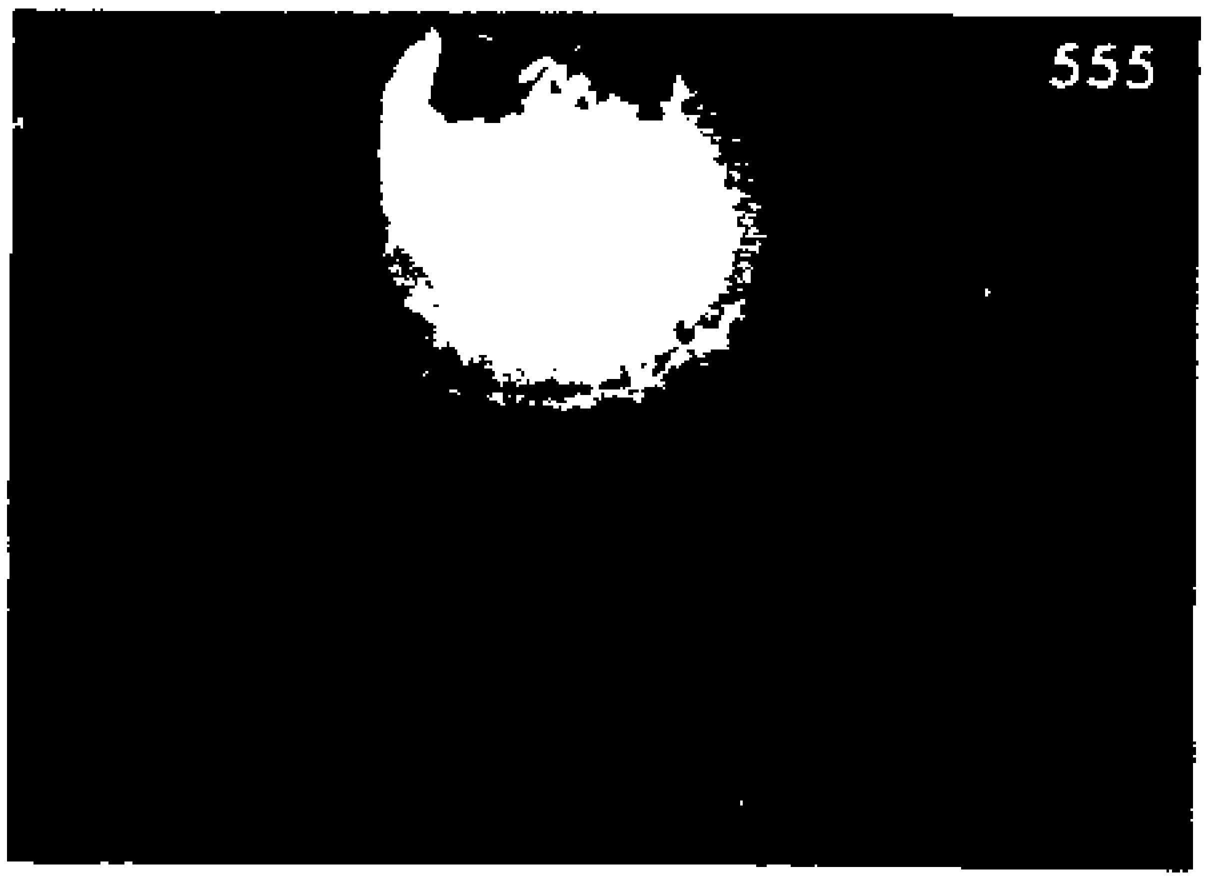
~~SECRET~~
~~RESTRICTED DATA~~
~~ATOMIC ENERGY ACT-1954~~

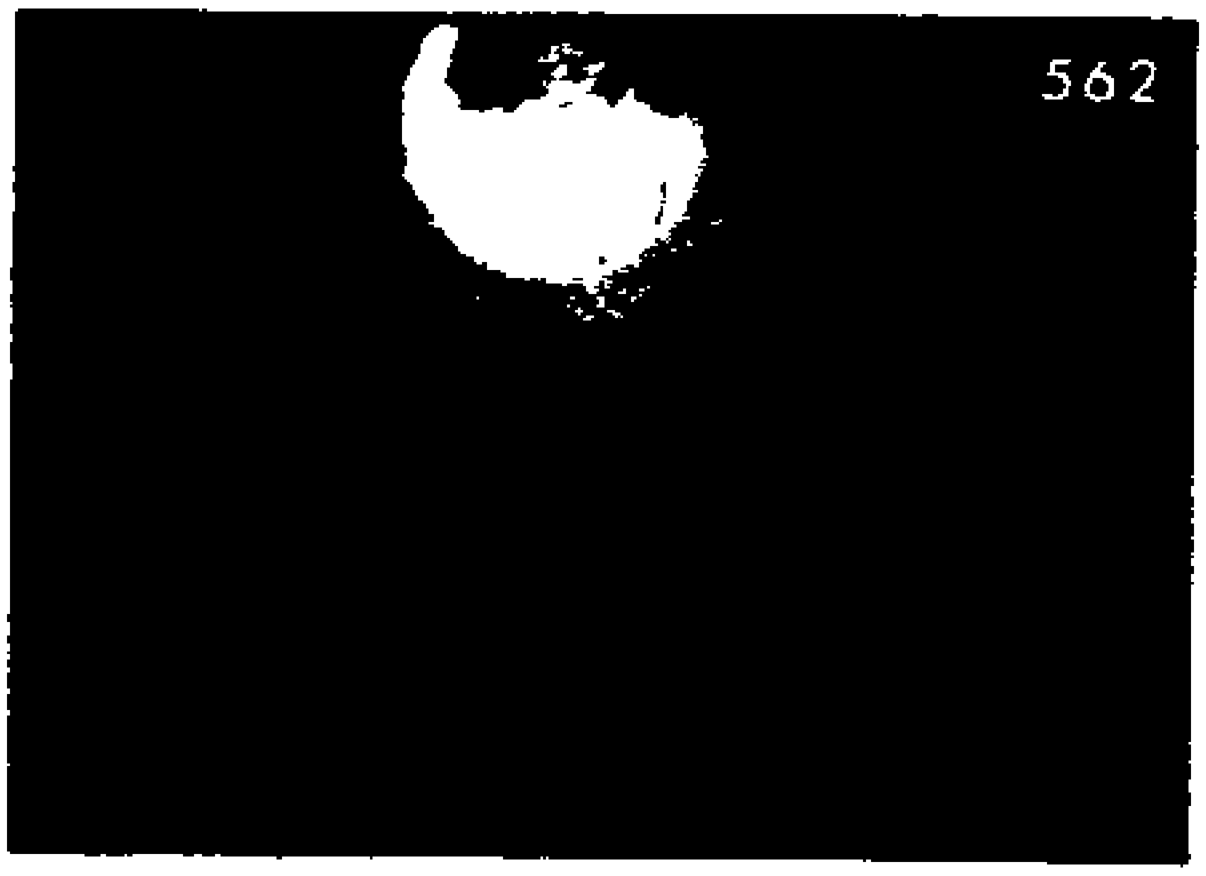

527

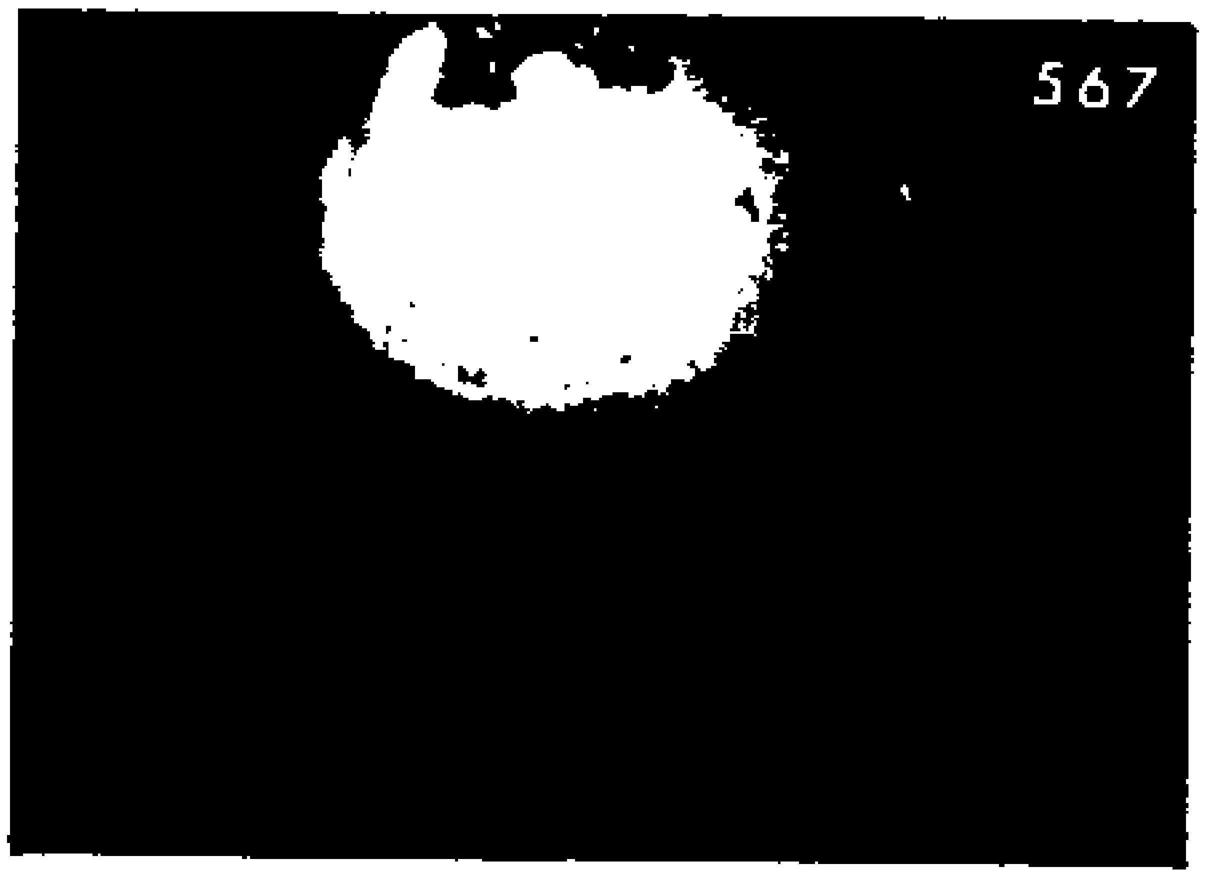

534

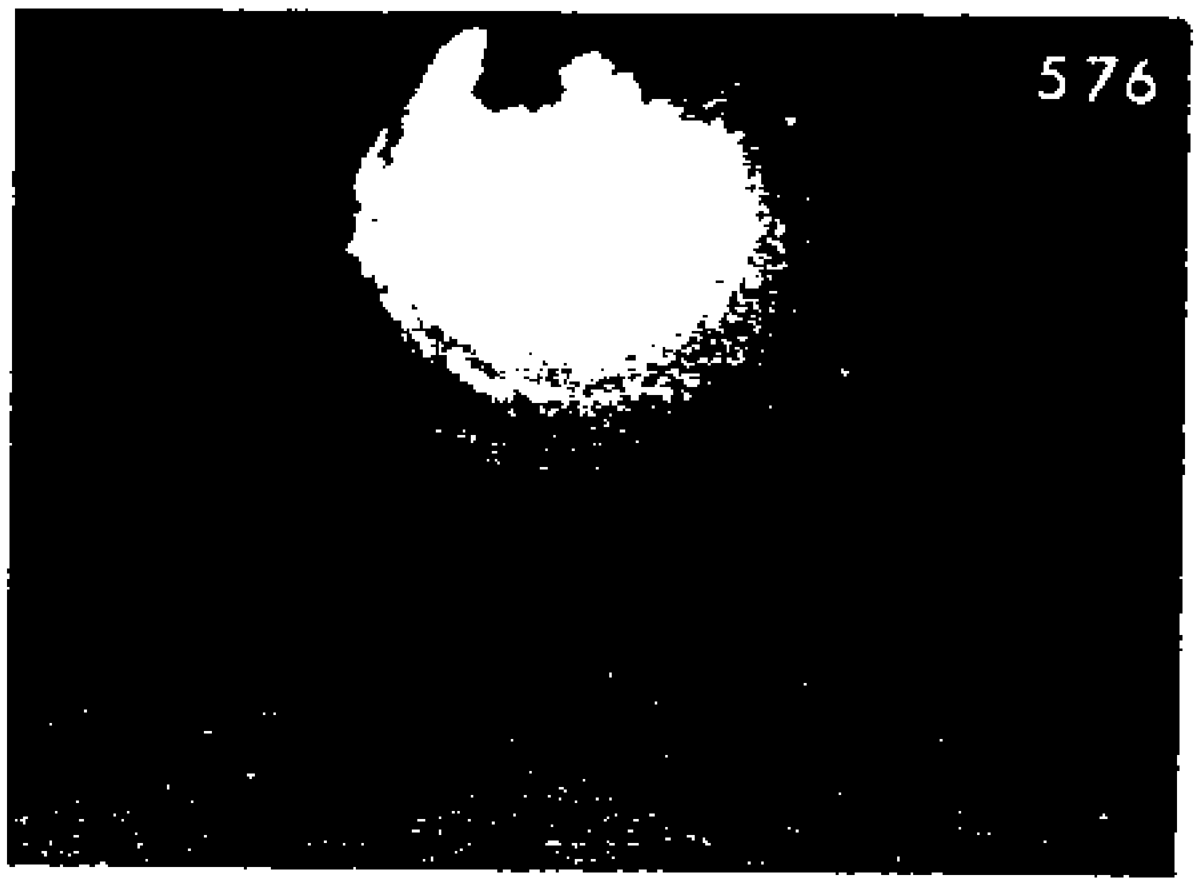

541


548


555

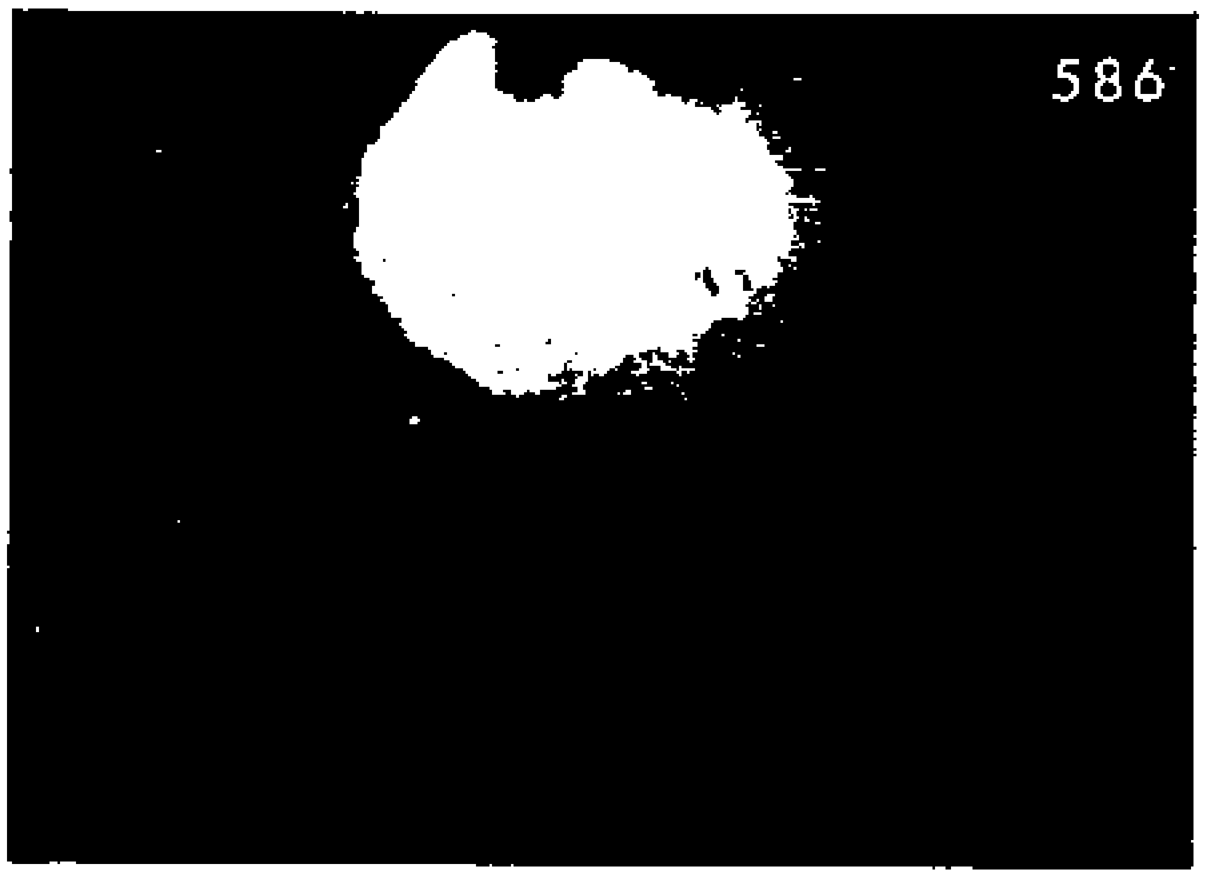

562


567


576

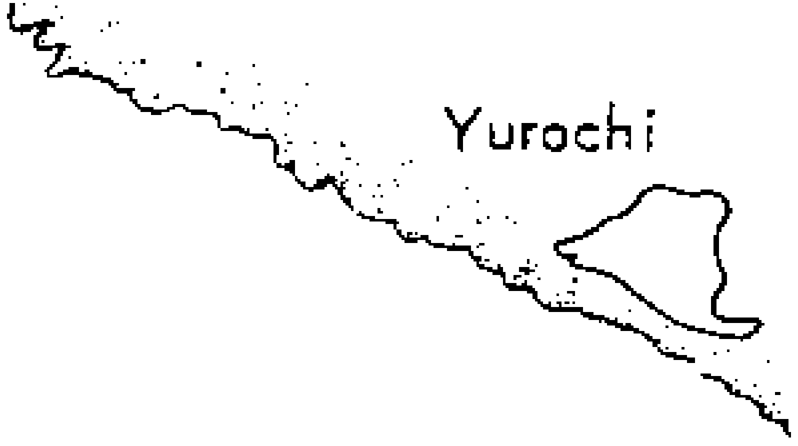
UNCLASSIFIED
~~UNCLASSIFIED~~


579


586


593

~~SECRET~~
~~RESTRICTED DATA~~
~~ATOMIC ENERGY ACT 1954~~



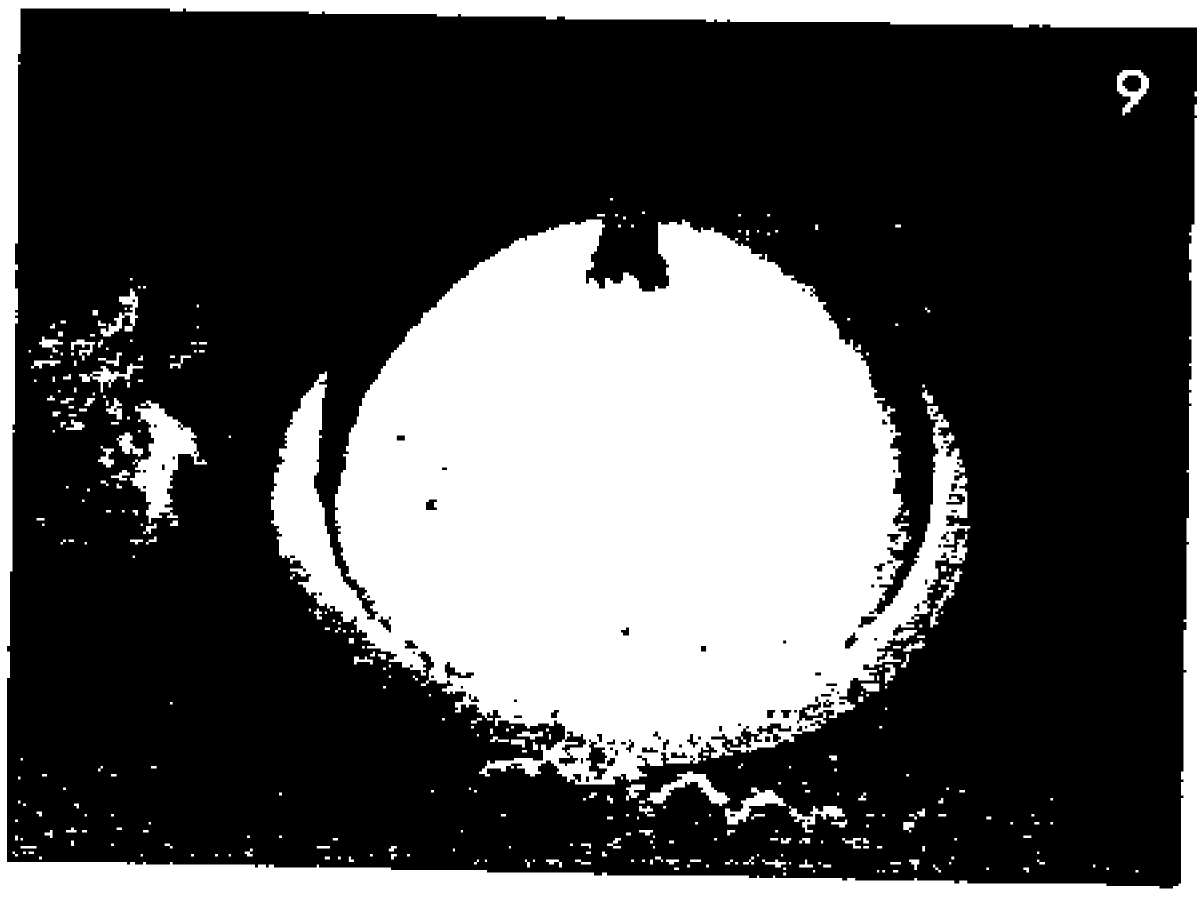

16


1


23


2


30


9

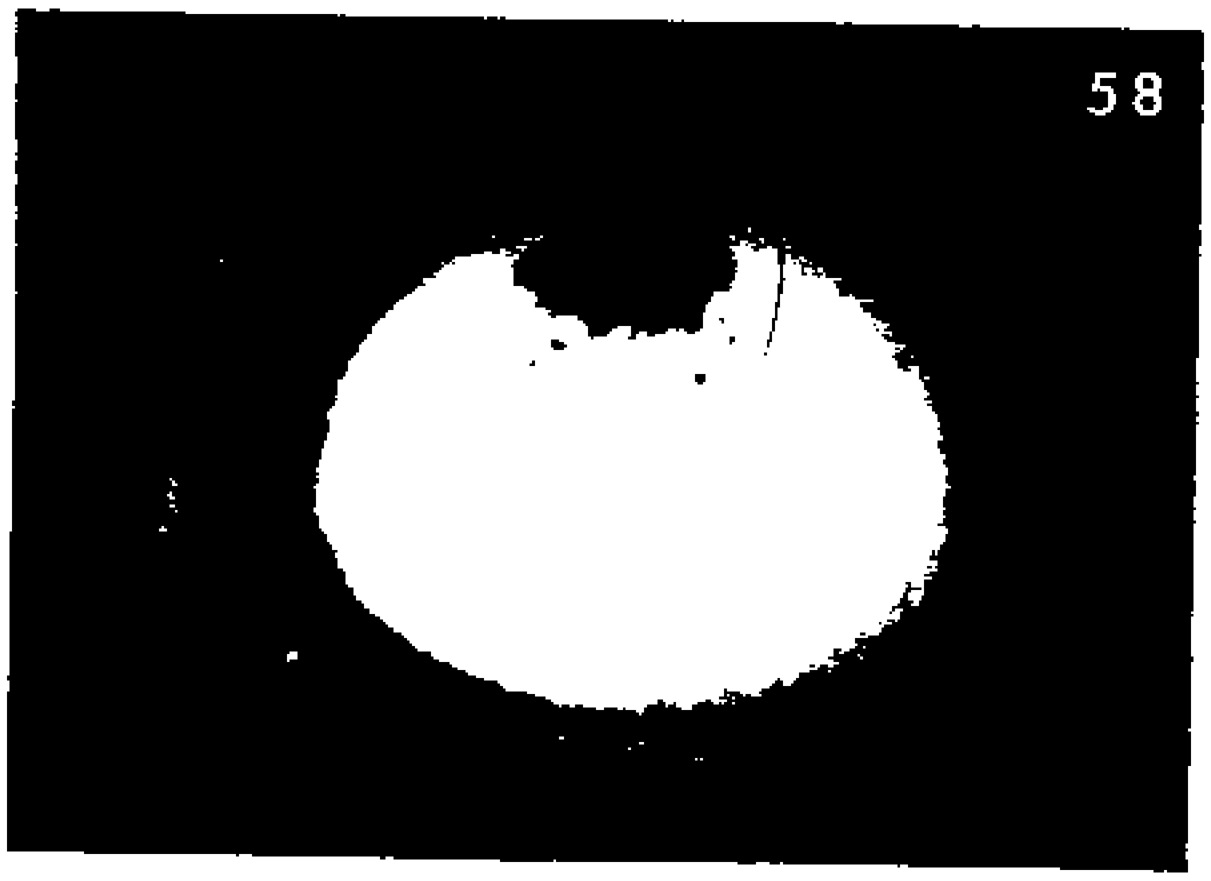

37

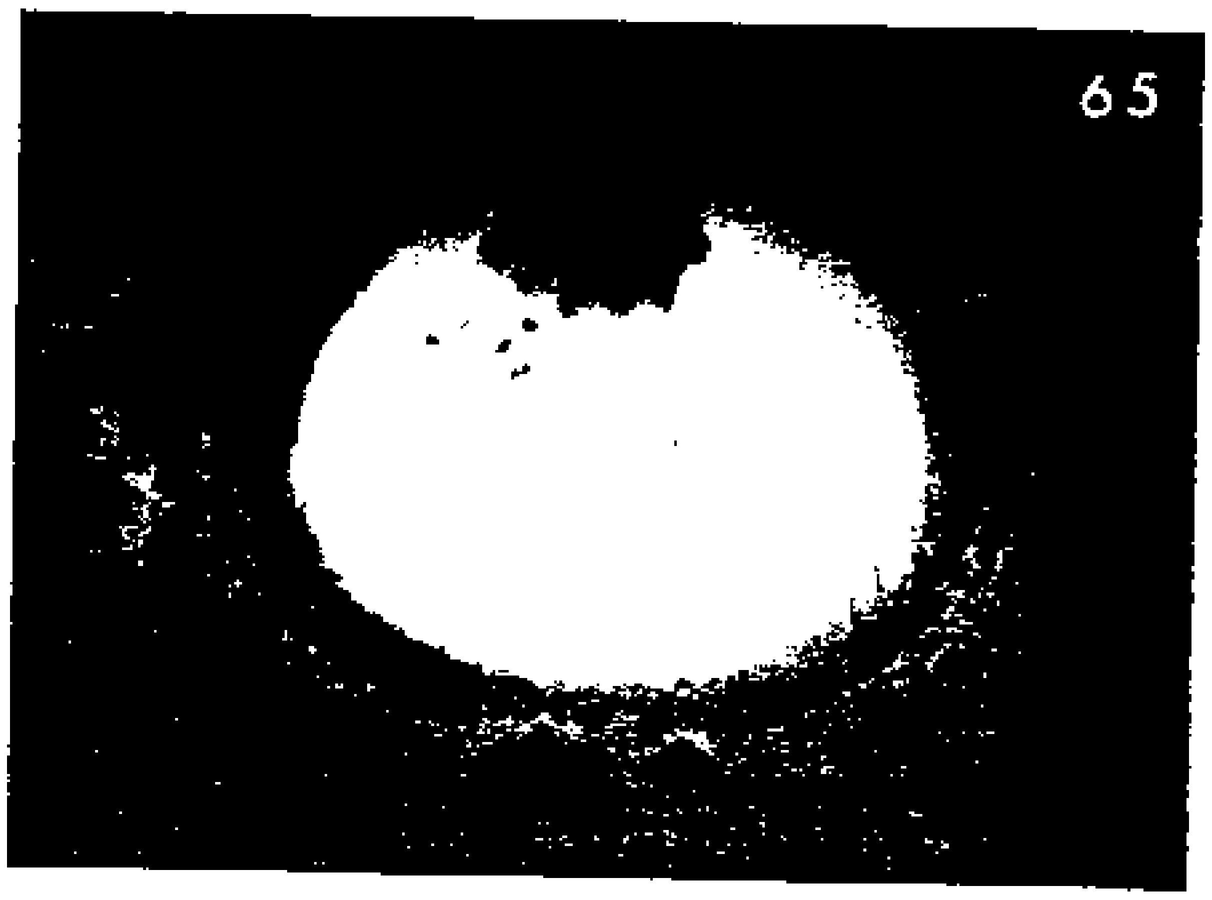
Set 2

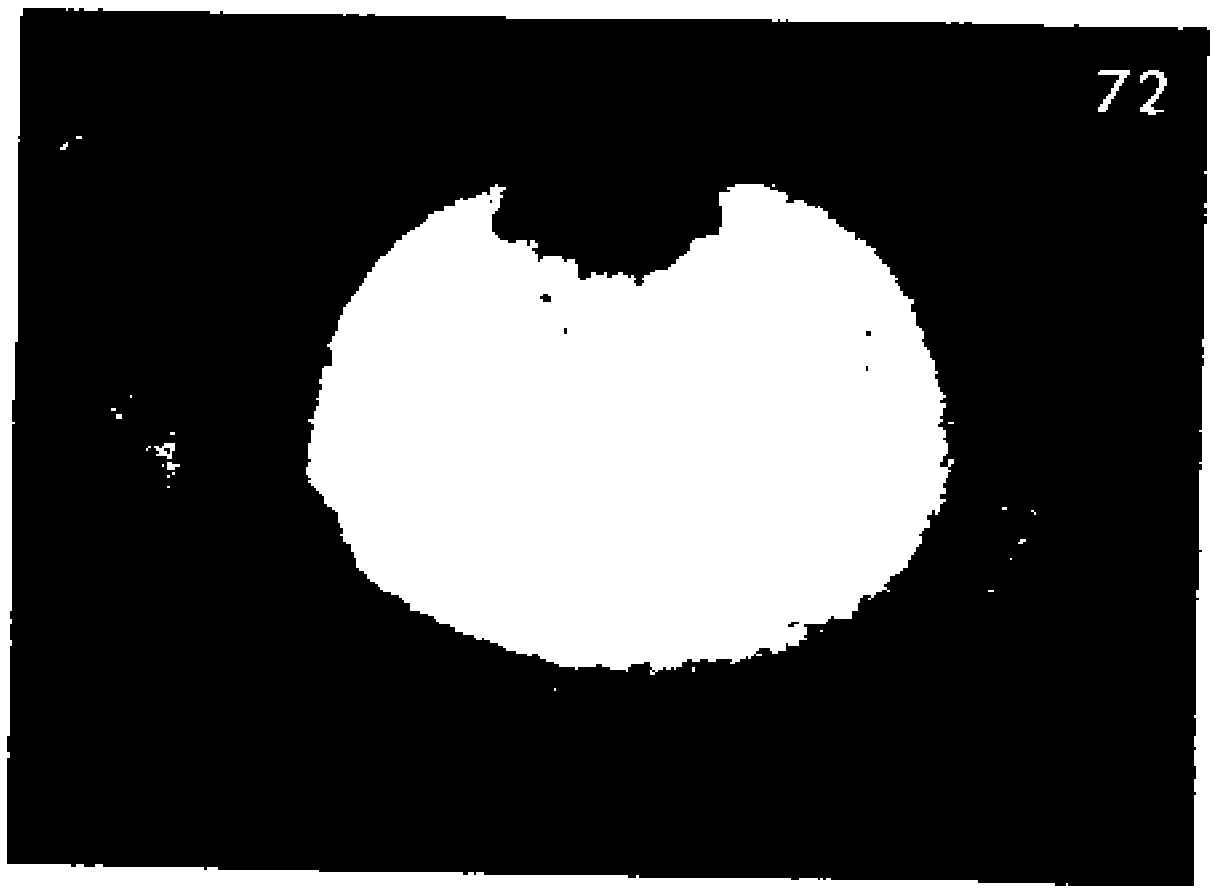
UNCLASSIFIED

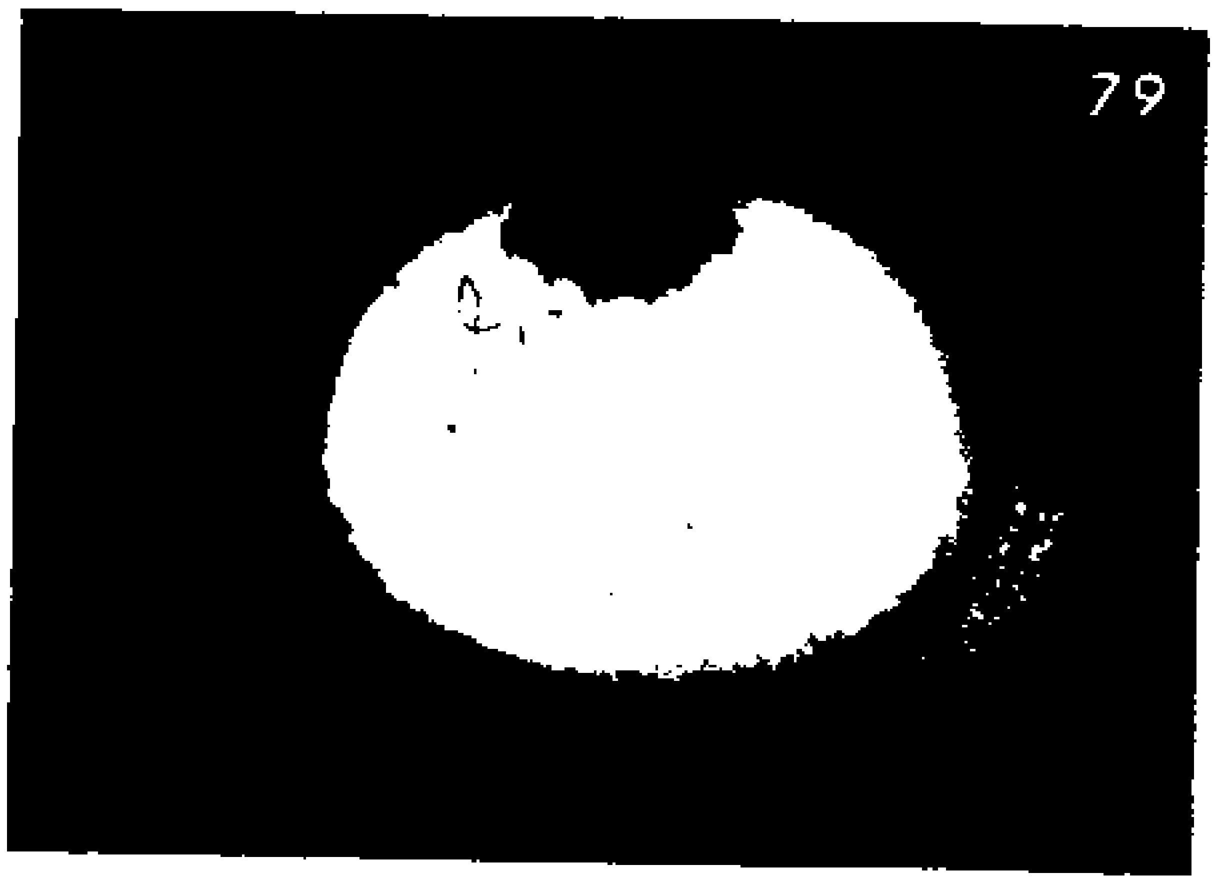

44


51

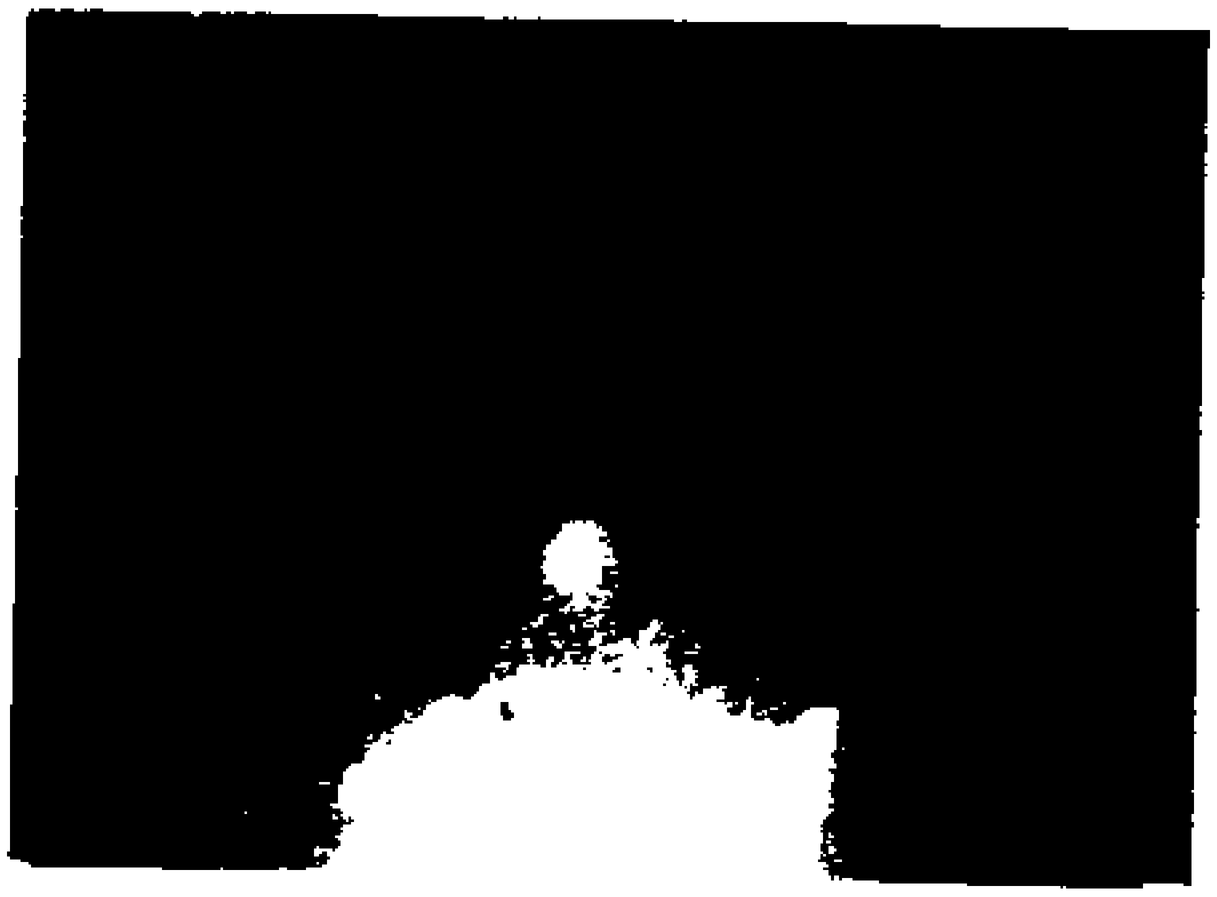

58


65

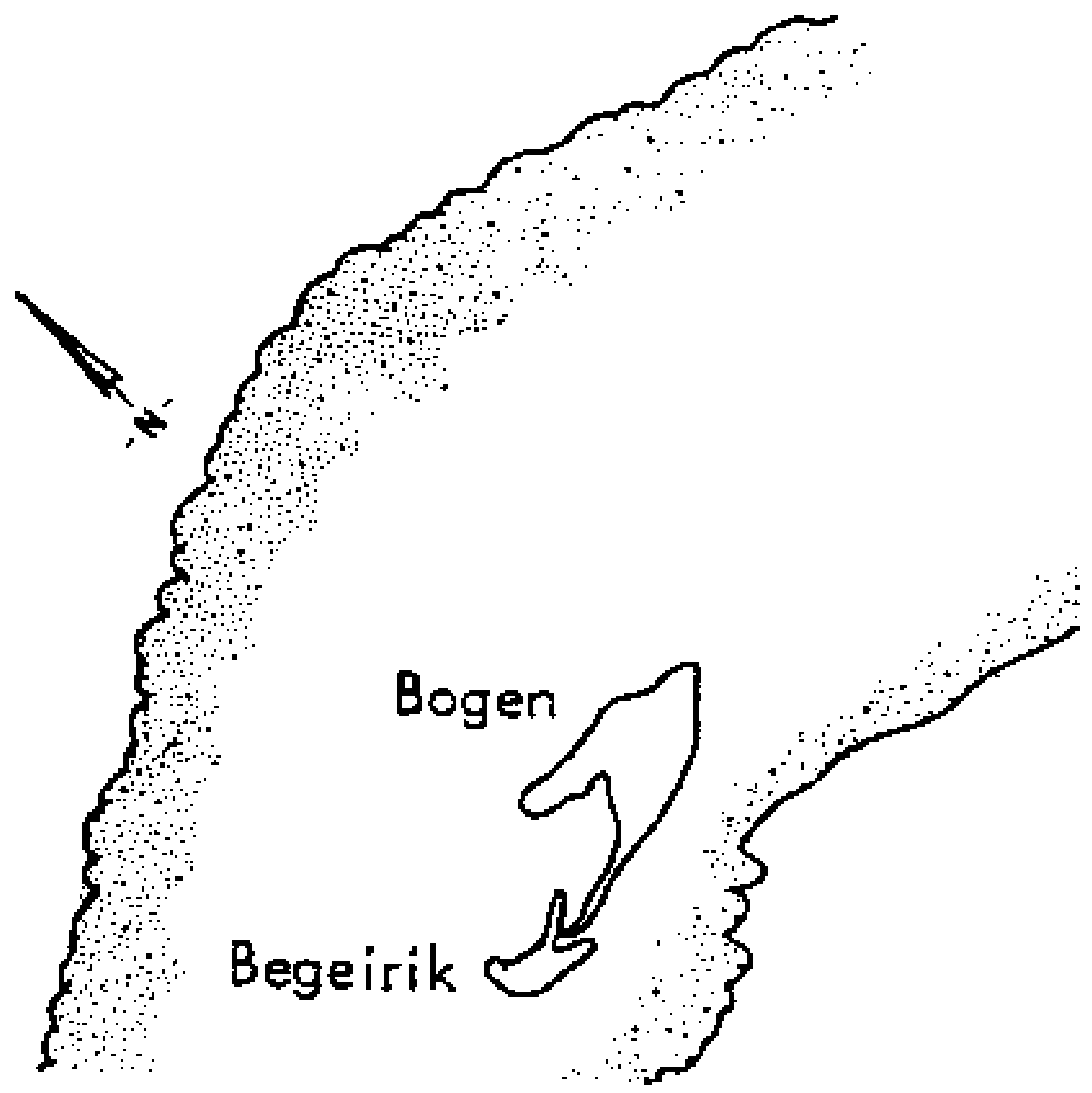

72


79

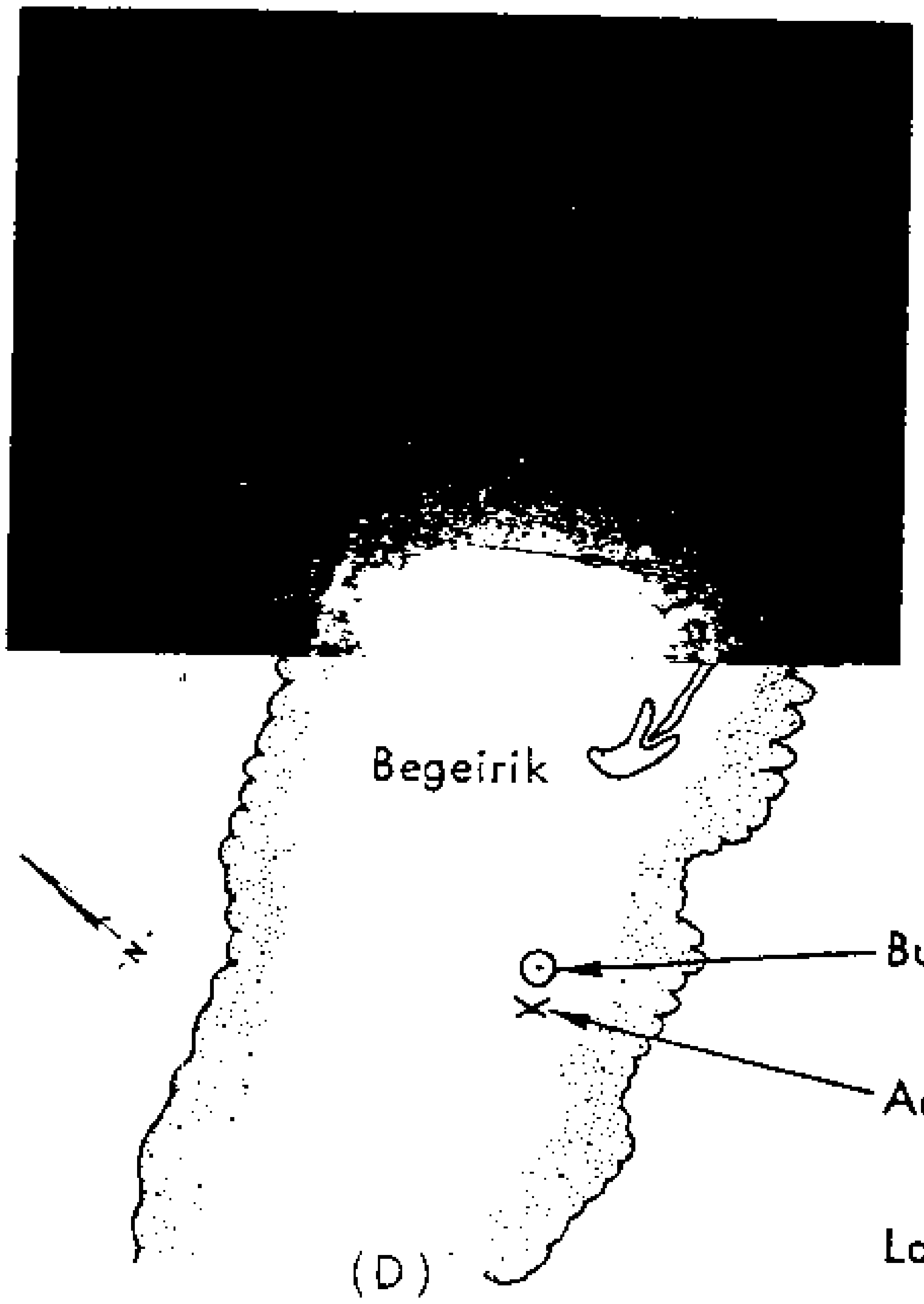
(A)



(B)



(C)



(A) Photograph taken during initial flash from the burst.

(B) Map of illuminated area.

(C) Photograph taken about five seconds after burst—positioned approximately with respect to map C of roughly the same scale, and a compass used to locate the burst point.

The maps represent the burst area as of 1962, and the photographs were taken in 1956.

Burst point as located by film.

Actual burst point (based on Ref. 18).

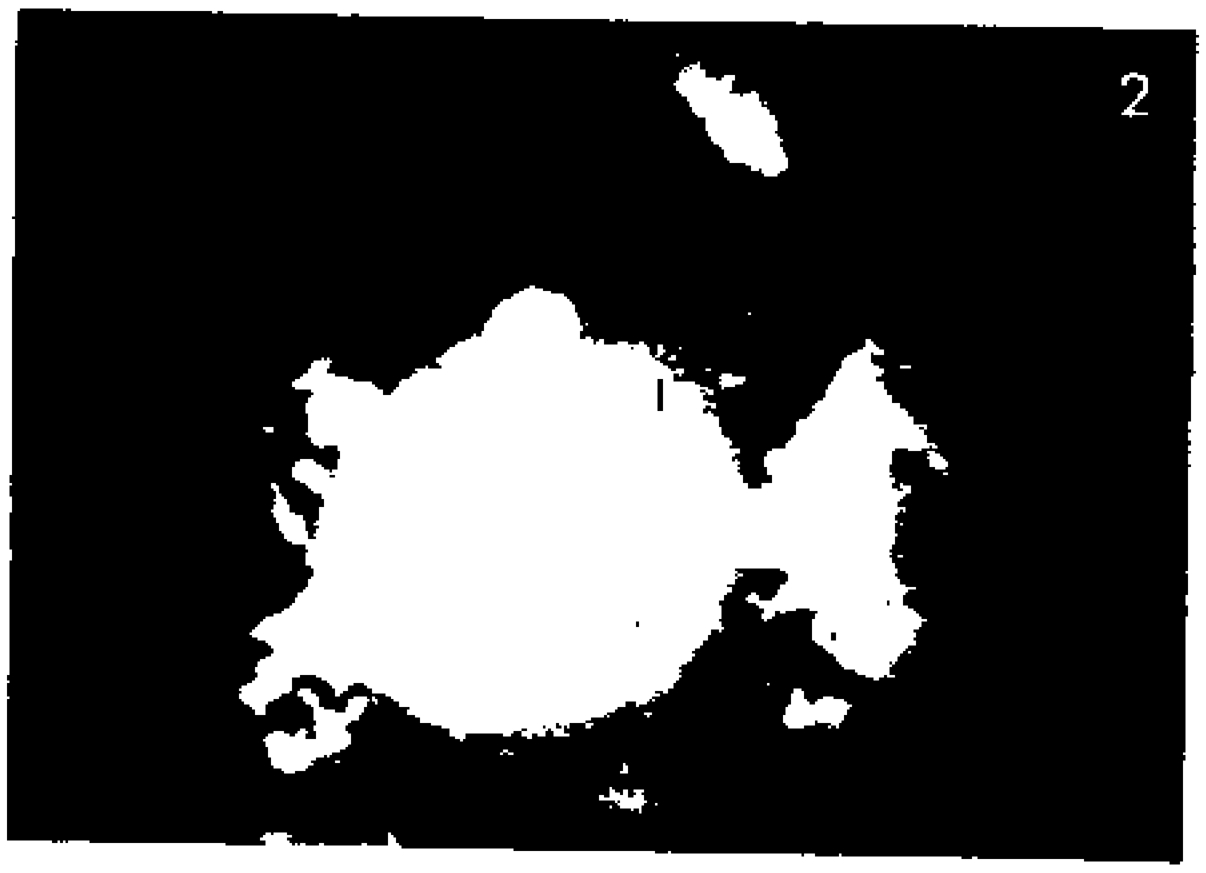
Location error ≈ 500 ft (within 1-MT crater).

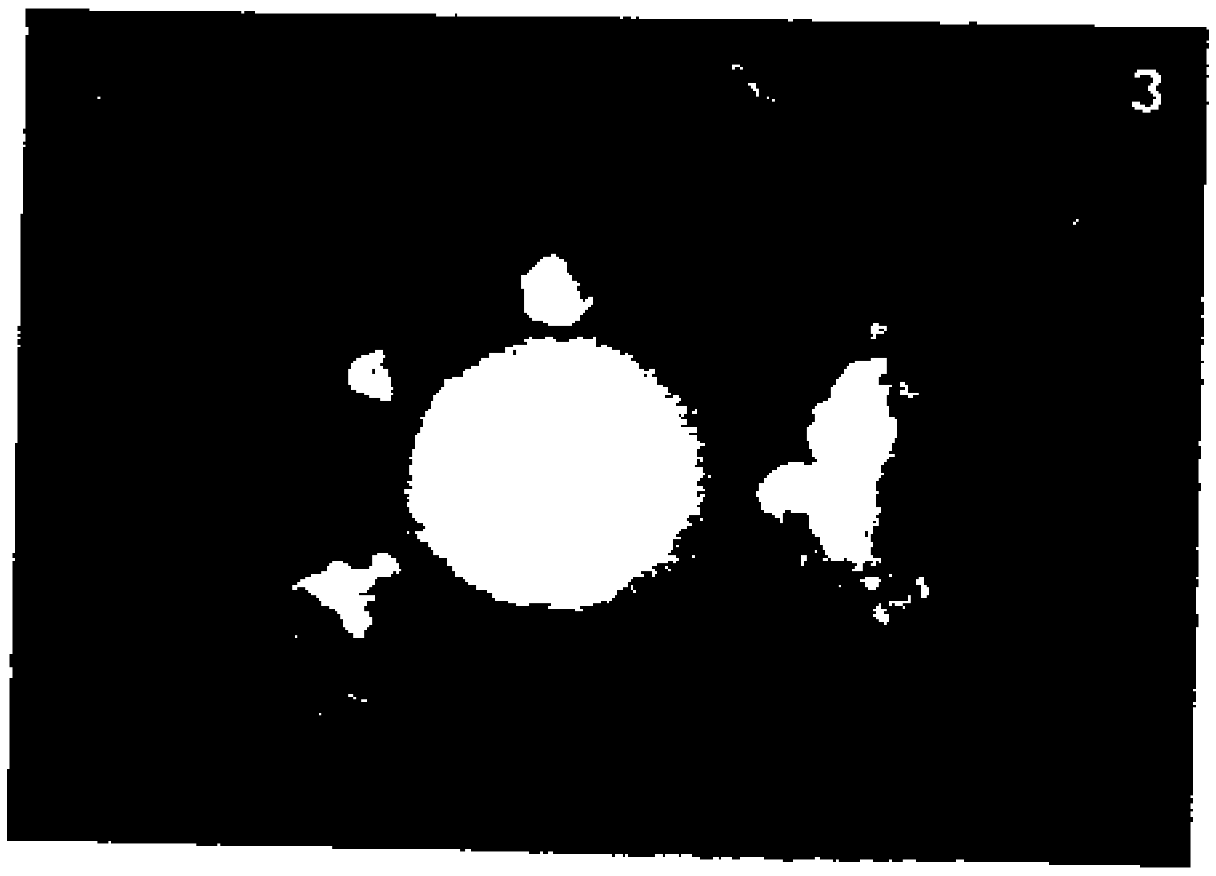
Scale: 1.47 in. = 1 n mi

The use of offset photography to locate burst point

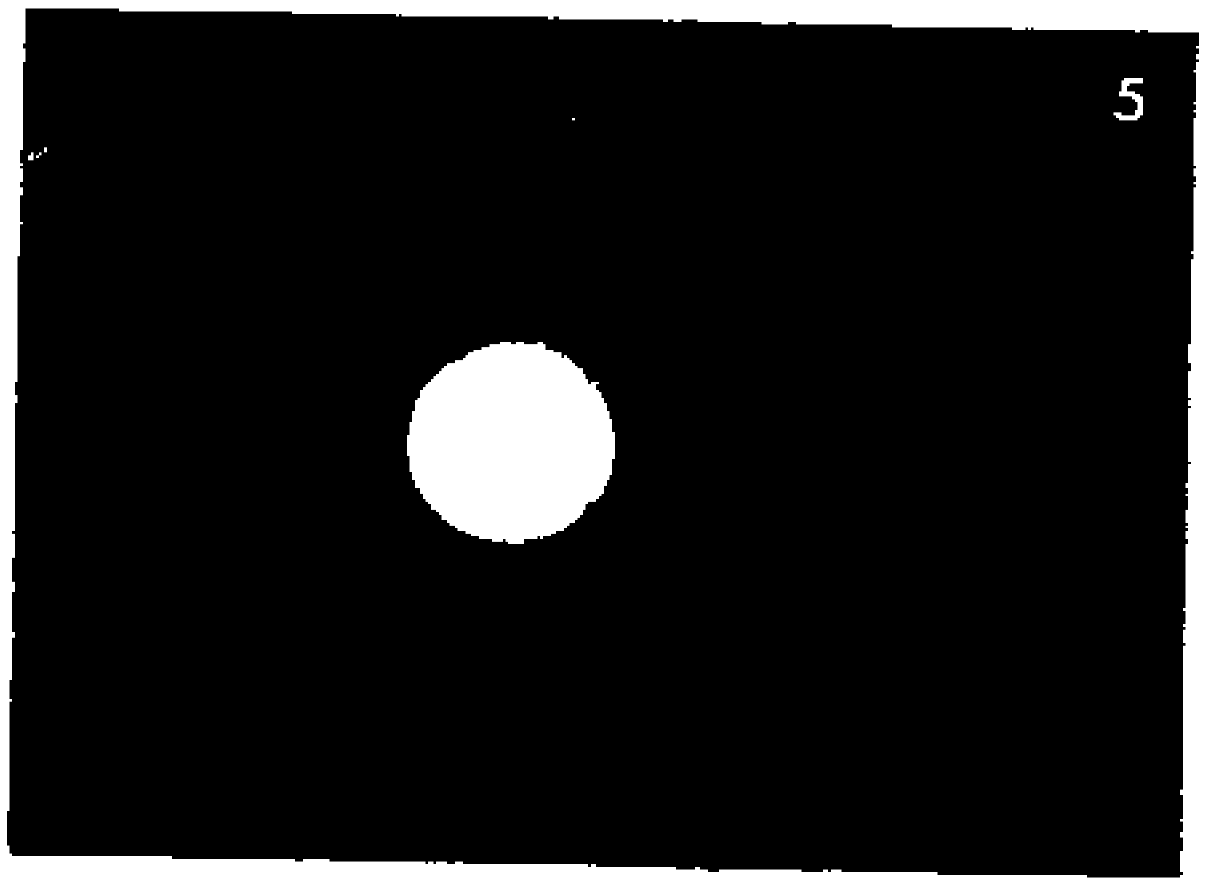
Set 3

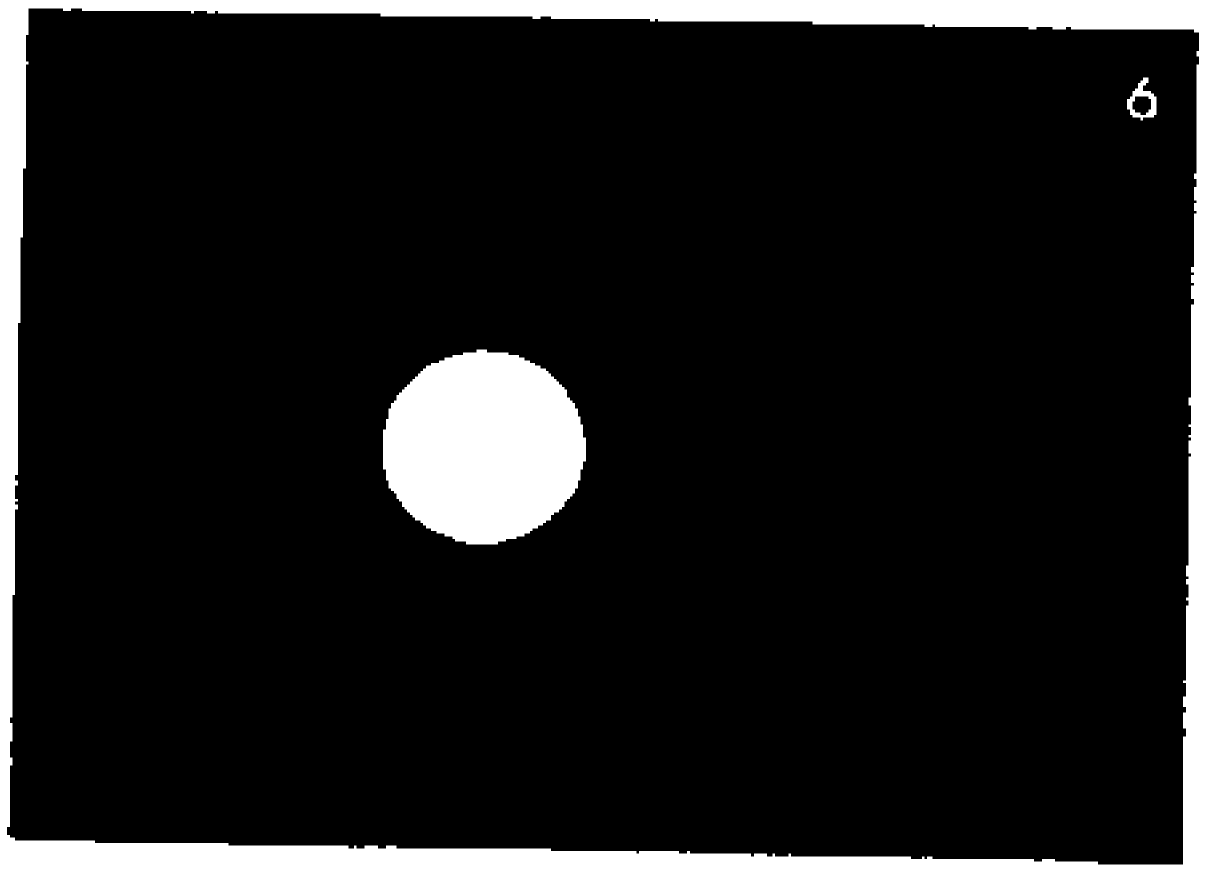

1

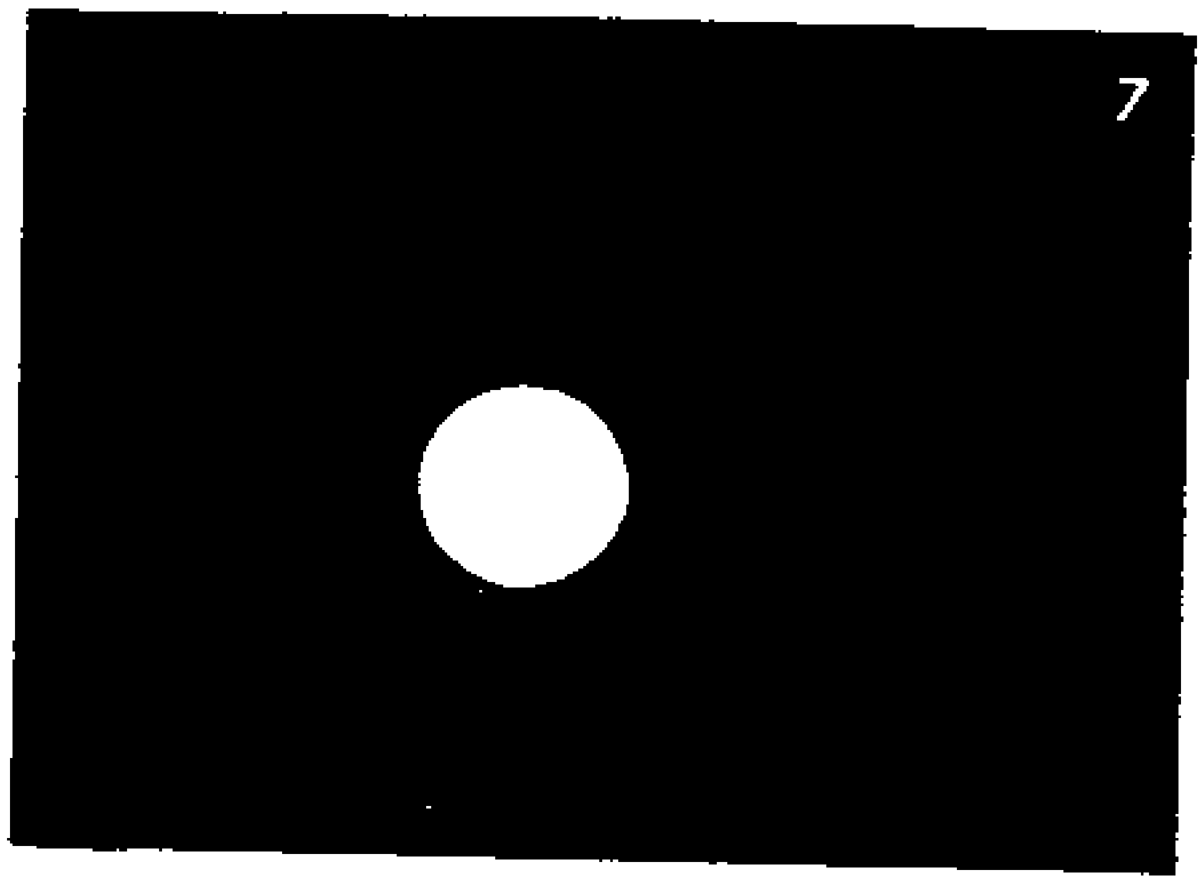

2

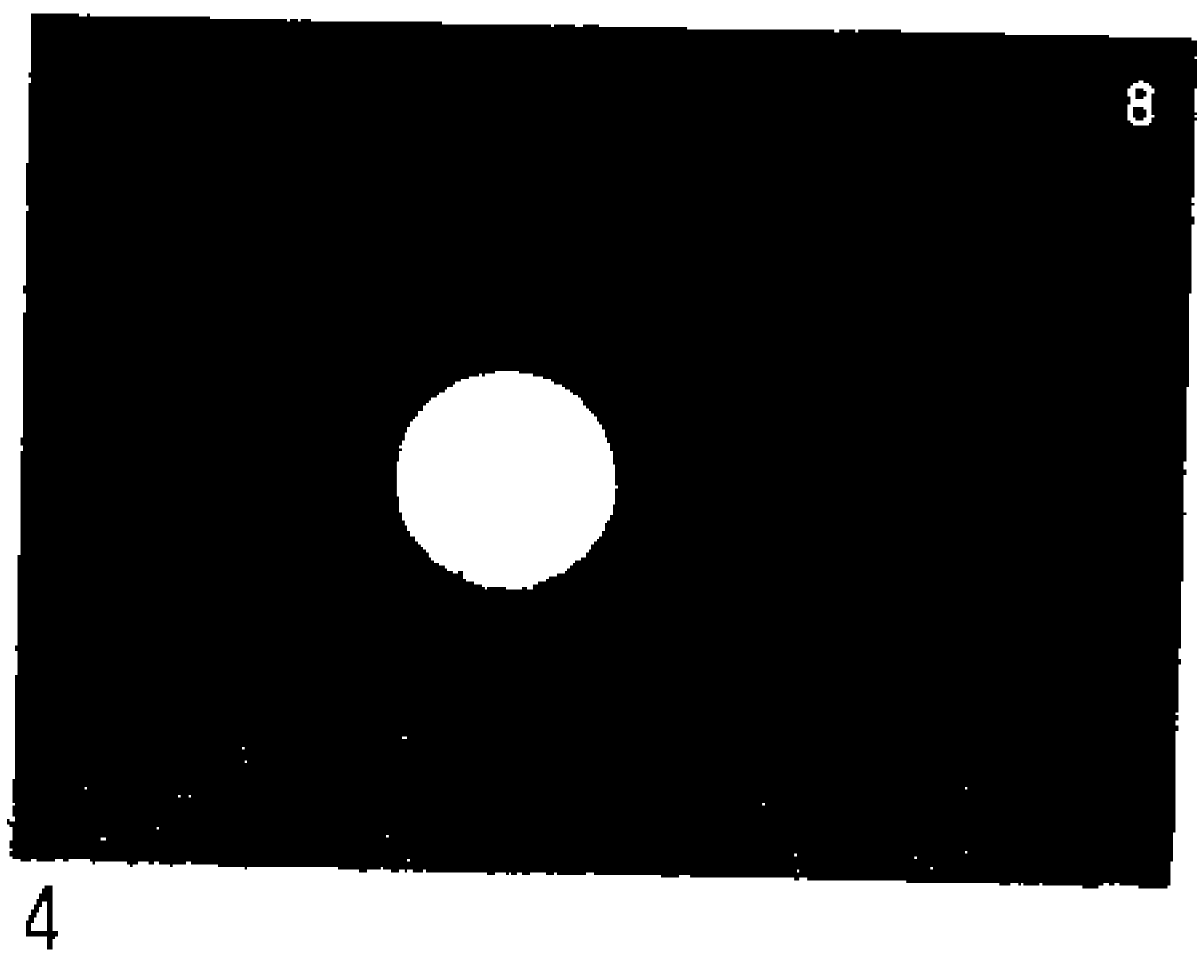

3


4

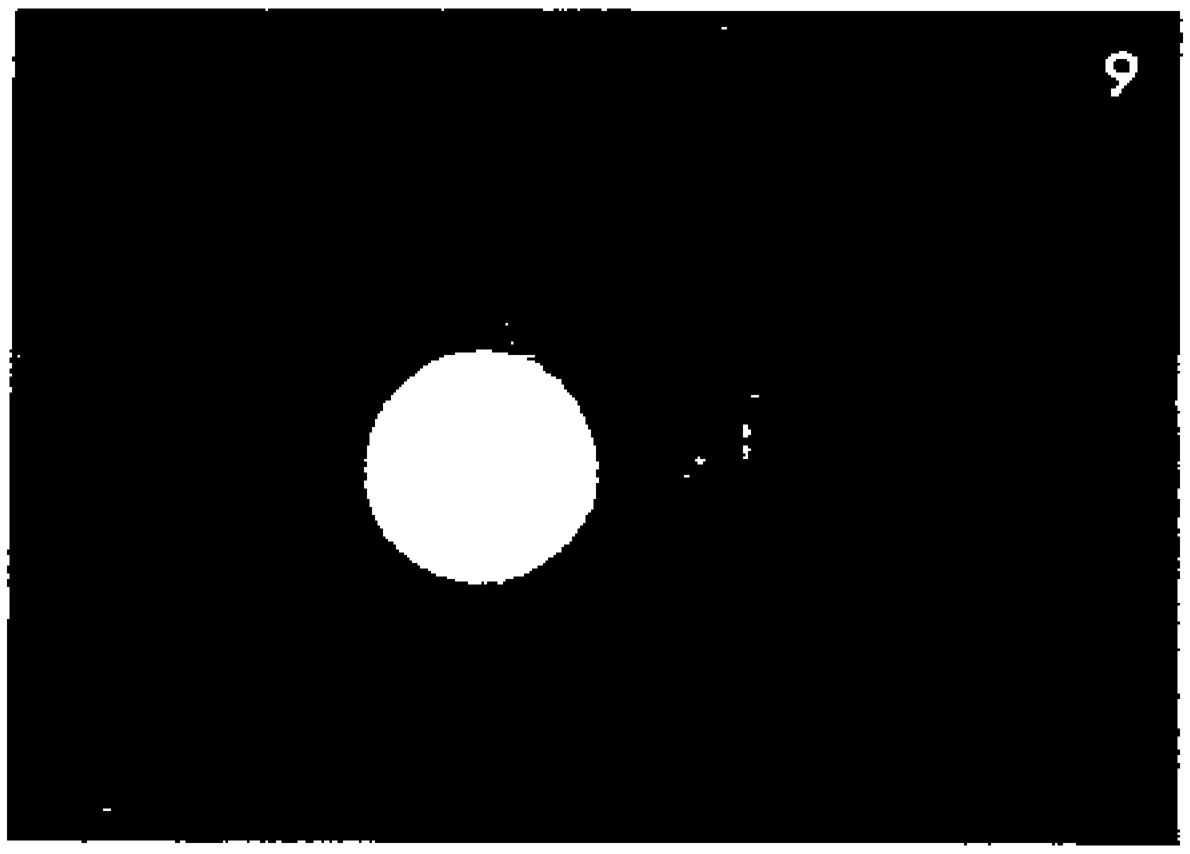

5


6


7

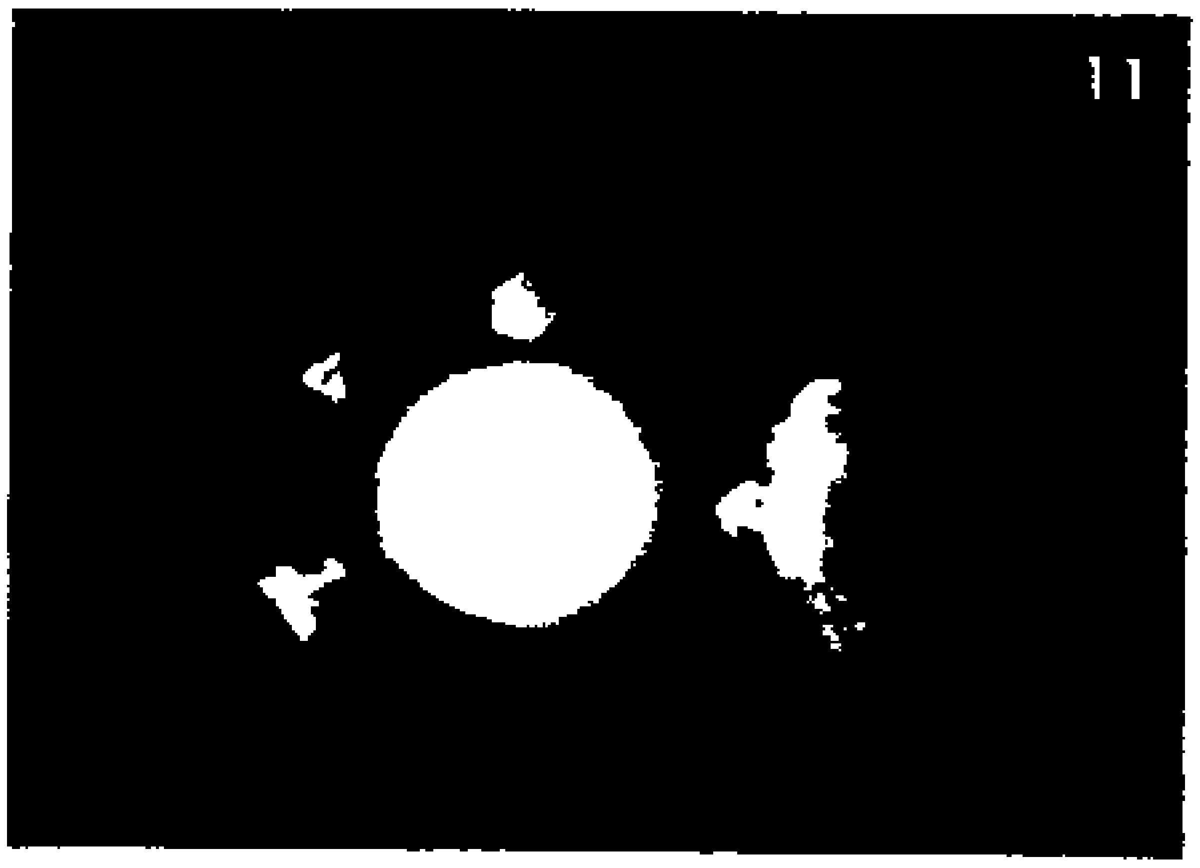

8

Set 4



9

10



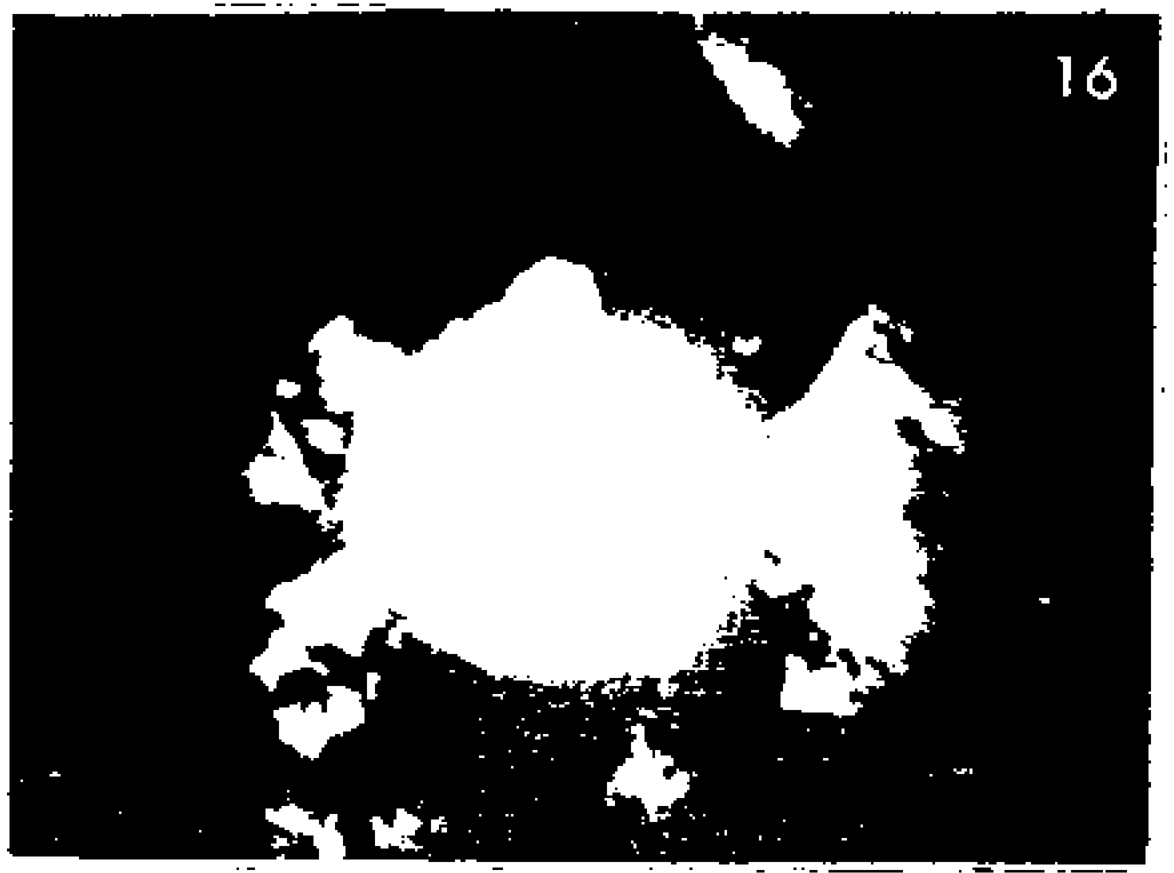
11

12

13

14

15



16

Appendix H

CAMERA SENSITIVITY TO WARHEAD BURST EFFECTS

RADIATION

The serious-degradation threshold of electronic components to radiation is given as:(19)

$$10^4 \text{ roentgens/second}$$

$$10^{12} \text{ neutrons/cm}^2 \text{ second}$$

A safe level, at least for short-duration missions, is indicated(19) as being two orders of magnitude lower.

The initial gamma radiation at 15,000 ft from a 1-MT nuclear blast is given(5) as 0.0008 x 6000 = 4.8 roentgens total, or well below the limit.

The initial neutron radiation from the blast (30 R)(5) can be converted approximately by assuming 14 MEV neutrons and full absorption (worst case)

$$1 \text{ R} = 7 \times 10^8 \text{ neutron/cm}^2 \text{ sec}$$

or

$$30 \text{ R} = 2 \times 10^{10} \text{ neutron/cm}^2 \text{ sec},$$ which is well below the danger level.

THERMAL PULSE

At 15,000 ft the thermal radiation is

$$\frac{\text{Thermal Energy}}{4\pi(R^2)} = \frac{0.4 \times 10^{15}}{4\pi\,(3 \times 1.6 \times 10^5)^2} \approx 130 \text{ cal/cm}^2$$

1500 BTU/ft^2 = 460 cal/cm^2, which is the melting point for 1/8 inch thick ceramics (camera lens) and ½ or 230 cal/cm^2 is the point of loss of strength.(20) The total thermal radiation is 130 cal/cm^2 distributed over more than 10 sec and is within the safe region by a factor of two.

BLAST WAVE

The blast wave time of arrival at 15,000 ft(5) is

$$t = t_o \times W^{1/3}$$

where t_o = 1 kt reference case

at

$$d = d_o \times W^{1/3}$$

where d_o = 1 KT reference case

W = 1-MT

where d = 2.5 n mi and 1-MT yield d_o = 0.3 miles and t_o = 0.8 sec

$$t = .8 \times 10 = 8 \text{ sec.}^*$$

and at 1 2/3 n mi

$$t = 5 \text{ sec.}$$

The magnitude of the overpressure at 1-2/3 n mi is 9 psi. The package can be designed to withstand this amount of pressure and resulting turbulence.(21)

---

[*] Surface burst effects may cause this time to decrease to approximately 6 sec.

Appendix I

CAMERA PACKAGE AND RELAY PACKAGE WEIGHTS

A TV camera and 2.5-kw L-band transmitter and power for 10 seconds of operation can be packaged in a reentry vehicle for a total vehicle weight of about 50 lb. A lighthouse transmitter tube at L-band similar to RCA A2737 or A2587 would provide this output. Several companies(22,23) have proposed development of a 2- to 4-KW, 30-second operation TWT (90,000 watt-second output) that is less than 25 inches long, weighs less than 8 lb, and has a greater than 30-db gain, to be packaged for reentry. Under one contract a package has been developed with a gross weight of 70 lb.(23) TV pictures would be transmitted for 10 sec using 2500 watt of transmitted power, compared to 90,000 watt-seconds for these proposed packages. Assuming weight proportional to radiated energy to the 0.6 power, and with a minimum weight of 10 lb for zero power, (10-lb offset) 25,000 watt-seconds represents 38 lb. Forty lb allows a safety factor in case the proposed weights are too optimistic and/or the scaling does not apply exactly.

Based on the watt-second computations for the camera package, the relay weight would be 21 lb.

Minuteman at 2500 or 2000 n mi Apogee

From Reference 24 we obtain the following data:

3rd stage weight = 5033 lb with R/V
R/V weight = 828 lb
Isp = 245 sec
Load ratio = 0.88

Burnout velocity = 23,000 fps

2nd stage B.O. = 14,300 fps

The velocity added by a normal third stage is 23,000 - 14,300 = 8700 fps + losses. Using the data given, the total velocity added is computed to be the 10,400 fps, which includes 1700 fps losses.

From Ref. 14 the velocity requirements for lofted trajectories are estimated to be:

	Case 1	Case 2
Apogee	2000 n mi	2500 n mi
	43°	46.5°
α	24400 fps	25100 fps
less	-23000	-23000
velocity added	1400 fps	2100 fps

Using Ref. 25:

2000-n mi case	2500-n mi case
+1400	2100
+10400	10400
11800 required	12500 required

$\frac{828}{5033}$ = 16.4% payload at .88 LF, for 10400 fps added.

Going now to 11800 fps required	12500
The payload is 12%	10%
~600 lb	~500 lb

This 500 lb for the 2500-n mi apogee case represents 24 relay packages.

Appendix J

SYSTEM COST ESTIMATE

This Appendix, developed by The RAND Cost Analysis Department, provides the supporting detail for the system cost estimates given in the text. The estimates are intended to give the approximate financial implication of the proposed system for planning purposes. All costs are in millions of current dollars.

The cost of the AIDE system is summarized as follows:

	($ million)
Research and Development	$250.0
Initial Investment	125.0
Annual Operating (5 year)	250.0
Total Acquisition and 5-year Operating (including R&D)	625.0

Research and Development costs are estimated to be:

	($ million)
Design and Development	$75.0 - 100.0
System Test	100.0 - 125.0
System Management	20.0 - 25.0
Total	195.0 - 250.0

The Design and Development category includes the cost of engineering, fabrication, and in-plant testing associated with the separate components and subsystems. Included also is the design effort for modification of the missile for substitution of the communication relay package for the payload and for adaptation of the sensor package to the operational missile configuration.

The System Test category includes the cost of testing the mission hardware individually and as a system. Such costs include producing and assembling the test hardware and constructing test facilities, installing ground equipment, operating the test facility, and evaluating the results. For this system, the use of missiles scheduled for crew training or quality assurance launches is not assumed. Utilization of these missiles would of course result in a decrease of flight test cost of approximately $25 - 30 million. The test operation part of this category includes the cost of the support and operational personnel, logistic supplies and equipment, data analysis, and the preparation of handbooks and technical descriptions for various items of equipment.

The third category, System Management, is considered separately as a matter of convenience in estimating rather than as a major cost-generating function. This cost includes the program management, system engineering, and technical direction (to associate contractors) for the subsystems as well as for the complete system. The effort is divided between subsystem development and system test. The cost for comparable Air Force development programs has been about ten per cent of the sum of Design and Development and the test operation effort of System Test.

Initial Investment can be broken down into three items:

	($ million)
Sensor Package	64.8
Communication Relay Package	30.3
Ground Receiving Station	31.1
Total	126.2

The Initial Investment includes the cost of equipping the Minuteman and Titan II forces with the sensor package or with the communication relay package. Ground receiving stations are costed as additions to the facilities at each headquarters. Existing communications between the ground receiving stations and launch control centers are utilized. The total forces assumed are 1000 Minuteman missiles, 54 Titan II missiles, and nine ground receiving stations. One missile per squadron is equipped with the communication relay package, for a total of 26 missiles.

In addition to mission hardware cost, the Initial Investment includes transportation, spares, installation and checkout, training, site activation, stocks, and supplies. The same elements of cost are included for the ground receiving stations. A facilities modification to the wing headquarters facility is provided for the ground receiving station.

The Annual Operating Cost for the proposed system is estimated to be $50.0 million. This includes maintenance personnel over and above the usual missile squadron complement. For the sensor and communication relay equipment, a total of four per squadron is required. For the ground receiving station, four per shift is required, or a total of 20 per station for 24-hour manning. Spares are provided at the level of 20 per cent per year for mission equipment. The Annual Operating Cost also includes a charge for maintenance of the missiles used for communication relay. This is approximately half of the total operating cost for this system. This cost is included as a cost to the AIDE system because the communication relay missile does not function as a firepower missile whose maintenance cost is part of the missile system.

REFERENCES

1. Arnsten, M. E., Shoot-look-shoot at Hard Targets: An Evaluation of the Usefulness of Bomb Damage Assessment (U), The RAND Corporation, RM-3614-PR, July 1963 (Confidential).
2. Latter, R., Bomb Damage Assessment (U), The RAND Corporation, RM-3713-PR, June 1963 (Secret).
3. SOR Intelligence Annex, revised 28 May 1964, Headquarters USAF, Washington, D.C., A.C.S./Intelligence (Secret).
4. Project CODAR Proposal CAA-180A, Conduction Corporation, Ann Arbor, Michigan (no date) (Secret).
5. U.S. Atomic Energy Commission, The Effects of Nuclear Weapons, AFP 136-1-3, 1957, 1962.
6. Kuppen, W., Handbuch der Klimatologie, Band III, Teiln, Klimakunde von Russland, Verlag Gabruder Borntraeger, Berlin, Germany, 1939.
7. Redwing, Pacific Proving Grounds, Thermal Flux and Albedo Measurements from Aircraft, Headquarters Field Command, Defense Atomic Support Agency, WT-1333 (Secret--Formerly Restricted Data).
8. Television Feasibility Demonstration Project (U), Vitro 2331-2-60, September 15, 1960 (Confidential).
9. Cahile, John, Harvey Gauvin, and John Johnson, Effective Transmission of Thermal Radiation from Nuclear Detonations in Real Atmospheres, AFCRL-62-456, April 1962, Air Force Cambridge Research Center.
10. Handbook of Chemistry and Physics, The Chemical Rubber Publishing Company, Cleveland, Ohio, 1962.
11. Fletcher, N. H., The Physics of Rainclouds, Cambridge University Press, Cambridge, Mass., 1962.
12. Brode, H. L., A Review of Nuclear Explosion Phenomena Pertinent to Protection Construction, The RAND Corporation, R-425-PR, May, 1964.
13. National Intelligence Survey, Number 26, Section 23, Central Intelligence Agency, Washington, D.C. (Secret).
14. Morris, D. N., Charts for Determining the Characteristics of Ballistic Trajectories in a Vacuum, The RAND Corporation, RM-3752-PR, April 1964.
15. Operation Redwing, Technical Summary of Military Effects, Programs 1-9(U), WT-1344, Defense Atomic Support Agency, Sandia Base, New Mexico, April 25, 1961 (Secret--Restricted Data).

16. Redwing Dakota, Film FC/10560692, Reel N-50, Chief, Weapons Test Division, Defense Atomic Support Agency, Sandia Base, Albuquerque, New Mexico, 1956 (Secret--Restricted Data).

17. Redwing Flathead, Film FC/10560109, Reel N-26, Chief, Weapons Test Division, Defense Atomic Support Agency, Sandia Base, Albuquerque, New Nexico, 1956 (Secret--Restricted Data).

18. Operation Redwing: Technical Summary of Military Effects Programs 1-9 (U), WT1344, Headquarters Field Command, DASA, Albuquerque, New Mexico, April 1961 (Secret--Restricted Data).

19. Transient Radiation Effects in Electronics (U), AFSWC-TR-59-33, Headquarters AFSWC, 1959 (Secret--Restricted Data).

20. Gazley, Carl, Heat Transfer Aspects of the Atmospheric Reentry of Long Range Ballistic Missiles, The RAND Corporation, R-273, August 1, 1954.

21. Ruhge, Justin, A Study of Image Orthocon Ruggedness in Simulated Missile Environments (U), Naval Ordnance Test Station, NOTS TP 3012, September 1962 (Confidential).

22. Second Interim Engineering Report, Reentry ECM Investigation (U), Aeroneutronics Division of Philco, Ford Motor Company, S-2362, November 1963 (Secret), pp. 80-85.

23. Twentieth Monthly Progress Report, ECM Feasibility Flight Test Program (U), Sperry Gyroscope Company, EB-5291-0275-20, November 1964 (Secret).

24. Air Force Ballistic Missile Program Status Report, Air Force Ballistic Systems Division, WOL PR-4-290, May 31, 1961 (Secret--Restricted Data).

25. Frick, R. H., W. I. Rumer, and E. H. Sharkey, Trajectory and Orbit Plotter Instruction Manual, The RAND Corporation, R-418, October 1963.