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BUILDING 11-14A INCIDENT INVESTIGATION

R. J. Slape

DEVELOPMENT DIVISION

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ABSTRACT

On March 30, 1977, an explosion occurred in Building 11-14A, Bay 8, during a contact machining operation. An immediate investigation, under the direction of an Energy Research and Development Administration (ERDA) investigating board, was conducted. The board concluded the accident resulted from one or a combination of four probable causes.

A follow-up investigation was conducted to determine the single most probable cause for the incident. It was concluded that the explosive billet on the lathe was initiated somewhere on the top circumferential area of the billet indicating that the most probable cause for the initiation was a machinist mallet used in centering operations.

DISCUSSION

On March 30, 1977, an explosion occurred in Bldg. 11-14A, Bay 8, during a contact[a] machining operation resulting in three fatalities and the destruction of the 11-14A machining facility. An investigation began immediately with the establishment of an ERDA investigating board. The complete results of their investigation can be found in "Report of the Investigation of the Explosion with Fatal Injuries in Building 11-14A on March 30, 1977 at the Pantex Plant, Amarillo, Texas," dated June 28, 1977. During the course of the ERDA board investigation, the four most probable causes developed were

1. Loss of vacuum on holding fixture.

2. Overrun of template.

3. Cutting too deep.

4. Initiation during centering of billet with a mallet.

These served as the foundation for a follow-up investigation intended to narrow the field of possibilities to one most probable cause. After the ERDA board returned site control to Mason & Hanger, this investigation was conducted by Mason & Hanger-Silas Mason Co., Inc. with the assistance of LASL, and LLL. During the course of this second investigation other possibilities that came under consideration were

1. Initiation of explosive in the drive train with subsequent propagation to the lathe billet.

2. Initiation of the billet by lifting with the hoist with the billet still wedged between the cutter and vacuum holding fixture.

[a] *Contact refers to an operation conducted with personnel in the immediate proximity of the explosive.*

3. Adjustment of the cutter in close proximity to the billet with explosive in the threads and/or socket head cap screw being initiated causing initiation of the lathe billet.

4. Impact of the billet by falling overhead objects.

Search for Evidence

The investigation began with the collection of all debris in and around Bldg. 11-14A. Metal detectors were used in the principle search area outside 11-14A shown in Fig. 1. Attempts were made to identify the origin of all parts found and their significance considered relative to the incident.

The most significant items recovered, outside the immediate vicinity of 11-14A, were the boring bar (Item B of Fig. 1) found approximately 110 meters north of the building and various parts of the aluminum wet pan (Item A of Fig. 1) found a few meters north of the building. The wet pan parts, though badly damaged, were identifiable by assembly brads used in wet pan fabrication found in some of the aluminum pieces.

The major items not found were the machinist's mallet, typically used in centering operations, and any identifiable portions of the vacuum holding fixture. The vacuum holding fixture was made of aluminum and many aluminum fragments were found but none were physically identifiable as being from the holding fixture.

Analysis of Metal Parts

Two explosives were involved in the incident, LX-09 and LX-14. A 34.0 to 34.5-kilogram pressed billet of each was in Bay 8 prior to the incident, for a potential total weight of approximately 68 kilograms. Considering the elapsed time before the incident occurred on March 30, it is likely that at least one piece had been rough machined to a weight of approximately 22.7 kilograms, representing a combined total weight of approximately 57 kilograms, disregarding a possible partial rough machining of the second billet.

From the damage pattern produced in the structure and machines in the bay, it was evident that one billet was on a Series 60 Monarch Lathe and the other on or in the immediate vicinity of the surface plate approximately 3.5 meters from the lathe near the south wall as shown in Fig. 2. It was concluded that the initial explosion occurred on the lathe rather than the surface plate since the lathe represented the greater potential energy source required for initiation, short of dropping the second piece at the surface plate. But the area of maximum damage to a steel column adjacent to the surface plate table corresponded to a height comparable to the table height, indicating that the billet initiated on the surface plate, not on the floor as one would expect if the billet had been dropped sufficiently far to cause initiation. Additionally the missile pattern and missile generating potential of the lathe constituted more evidence for initial detonation on the lathe rather than the surface plate.

Therefore, determining which explosive was on the lathe would determine the explosive responsible for the incident. For this purpose the metal parts were analyzed for fluorides. From the compositions of LX-09 and LX-14 shown in Table I, LX-09 contains FEFO, 1-fluoro-1, 1-dinitroethylformal. In

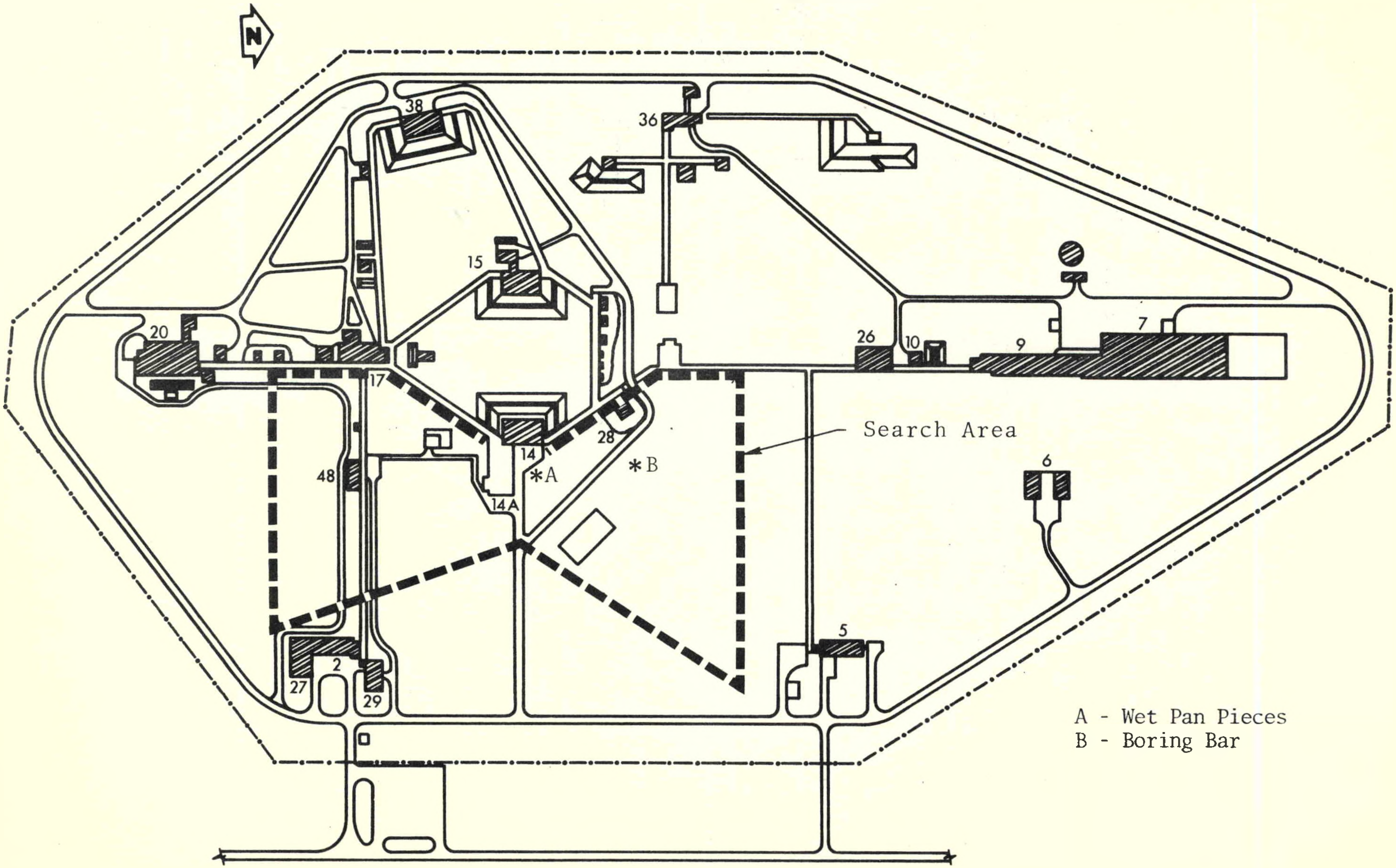

Fig. 1. Zone 11 Search Area

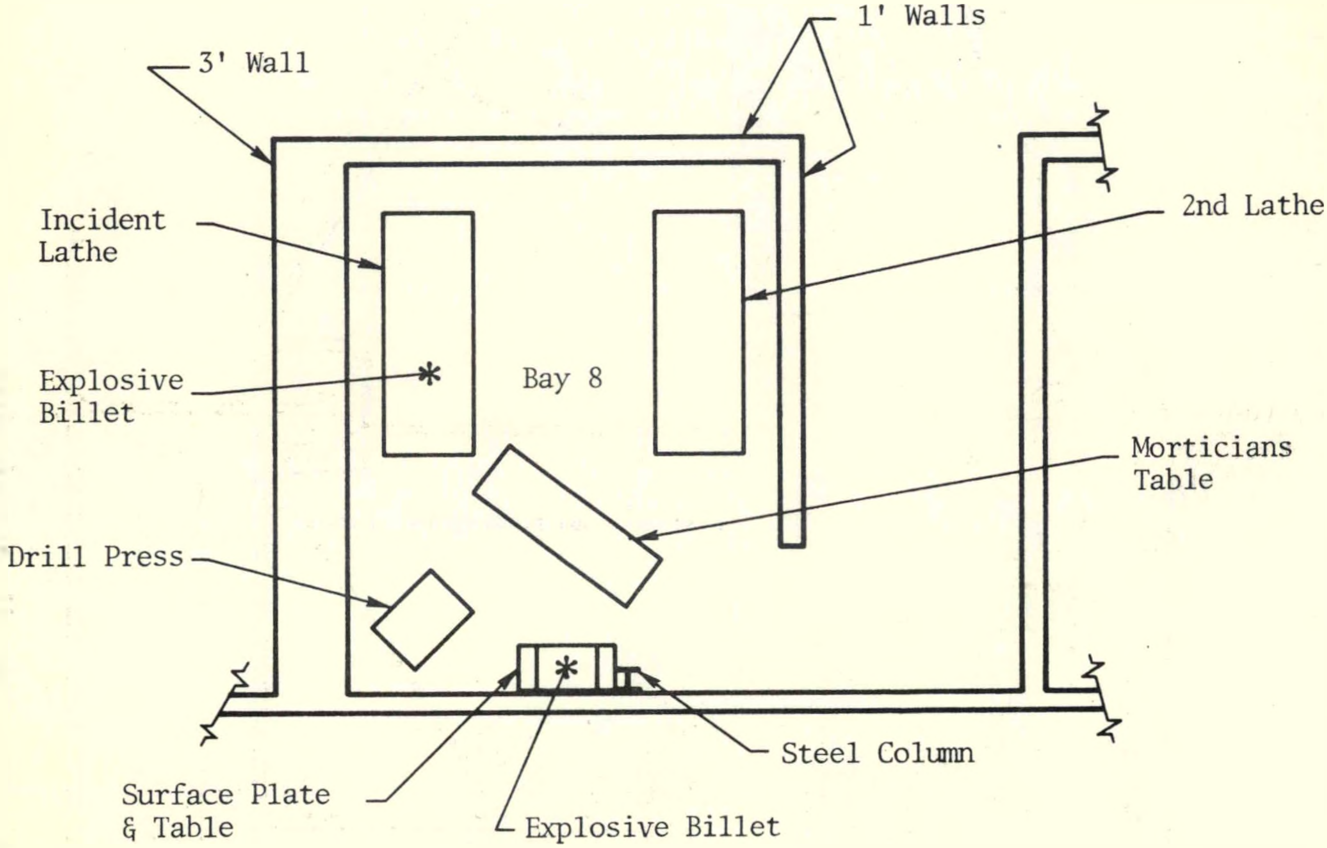

Fig. 2. Bay 8 Layout

the event of an LX-09 explosion in the close proximity to aluminum, fluoride traces would be expected in the aluminum. Aluminum parts, some identified as wet pan parts and others of unknown origin obviously close to the explosion because of metal flow, were analyzed by LASL for fluoride content. Aluminum soaked in plant water was also analyzed, because of fluorine in the water, to insure that any fluoride found did not come from exposure to water. No fluorides were found in the water-soaked aluminum but fluoride traces were found in some of the incident aluminum parts. Most of those fluoride containing aluminum parts were removed from the morticians table shown in Fig. 2. These aluminum missiles were found in the hollow steel legs of the morticians table. From the penetration pattern produced, they came from the general direction of the incident lathe. This, combined with the machining schedule for the day and the fact that LX-09 is more sensitive than LX-14, indicated that LX-09 was on the lathe at the time of the incident and was the explosive initiated first.

Table I. Explosive Composition

Explosive	Ingredient	Wt %
LX-09-0	HMX	93.0
	PDNPA	4.6
	FEFO	2.4
LX-14	HMX	95.5
	Estane 5702-F1	4.5

Inventory of Lathe Fixtures

On March 29, one day prior to the incident, the subject machining operation was set up in Bay 8 by a machinist. On March 30 the same operation was performed by another machinist. Although the first machinist knew what fixtures and equipment were used in the original setup, it was necessary to verify the setup at the time of the incident for later dimensional reconstruction to insure that the second machinist had not modified the original setup. The only fixture in question was the vacuum holding fixture which was damaged so badly as to preclude positive identification from the debris. Therefore, all fixtures on inventory were physically checked and the only fixture not found was the vacuum holding fixture used in the original setup.

Lathe Reconstruction

Initially, the primary goal of lathe reconstruction was to determine the position of the cutting tool relative to the explosive billet at the time of the incident. This required knowledge of the transverse position of the boring bar, longitudinal position of the carriage, extension of the boring bar, the cutter used, and dimensions of the lathe adaptor, vacuum holding fixture, and explosive billet. Knowledge of the feed rate and speed control settings of the lathe and proof that the spindle was or was not rotating at the time of the incident were also desired. All reconstructed dimensions were duplicated on a "sister" Series 60 Monarch Lathe only five serial numbers different from the incident lathe to determine all relative positions.

Relative to the transverse position of the boring bar, the cross-feed screw shown in Fig. 3 was positioned by the jammed and sheared brass cross-feed screw nut on the cross feed screw at 11.7 cm from the back side. The brass compound-feed screw nut shown in Fig. 4

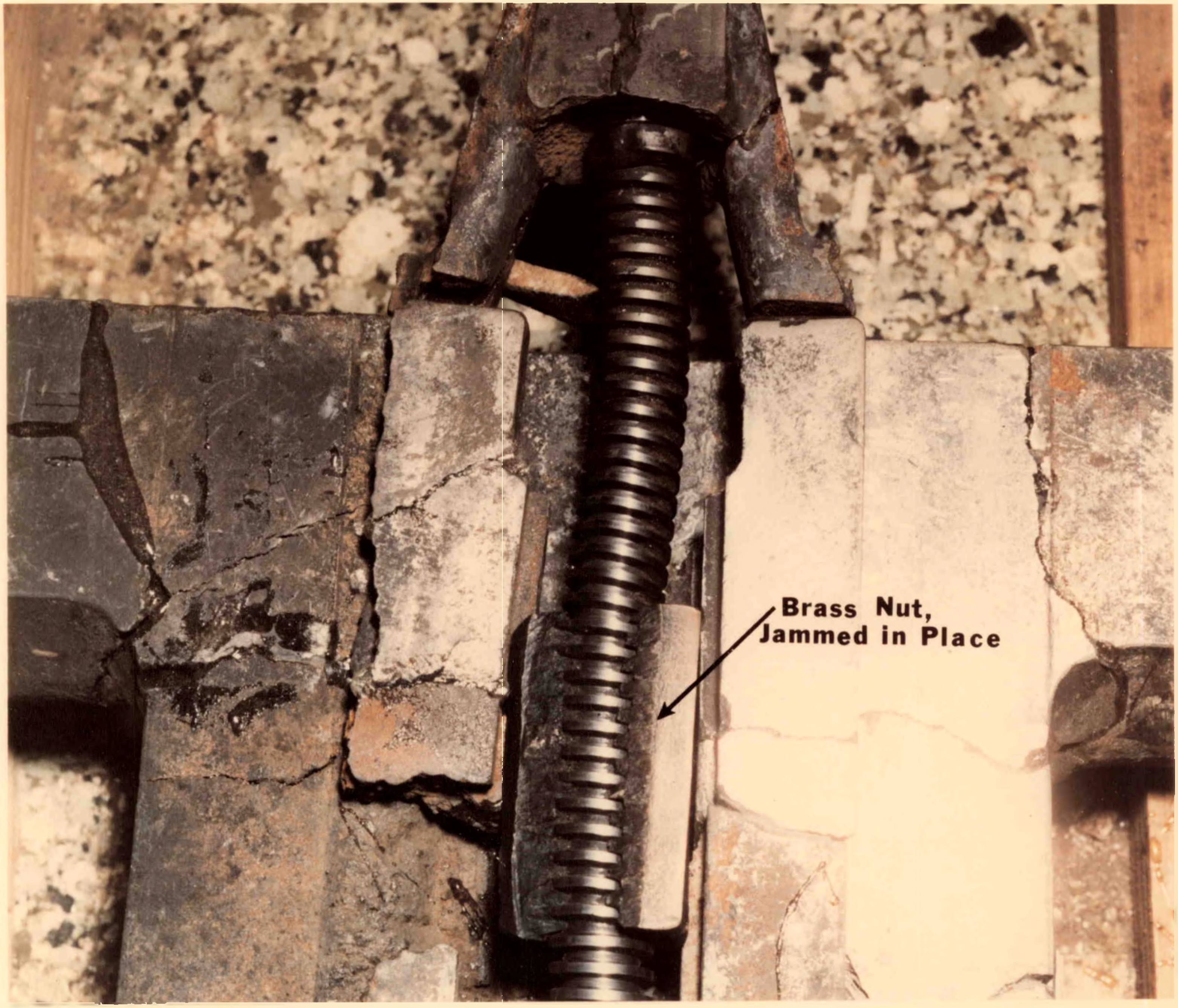

Fig. 3. Cross-Feed Screw

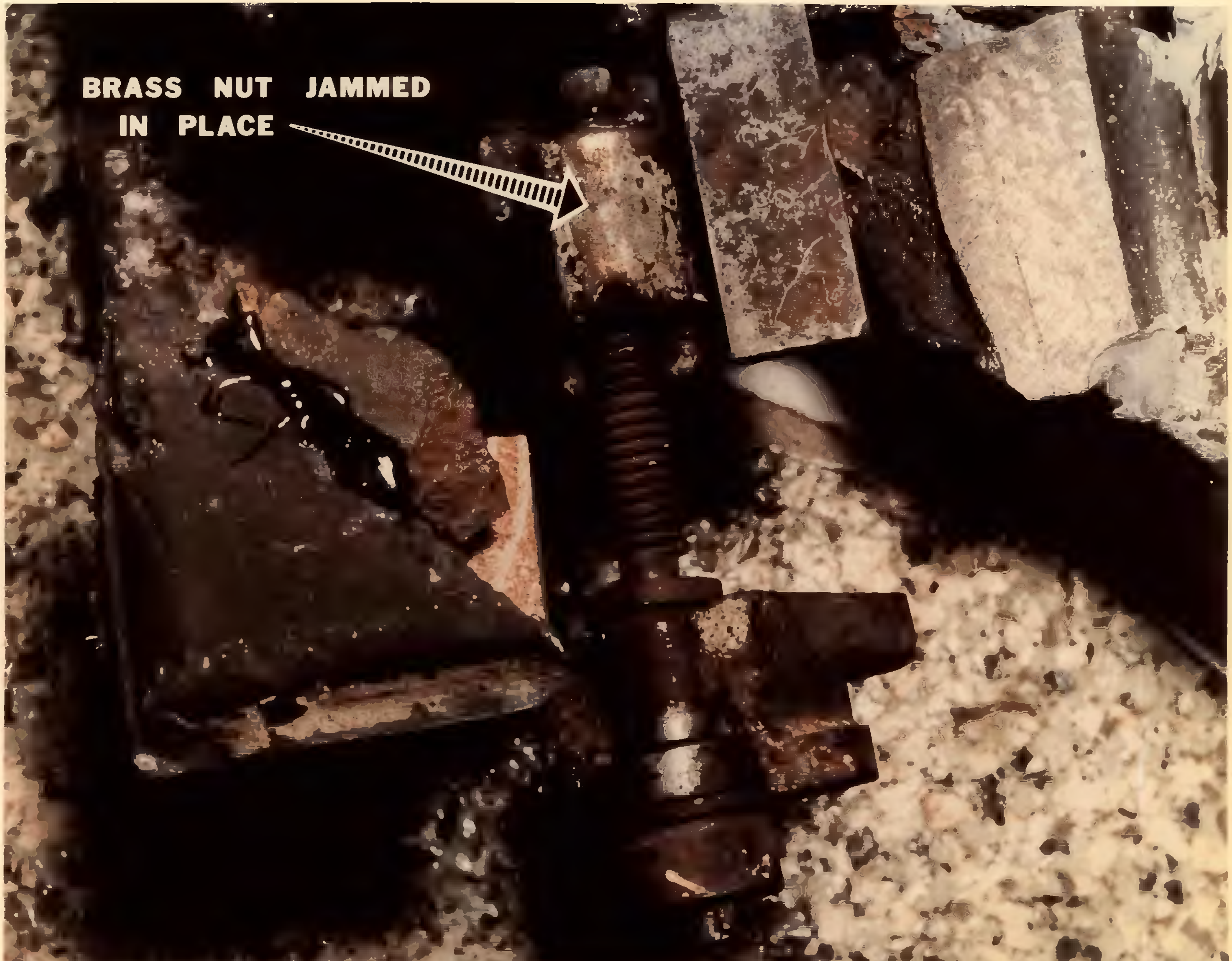

Fig. 4. Compound-Feed Screw

was jammed 0.6 cm from its maximum travel. The air gage tracer piston, Fig. 5, was found scoured, bent, and jammed in the full forward position. Being set at a 45° angle the air gage tracer piston affected both transverse and longitudinal positions of the boring bar/cutter. Reproduction of these positions on the second lathe indicated that the boring bar holder was essentially on the axis of rotation of the billet. However, burn marks on the underside of the boring bar holder indicated that it was rotated slightly (∿ 4°) counterclockwise such that the cutter was moved closer toward the machinist (see Fig. 13).

Scour marks on the clutch control rod, traverse feed rod, and lathe bed, Fig. 6, were used in an effort to determine the longitudinal position of the carriage. Marks on the clutch control and traverse feed rods were found that agreed reasonably well with each other but not with the lathe bed marks found. All mark positions were measured relative to the lathe rear leadscrew box because of less damage to the tailstock end of the lathe bed, thereby decreasing measurement error in this area. Eventually the clutch control and traverse feed rod marks were discounted because of the relative flexibility of the rods, being approximately 25 cm square or diameter by approximately 220 cm long steel rods. The marks on the rods could have been made after leaving the lathe. There were, however, three marks found on the lathe bed, which because of its rigidity and the nature of the marks, were considered more definitive because they had to have been made with the carriage in contact with the lathe bed. The most reliable mark was an embedded gear tooth which was removed from the notch shown in Fig. 7. This tooth came from the pinion gear in the carriage used to move the carriage. The tooth and pinion gear are shown in Fig. 8. The other marks resulted from the impact of bolt heads on the underside of the carriage. Using these marks the carriage location relative to the lathe bed was established as tabulated in Table II and agree within 0.8 cm. Another mark found but not used in the longitudinal position reconstruction was made by the pinion gear on the rack. This mark generally agreed with the gear tooth position but was dimensionally less accurate than the tooth and was therefore not used.

Table II. Carriage Location

Marks	Distance To Rear Leadscrew Box (cm)	Carriage Location* (cm)
Gear Tooth	118.1	72.4
Bolt No. 1	86.4	71.6
Bolt No. 2	72.4	71.8

**Distance from rear of carriage (bottom portion) to rear leadscrew box.*

With the carriage location established, the carriage itself was effectively used as a positional reference. It was found in examining the underside of the boring bar holder that in addition to being rotated 4° counterclockwise as previously discussed, it was also extended 1.6 cm from the carriage toward the explosive billet.

For some time the major portion of the boring bar which included the cutter end was missing, but was eventually found approximately 110 meters north of 11-14A. Fig. 9 shows the relatively symmetrical damage to the cutting tool end of the boring bar which tends to support the previously established transverse position of the boring bar holder—along the axis of rotation of the billet. The longitudinal position

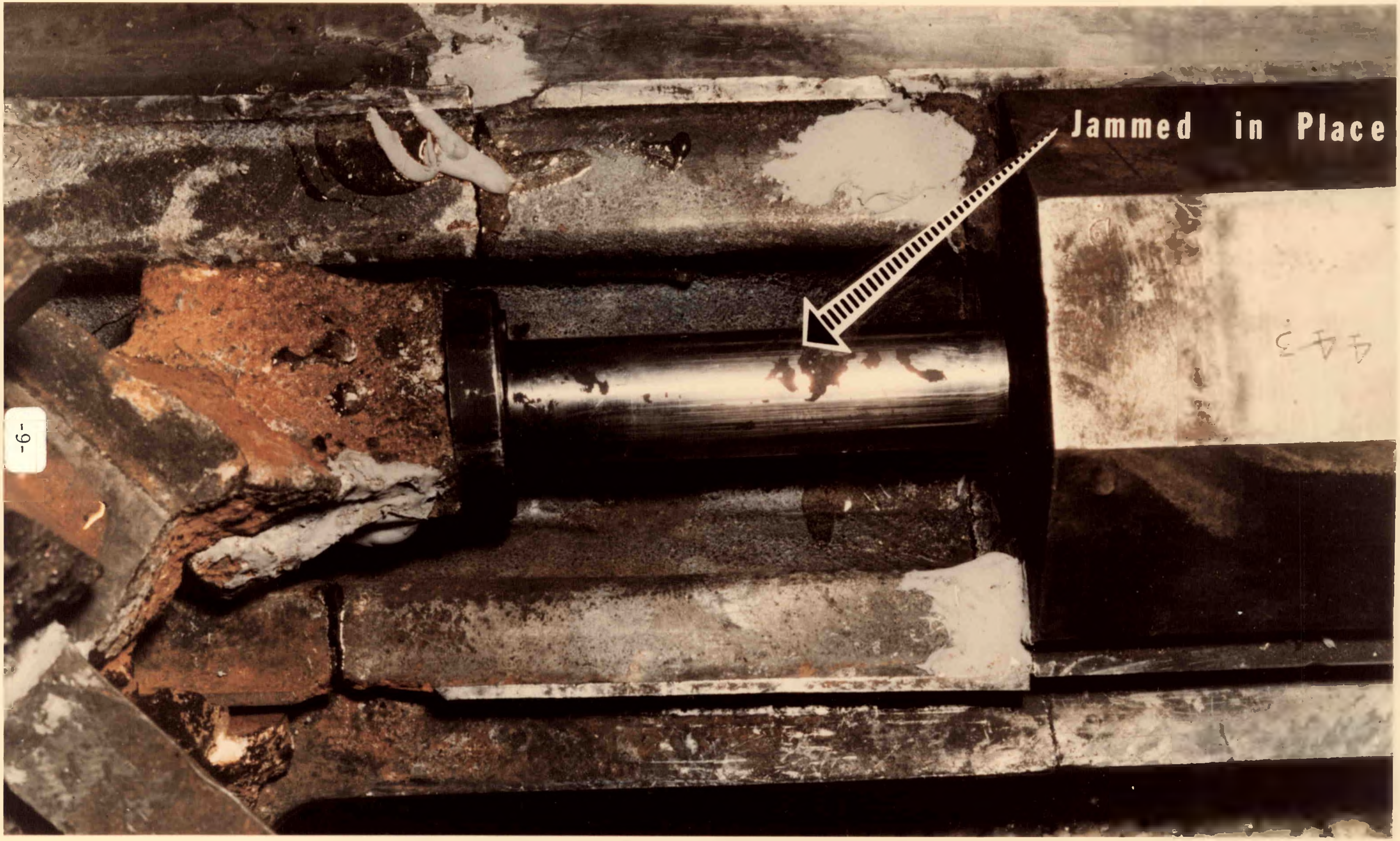

Fig. 5. Air Gage Tracer Piston

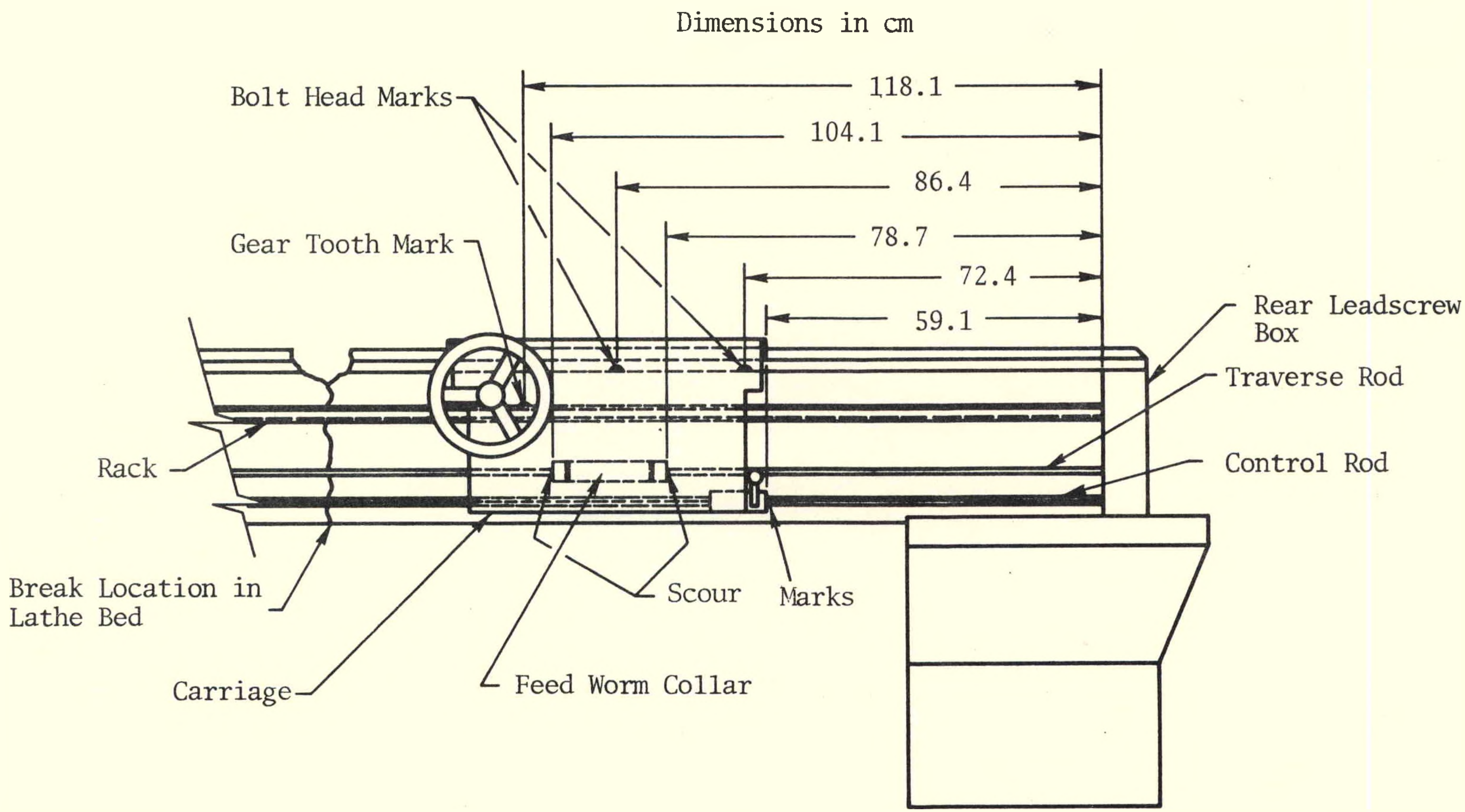

Fig. 6. Location of Lathe Markings

Fig. 7. Gear Tooth Notch in Lathe Bed

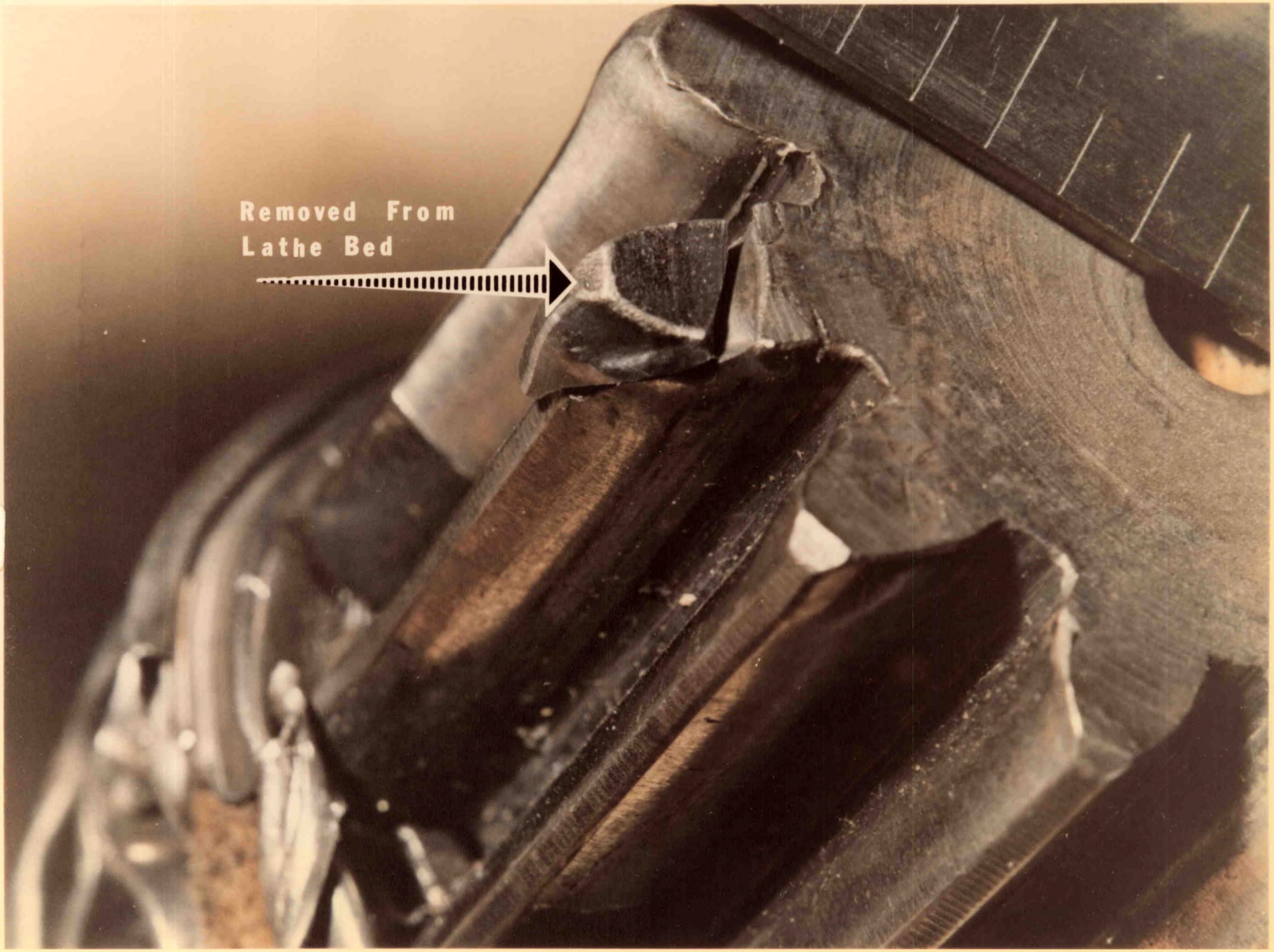

Fig. 8. Pinion Gear with Broken Tooth

Fig. 9. Cutting Tool End of Boring Bar

of the boring bar (shown in Fig. 10) was established by matching the scour marks on the two pieces of the boring bar to the boring bar holder on the carriage. Originally this boring bar had been fabricated from two pieces and the break occurred at the junction of these two pieces at a point within the holder. From the boring bar reconstruction its extension from the boring bar holder to the center of the cutter holder bolt hole was 29.8 cm. It should also be noted from Fig. 10 that the boring bar was bent down relative to its position on the lathe at the time of the explosion.

Although the original setup of the machining operation had been with a 1.27 cm button cutter, the possibility existed that the second machinist may have changed the cutter to another he may have preferred for roughing cuts. Because of the wide dimensional variations possible between cutters it was essential to know which cutter was used to dimensionally reproduce the incident conditions and to determine the relative position of the cutter and explosive billet. The remains of the incident button cutter holder were eventually found. Fig. 11 shows this holder along with a typical button cutter for comparison purposes. The threads at the front of the incident holder correspond to the threads of the socket head cap screw seen in the typical holder. There are also indications at the rear section of thread marks from the cap screw used to hold the cutter holder to the boring bar. The line of break across the rear hole as well as marks on the holder and boring bar face caused by their collision were taken as a rough indication of the angular position of the cutter holder relative to the boring bar ($\sim 45°$) at the time of the incident. It should also be noted that the incident cutter holder was bent down as was the boring bar. This reconstruction along with the boring bar, boring bar holder and carriage locations located the cutter with respect to the lathe bed.

One possible initiation sequence that was considered involved the adjustment of the cutter and/or cutter holder. There have been known instances in which explosive in threads has been initiated during turning of the associated cap screw or explosive in socket head cap screws initiated by the inserted Allen wrench during turning. Relative to Fig. 11, one such socket head cap screw is shown in the typical button cutter holder and is used to clamp the button cutter in place. On inspection of the recovered portion of the incident cutter holder the threaded portion corresponding to this cap screw does not show flow marks indicative of an explosive reaction in the threads. The cap screw itself was not found and so it is not possible to eliminate a possible reaction in the head. A second socket head cap screw not shown in Fig. 11 went through the larger unthreaded hole of the button cutter holder into a threaded hole on the front of the boring bar attaching the cutter holder to the boring bar. Again the recovered threaded portion of the boring bar (Fig. 9) did not show flow marks indicative of a reaction in the threads but this cap screw was also not found leaving initiation in the head a possibility.

At this point in the reconstruction we had located the cutter relative to the lathe bed, so if we now located the billet relative to the lathe bed the cutter-to-billet position would result. Starting from the headstock end of the lathe, the lathe adaptor and vacuum holding fixture dimensions were obtained from fabrication drawings of these parts, leaving only the

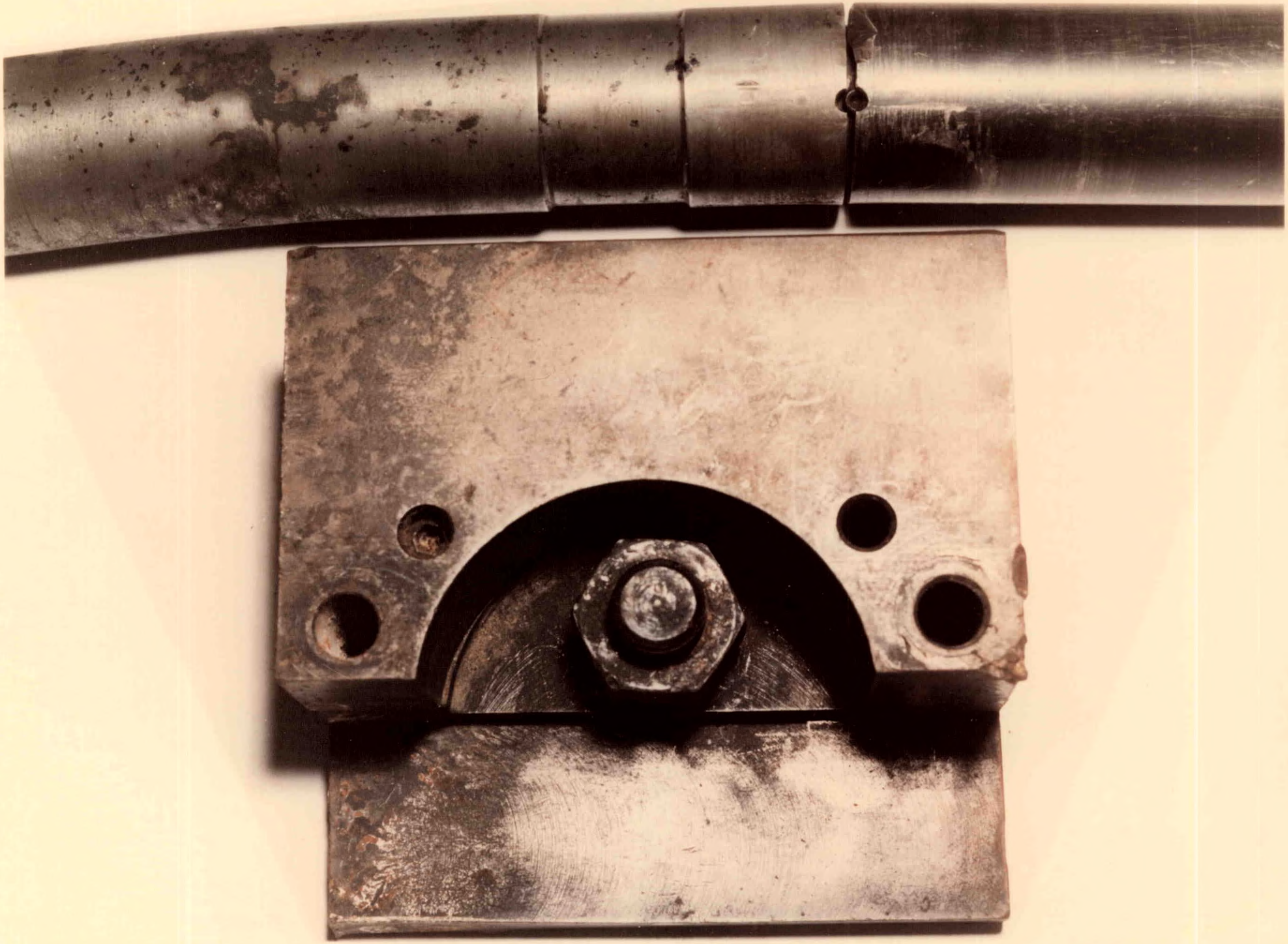

Fig. 10. Boring Bar and Boring Bar Holder

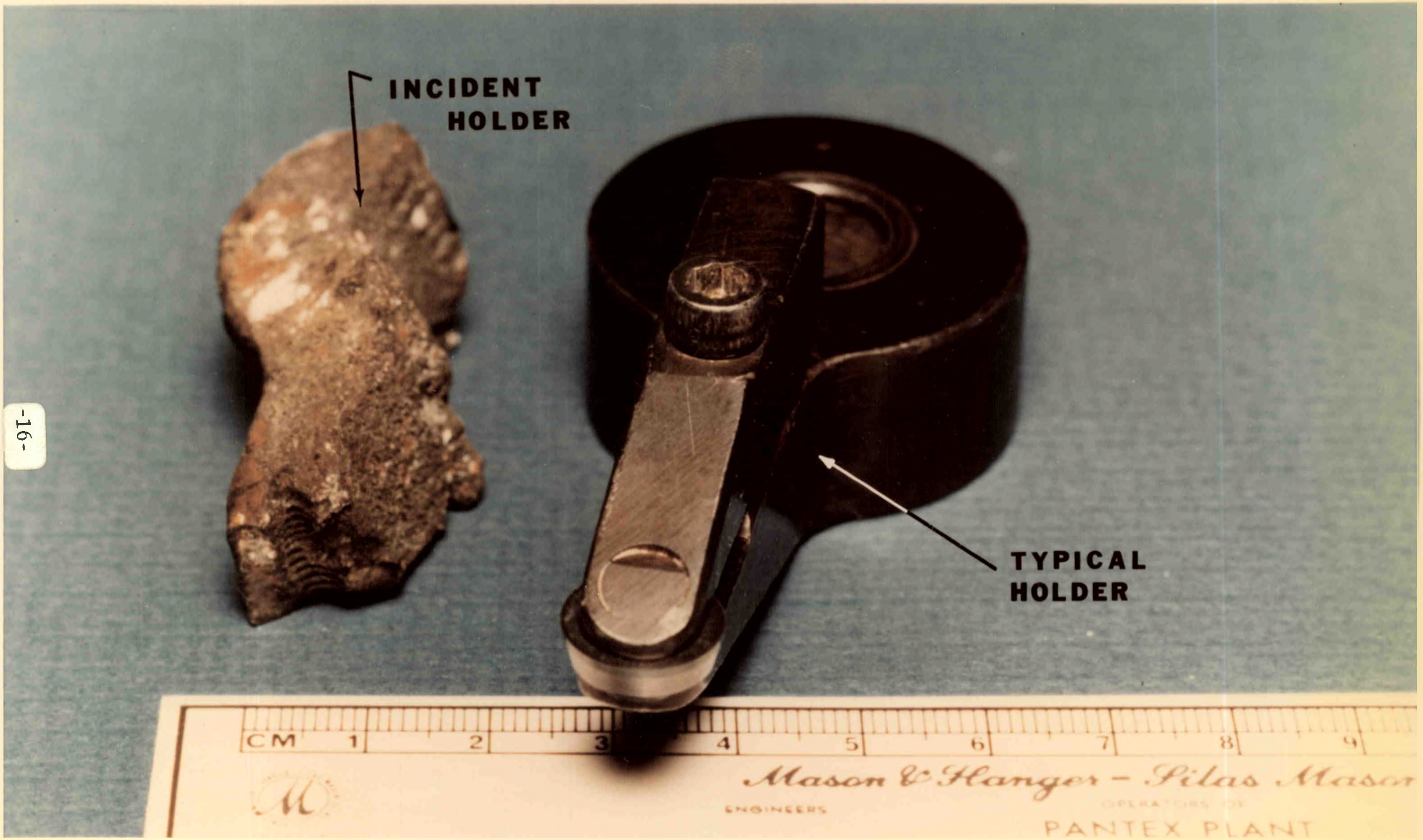

Fig. 11. Button Cutter Holders

explosive billet dimensions to be determined. Fig. 12 is a reconstruction of the probable LX-09 pressed billet dimensions based on the pressing reports of this particular billet and others being pressed at the same time which still existed. The desired finished piece is also shown to illustrate how little scrap material was available. In fact, the maximum depth of a roughing cut available at the pole, which was the general cutter location, was about 1.9 cm. This would have been an excessive depth of cut for the 1.27 cm diameter cutter used.

Combining all of these dimensions one arrives at a cutter-to-billet position which includes a cutter-to-billet separation of 0.2 cm with the cutter displaced 1.2 cm beyond the machine vertical centerline (away from the machinist) as shown in Fig. 13. Though based on best available information the potential accumulated dimensional uncertainty, estimated to be $\pm$ 1.3 cm, only justifies the conclusion that the cutter if not in contact with the billet was relatively close. Either situation is consistent with various phases of a typical machining operation that might be performed. It should also be noted in Fig. 13 that the crater in the lathe bed was displaced slightly from centerline of the billet toward the cutting tool.

Relative to lathe control settings since the tumblers were jammed in position 11 there were only two control levers that determined feed rate if the drive clutch was engaged and the spindle rotating. The position of one of these controls was determinable, even though the lever was broken off, by the rotational position of a cotter pin in the jammed control shaft which corresponded to only one possible position. The second control was still operational and could have been in either one of two positions. So, if activated, which was indeterminable, the feed rate would have been either 0.0448 or 0.0056-inch/revolution. The maximum allowable feed rate by operating standards was 0.035-inch/revolution.

The other lathe control setting of concern was the spindle speed which is determined by the combination of four clutches in the drive train controlled by levers on the headstock. Each clutch has three possible positions: (a) fast speed, (b) slow speed, or (c) disengaged. If any of these or the main power clutch were disengaged the spindle would not be turning. Inspection of the external levers revealed no information but reconstruction of the lathe drive train gears, Fig. 14, in the headstock did provide information on possible settings. Clutch "D" shown in closeup in Fig. 15, was found to be jammed permanently in the slow or down position. The gear train housing shown in Fig. 16 was reconstructed to determine the relative positions of the drive train shafts and allow matching of impact marks. By matching gear-to-gear and gear-to-housing impact marks Clutch "C" was determined to be in its fast or up position. However, positions of Clutches "A" and "B" were not so well defined with contradictory, poorly defined marks being found. The clutch arrangement is such that the extent of influence on final spindle speed increases from "A" through "D". Therefore, not knowing "A" and "B" had little effect on spindle speed determination. From Table III one can see that with "D" down, "C" up and "B" and "A" unknown the speed range, if the spindle were rotating, would have been from 64 to 140 rpm. For the particular piece size involved, the maximum allowable speed by operating standards would have been 56 - 57 rpm.

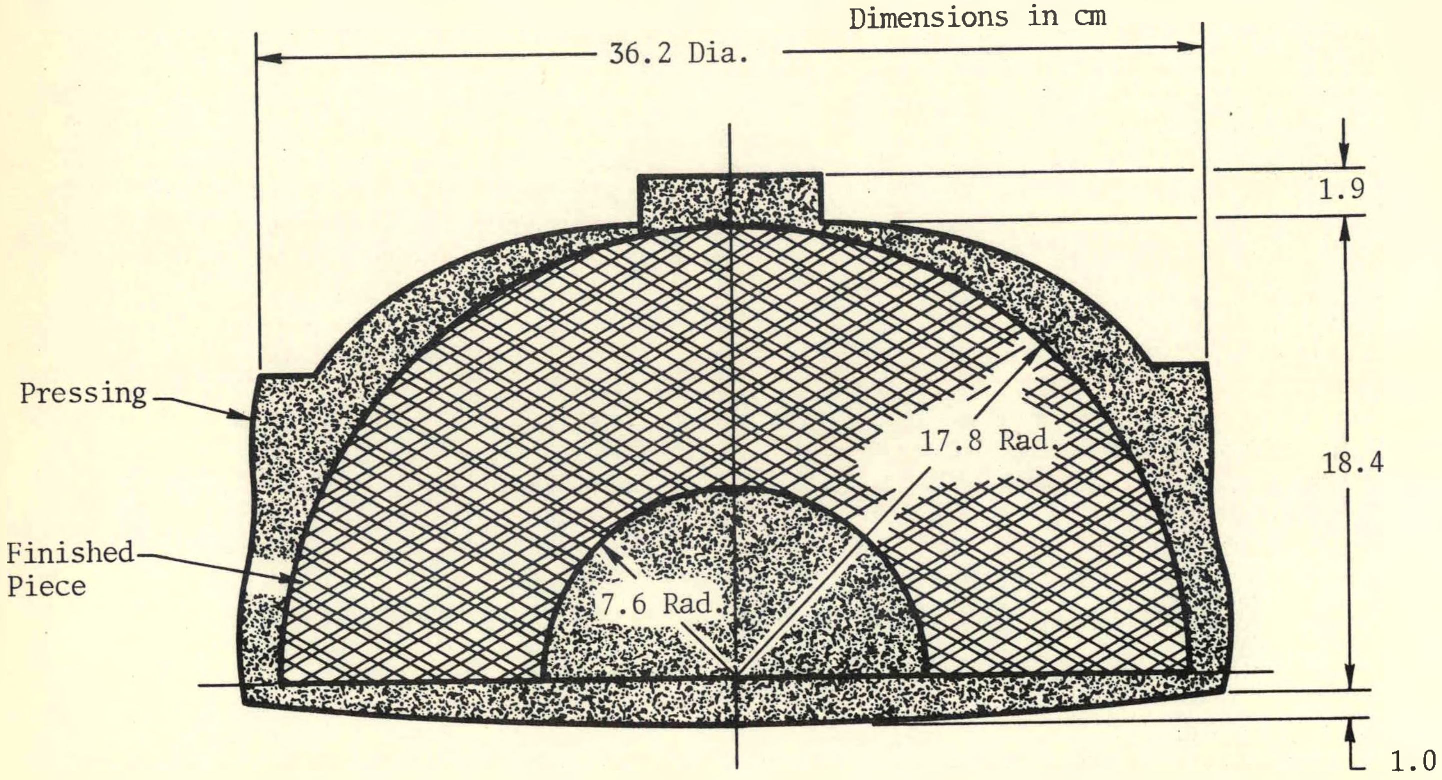

Fig. 12. LX-09 As-Pressed Billet with Finished Piece Dimensions

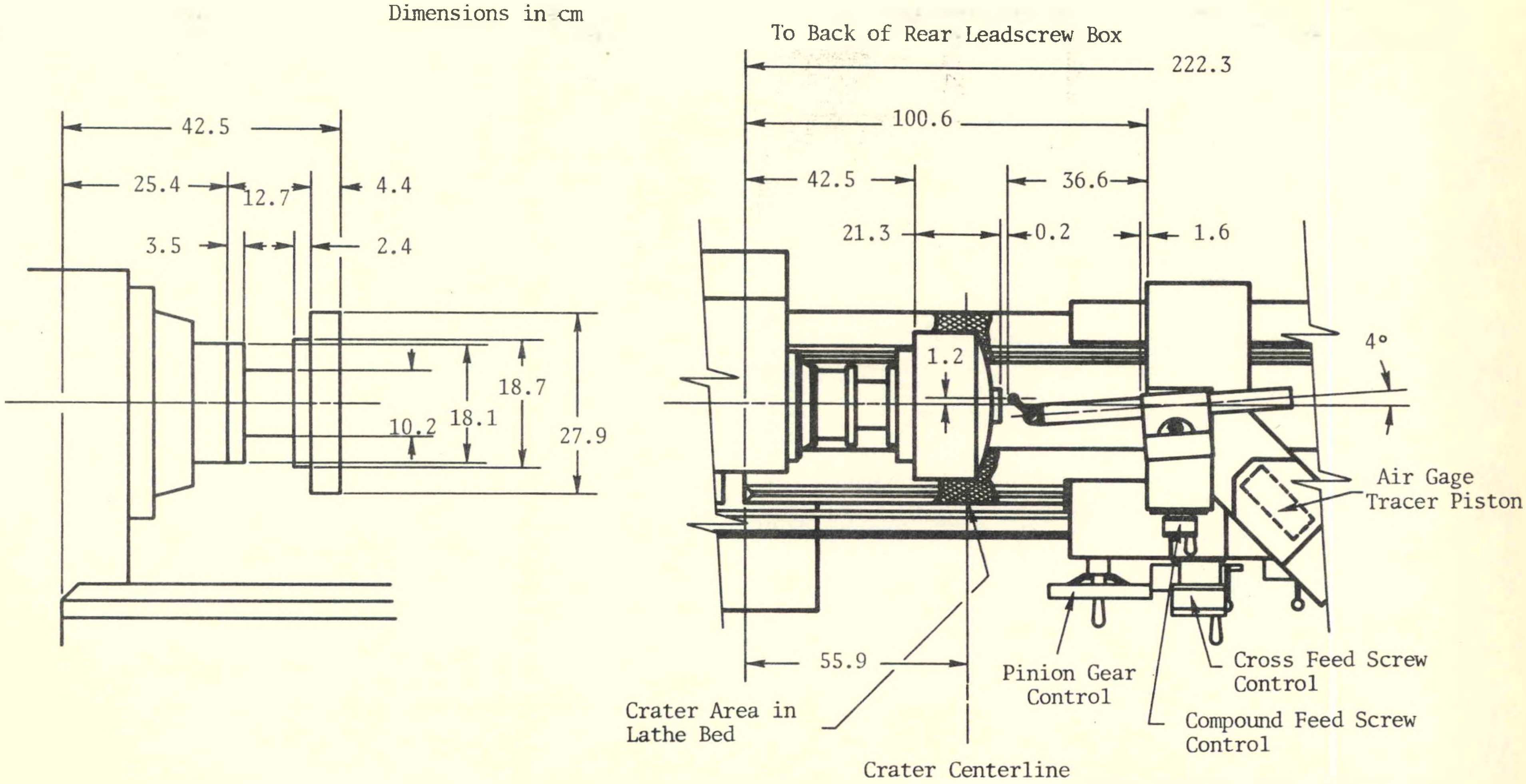

Fig. 13. Lathe Reconstruction Dimensions

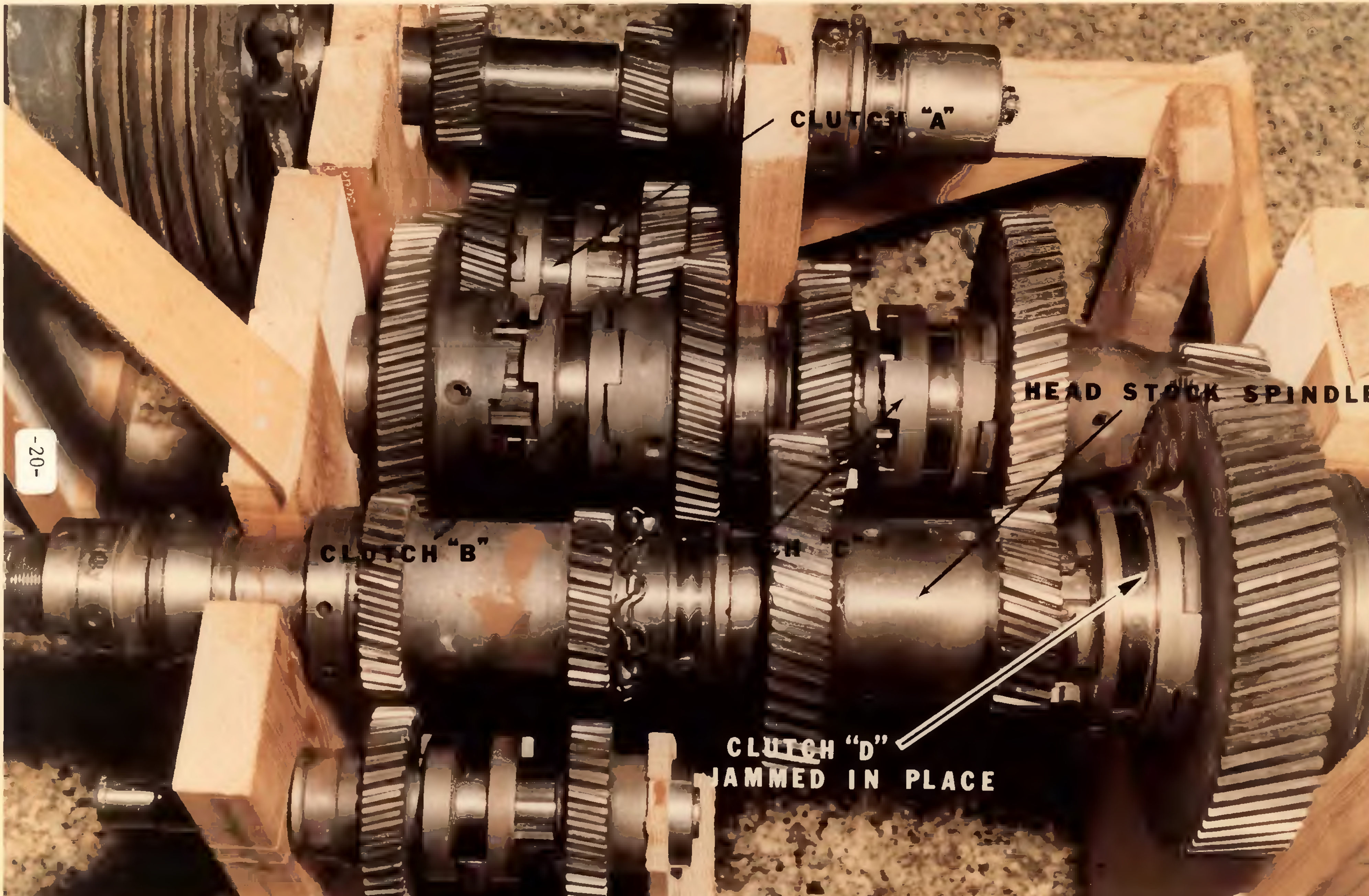

Fig. 14. Reconstructed Drive Train

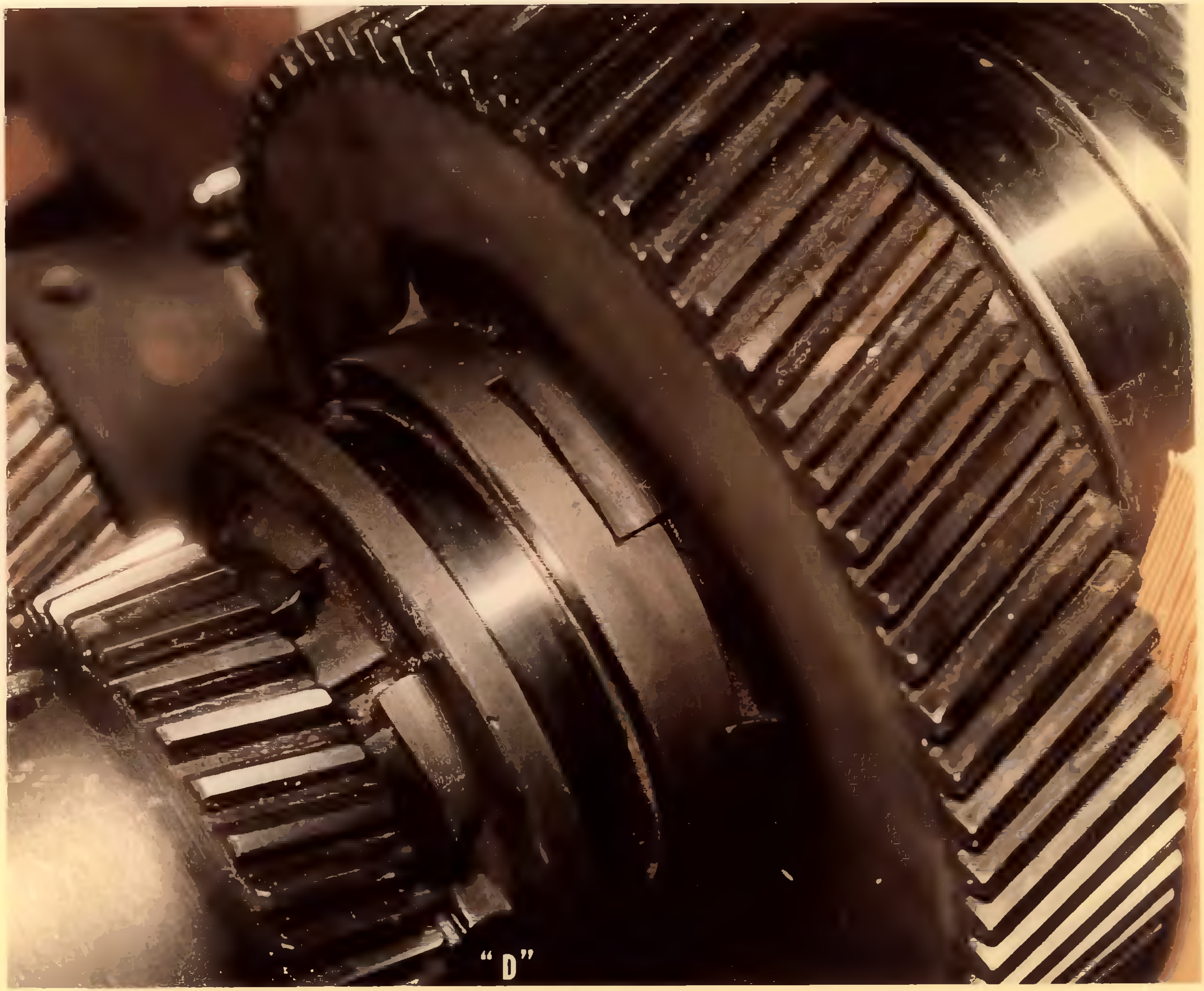

Fig. 15. Engaged Clutch "D" in Gear Train Assembly

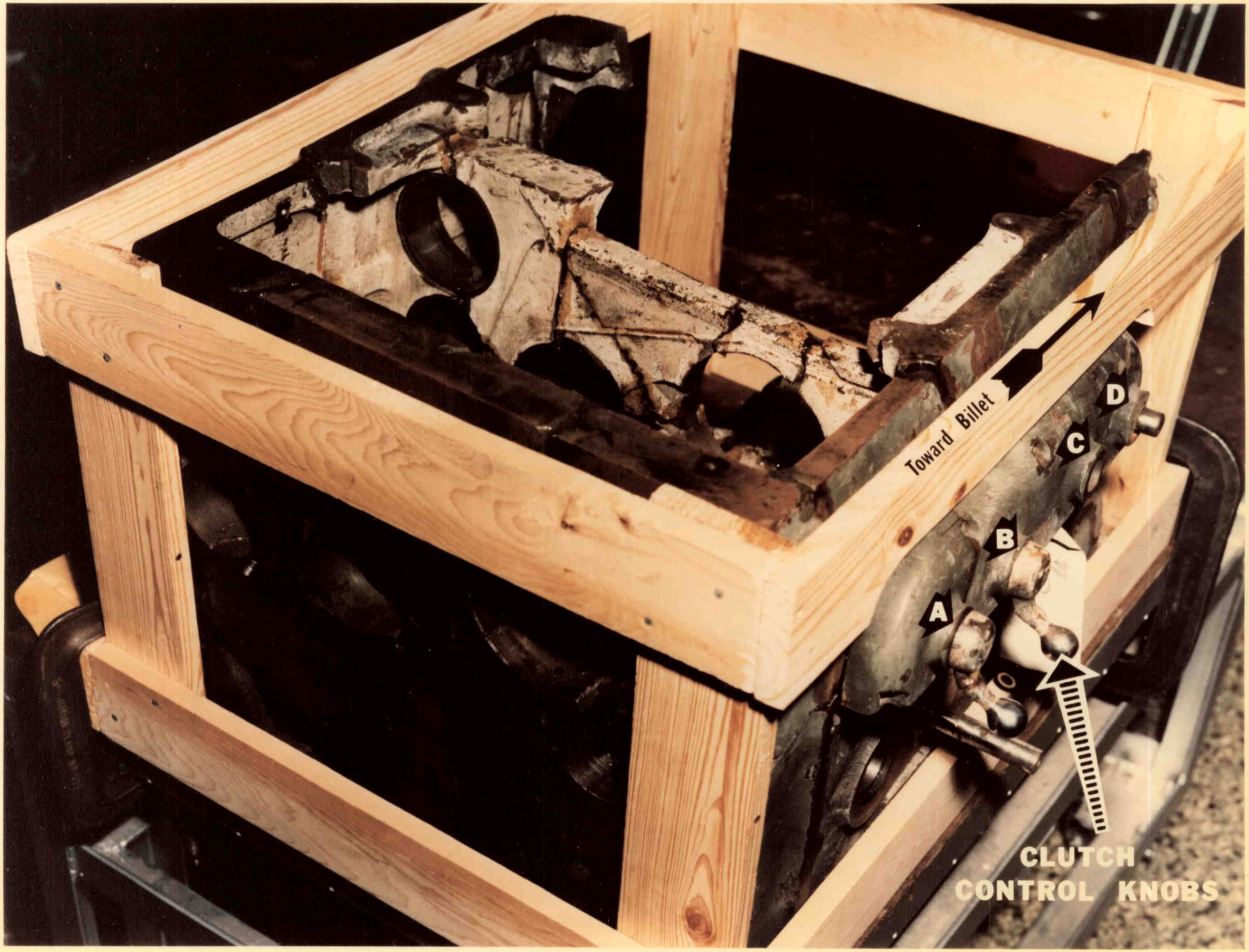

Fig. 16. Reconstructed Gear Train Housing

Table III. Series 60 Monarch Lathe Spindle Speed Chart

Speed (rpm)	Lever A	Lever B	Lever C	Lever D
24	Down	Down	Down	Down
31	Up	Down	Down	Down
40	Down	Up	Down	Down
53	Up	Up	Down	Down
64	Down	Down	Up	Down
84	Up	Down	Up	Down
107	Down	Up	Up	Down
140	Up	Up	Up	Down
171	Down	Down	Down	Up
227	Up	Down	Down	Up
287	Down	Up	Down	Up
377	Up	Up	Down	Up
455	Down	Down	Up	Up
600	Up	Down	Up	Up
762	Down	Up	Up	Up
1000	Up	Up	Up	Up

NOTE: 'Up' corresponds to fast and 'Down' to slow.

It would have been helpful had the drive train reconstruction yielded conclusive evidence as to whether the spindle was or was not turning. Unfortunately no stripped teeth, which would have been considered as an indication that the spindle was turning, were found. Conversely, the lack of stripped teeth does not prove that the spindle was not turning. In fact, the gears of the drive train were in remarkably good condition with the only significant damage being impact marks with other gears, the cast housing around the gears, or other items in the bay. There were impact marks on the main drive pulley indicating that it was turning at the time of impact, but it is generally standard procedure during machining operations to leave the power on the lathe and stop spindle rotation by disengaging the main power clutch leaving the main drive pulley turning, so these marks are inconclusive as to proof of spindle rotation.

One possible initiation source that had been considered up to this point involved initiation of explosive accumulated somewhere in the drive train via the hollow vacuum shaft of the lathe spindle or in the vacuum shaft itself with subsequent propagation to the lathe billet. As has been stated above the drive train gears were in remarkably good condition and there was no evidence of any explosive reactions having occurred in the gears. Inspection of the hollow spindle shaft through which vacuum is pulled revealed no metal flow or other damage to indicate explosive propagation had occurred in this area. Therefore, this sequence of events leading to the incident was discounted and eliminated from further consideration.

In a normal centering operation Clutch "D" would have been disengaged with the billet and spindle rotated manually while hitting the billet with a mallet to center the billet as close as possible around the center of rotation before any actual machining. If this were true would the Clutch "D" position found preclude a centering operation? Not necessarily! First, any of the other clutches could have been disengaged and manually turned but this is unlikely because it would be more difficult to turn in this fashion than if Clutch "D" were disengaged. Secondly, there is a remote possibility that Clutch "D" was disengaged but almost perfectly aligned with the slow position at the time of the incident and then jammed into the slow position by the explosion. However, alignment would have had to be almost perfect because there was no evidence of edge impacts of the clutch (Fig. 15) that would have occurred had it been slightly out of alignment. Any worse alignment would have precluded the condition found. Third, discussions with machinists revealed that occassionally billets were centered using the lathe to turn the billet at a slow speed while hitting the billet with a mallet, which could be consistent with the Clutch "D" position found.

The specific questions asked of the machinists about billet centering operations were:

1. "Have you ever seen explosive billets centered on horizontal lathes using the lathe to turn the billet while striking the billet with a mallet?"

If the answer to the above question was "yes" two more questions were then asked.

2. "What is the largest billet size you can remember having seen centered in this fashion on horizontal lathes?"

3. "For these larger billets, what would you estimate was the fastest spindle speed used?"

Eight of ten former and present machinists interviewed answered yes to the first question and then proceeded to describe billet sizes and speed ranges that potentially encompass the incident conditions making this operation worthy of further consideration. Maximum billet sizes described by the machinists ranged from 17.8 cm diameter up to, in their words, "as large as ever cut" which should be 45 to 48 cm diameter on horizontal lathes. Estimated speeds for these larger pieces ranged from 10 to 50 rpm. One answer was "approximately 210 linear feet per minute" or the maximum allowable for machining under operating standards.

Perhaps the most significant benefit from the drive train reconstruction was the ability to determine the rotational orientation of the spindle at the time of the incident. This was accomplished by matching gear-to-gear and gear-to-housing impact marks. As shown in Fig. 17 the maximum metal erosion to the cam lock on the spindle was on the bottom side. This, along with the downward bending of the boring bar and cutting tool previously discussed, were indications of a downward thrust from the explosion. Combined with the displacement of the lathe bed crater from billet centerline a damage pattern indicative of the point of initiation was evolved. In general, this point of initiation was considered to be somewhere in the upper half of the billet relative to its position on the lathe at the time of the incident. Fig. 18 shows the placement and orientation of the incident lathe adaptor on the cam lock of Fig. 17. The downward thrust though not so evident is still present. The light flow marks on the top are aluminum flow marks from the vacuum holding fixture. The generally symmetrical metal flow indicates that the billet was physically on the vacuum holding fixture at the time of the incident.

Another possible cause for the incident that was considered involved lifting the billet with the hoist while the billet was still wedged between the cutter and vacuum holding fixture. In a normal sequence of events the machinist would use the hoist and lifting strap to lift the billet into position on the vacuum holding fixture, move the cutter against the pole of the billet to wedge it in place against the vacuum holding fixture, and apply a soft pliable material (duxseal) at the billet/vacuum holding fixture intersection as a vacuum sealant in order to pull vacuum on the billet. With vacuum on the billet the hoist sling would still be around the billet and the hoist would be lowered in order to remove the sling. But, because of the tendency of the overhead hoists, as installed, to move generally to the center of the bay unless restrained, the control chains for the air hoists at this point in the operation are generally overhead and slightly behind the machinist standing at the lathe. Though the handles on the control chains are marked "up" or "down" and distinguished by color, it would be possible in this position to inadvertantly activate the "up" handle rather than "down" and suddenly pull the billet up while wedged between the cutter and vacuum holding fixture with resulting initiation at either of these two areas.

Efforts to reconstruct the location of the overhead hoist by marks on the overhead beams indicated that the hoist was to the left and slightly behind the normal working position of the machinist at the time of the

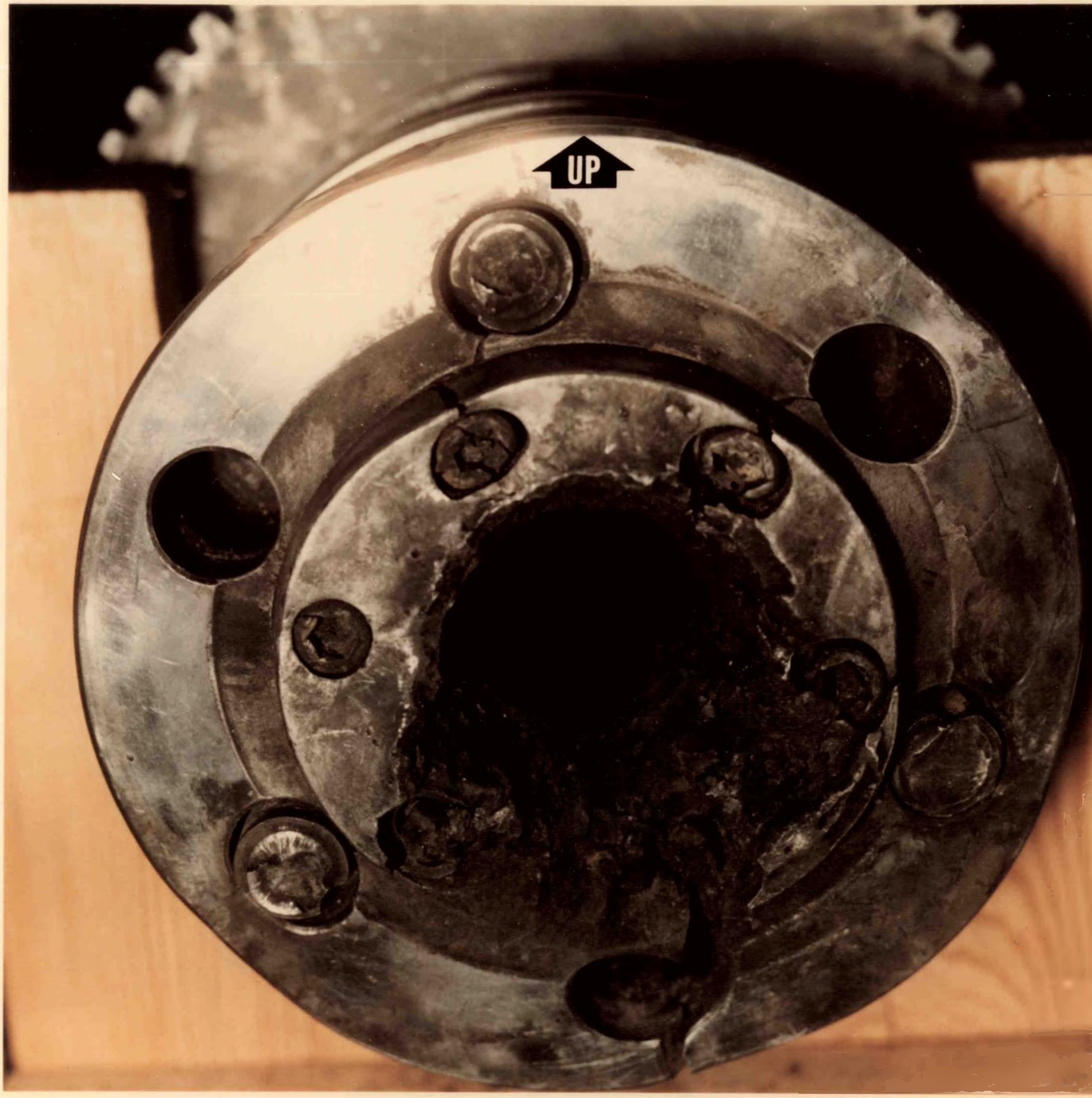

Fig. 17. Orientation of Incident Cam Lock at Time of Explosion

Fig. 18. Placement and Orientation of the Incident Lathe Adaptor

explosion. The remains of the sling found in the debris gave a clue as to the type of sling used, but it was physically impossible to reach the billet with these types of slings from the determined hoist location. For this reason as well as another to be discussed this initiation mechanism was discounted.

Summarizing the observations from the lathe reconstruction we found that (a) the cutter was either in contact or relatively close to the pole of the LX-09 billet, (b) if the spindle were turning the feed rate could have been either 0.0448 or 0.0056-inch/revolution, (c) if turning the speed was 64 to 140 rpm, (d) no positive proof as to spindle rotation was found, (e) the generally symmetrical damage to the boring bar and lathe adaptor indicates that the billet was in contact with the vacuum holding fixture, and (f) there was a definite indication of a downward thrust from the explosion indicating that initiation occurred in the upper half of the billet.

Lathe Simulation Tests

From the lathe reconstruction work, a damage pattern evolved consisting of maximum metal erosion of the bottom side of the cam lock/lathe adaptor, a downward bending of the boring bar/cutter, and displacement of the lathe bed crater from billet center line towards the cutter. The first two findings indicated probable initiation generally in the upper half of the billet while the significance of the third was uncertain. Therefore, a lathe simulation test fire series to attempt to duplicate the damage pattern observed in the reconstructed incident lathe was planned varying the point of initiation.

Rather than use actual lathes, 1100 kilogram castings simulating the area of interest from headstock to carriage were made as shown in Fig. 19. For the headstock area a solid approximately 20 cm thick casting to simulate the mass of the housing and drive train was used. Reinforcement ribs between the lathe bed runners were used as in the actual lathe. The boring bar holder (Fig. 20) though not identical was similar to an actual holder. The boring bar was similar to the incident bar as shown in Fig. 21 but did not have a hole through the bar, nor a flat on the top and was one piece rather than two. An actual button cutter was used. The vacuum holding fixture and lathe adaptor, Fig. 22, were made as duplicates of the originals. A simulated cam lock, Fig. 23, was made since actual cam locks are made as an integral part of the main spindle of a lathe. Two separate systems for mounting the cam lock to the simulated lathe, a solid shaft and a hollow shaft, were used; the reason for which will be discussed later.

As-pressed 35.4 kilogram PBX 9404 billets were used to simulate the 34.5 kilogram LX-09 incident billet. PBX 9404 was chosen because LX-09 was more difficult to utilize following the incident. Even though PBX 9404 is slightly less energetic the close-in damage pattern of interest was not expected to be adversely affected. The billets were mounted on the vacuum holding fixture using vacuum to simulate the incident but as an added safety precaution they were also glued to the fixture which was not considered to be a significant deviation. The mounting surface was smooth, not rounded as the as-pressed incident LX-09 billet.

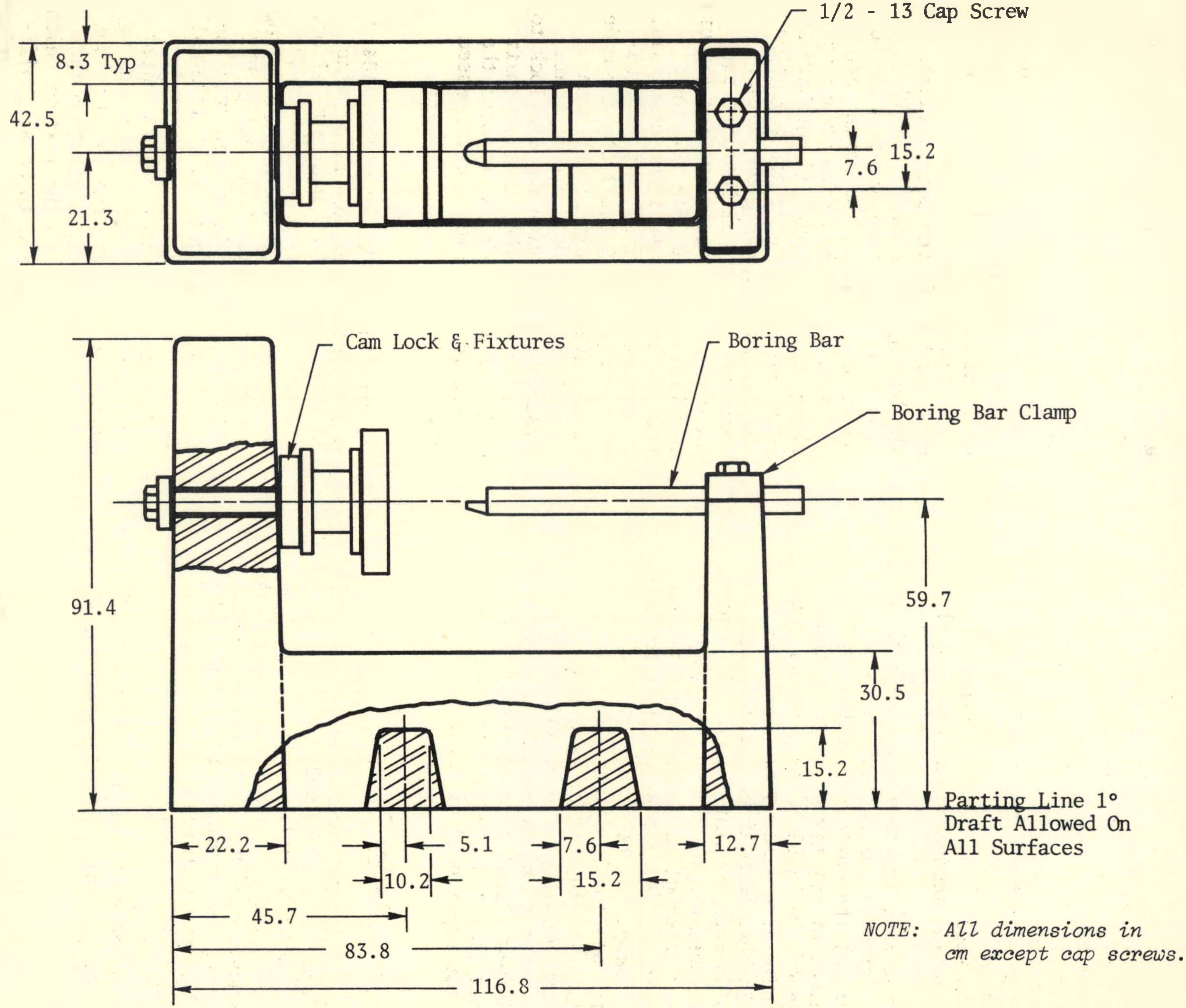

Fig. 19. Lathe Simulator (Grey Cast Iron)

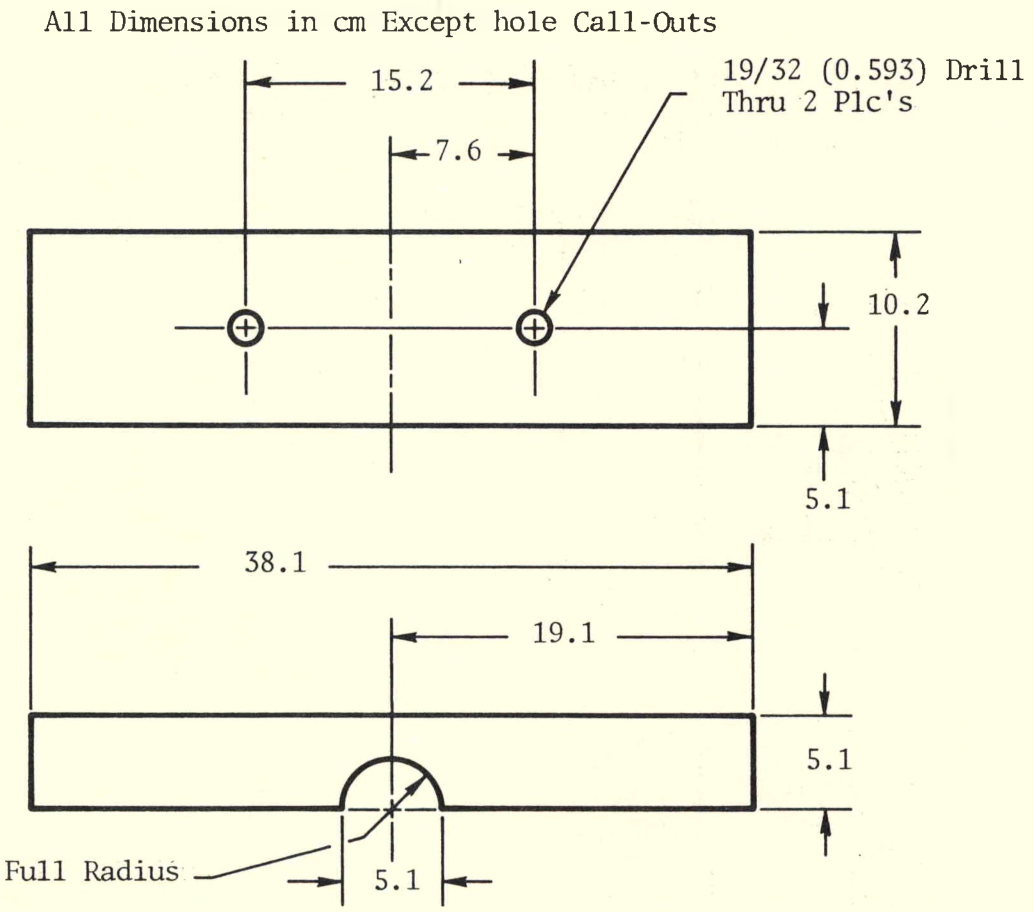

Fig. 20. Simulated Boring Bar Clamp (Mild Steel)

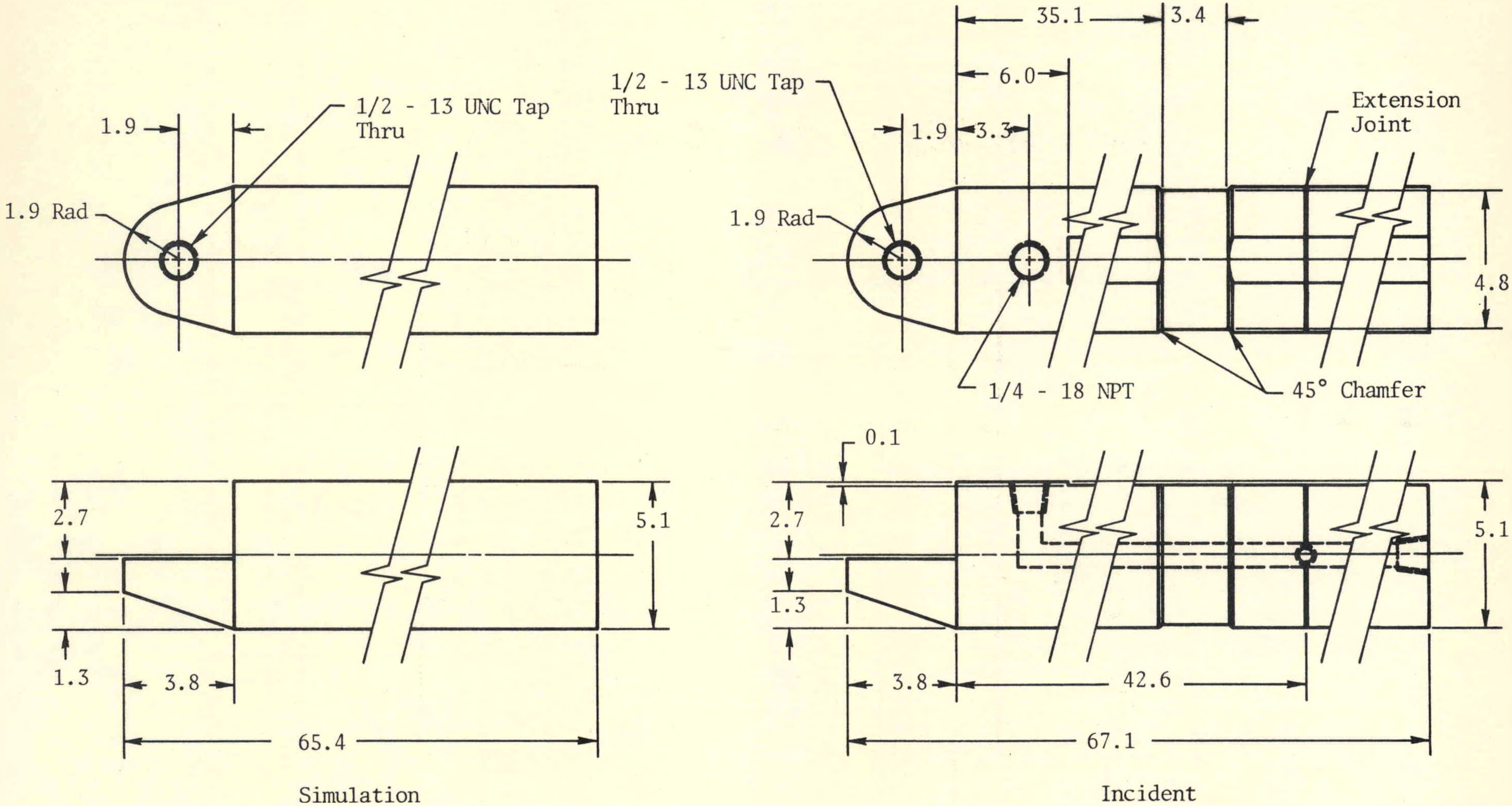

Fig. 21. Boring Bars (Mild Steel)

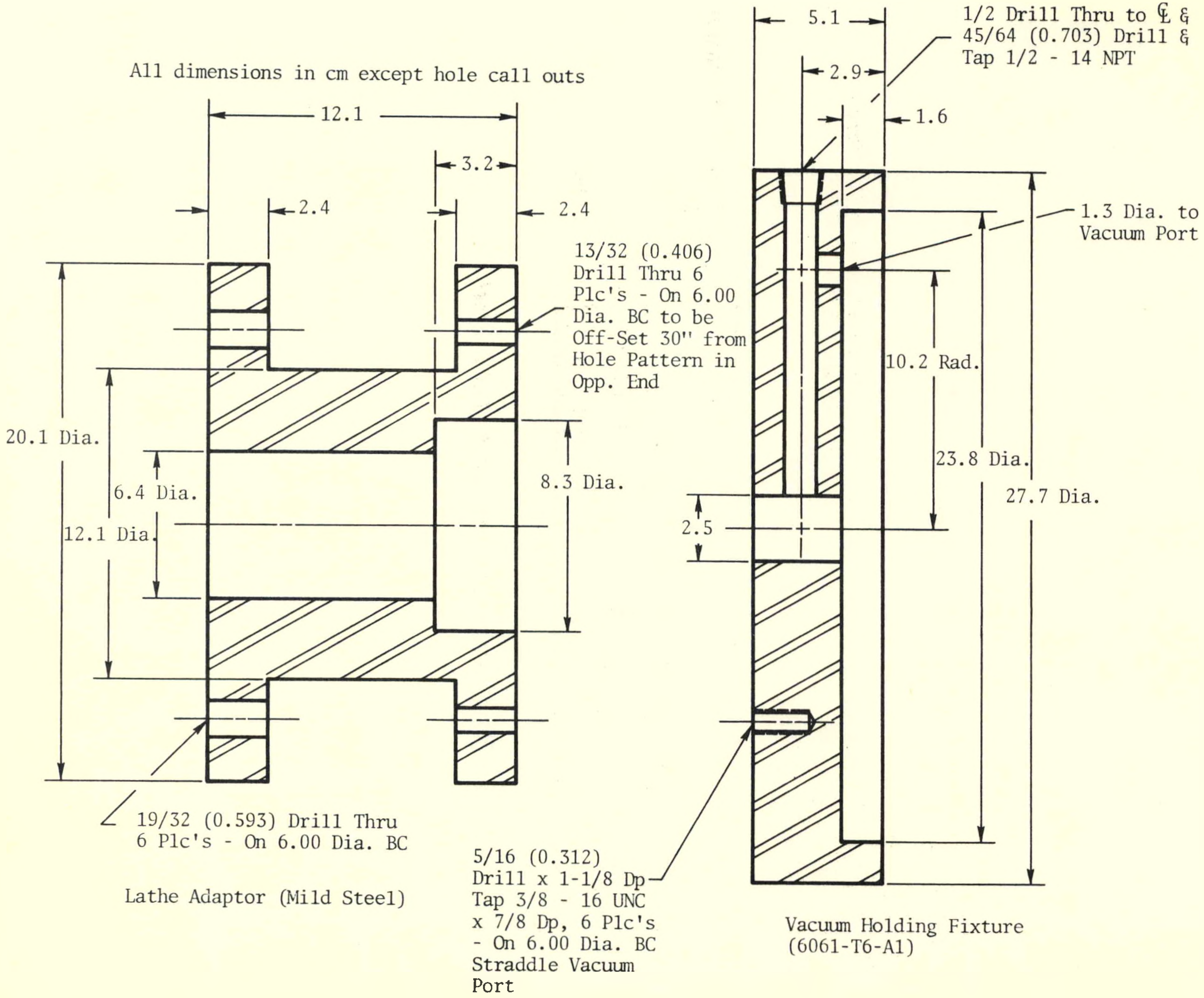

Fig. 22. Machining Fixtures

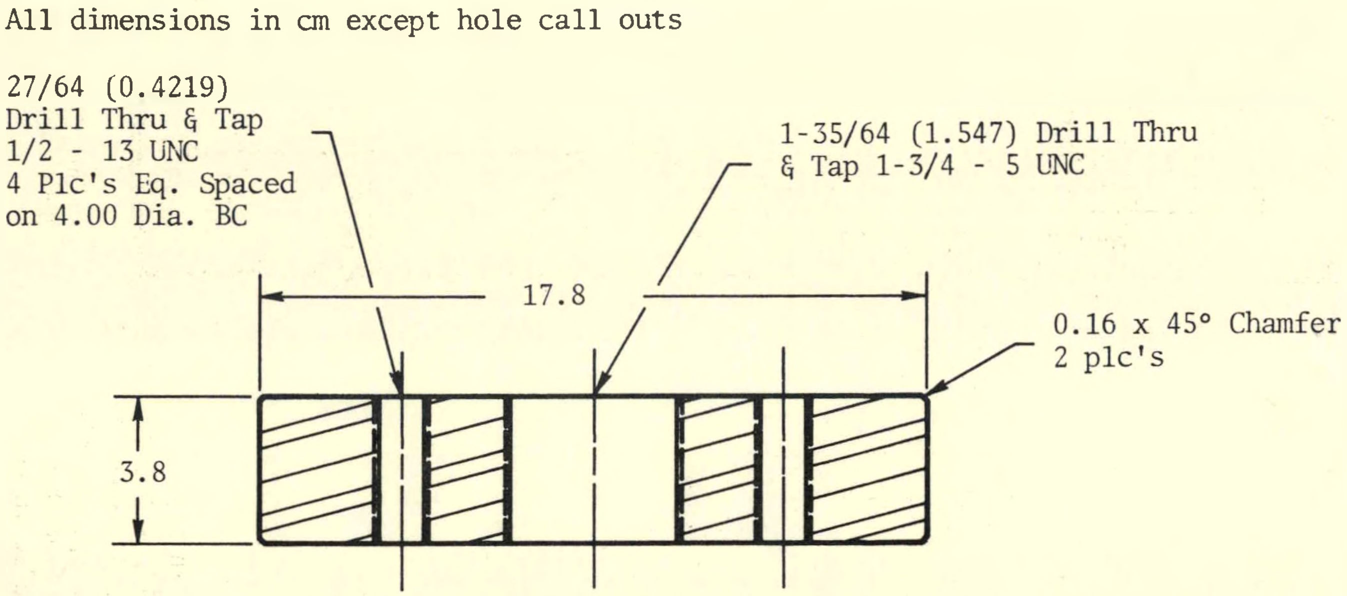

Fig. 23. Simulated Cam Lock (Mild Steel)

A series of tests was planned using three different points of initiation shown in Fig. 24 for comparison of the resulting damage pattern to the incident pattern. Point A was on the top side of the equatorial surface attached to the vacuum holding fixture. Point B was on the top side of the circumferential surface approximately 6.4 cm from the vacuum holding fixture surface. The last point, C, representing the location of the cutter, was on the horizontal center line of the billet in the plane of the cutter and displaced to the rear of the billet (relative to a machinist position) approximately 2.2 cm from the center of the billet.

Whatever the cause for the incident, it was felt that initiation probably started at some low order level and then built up to high order conditions. In an effort to simulate this condition brass attenuators were used between the RP-1 detonators and the 9404 billet. Testing prior to the lathe series was conducted to determine the proper brass thickness for near threshold conditions. Being near threshold conditions required machining smooth spots large enough (approximately 2.9 cm diameter) to accommodate the detonator assembly.

The first shot in the series was set up as shown in Fig. 25 with the detonator assembly at position A. The rubber and table shown across the lathe bed were for safety purposes and were removed prior to the shot exposing the lathe bed. Actually Fig. 25 is typical of all five shots in this series with the only major difference being the point of initiation. Fig. 26 and Table IV summarize the design conditions for all five tests. In all cases the cutter was positioned in contact with the billet angled toward the back of the billet from a machinist point of view except in Test No. 4 when the detonator was placed in the normal cutter position and the cutter moved to a corresponding position on the opposite (front) side.

Results of Test No. 1 indicated that the boring bar was bent down slightly though not as much as in the incident. There was no significant cratering of the lathe bed as in the incident but a general area of maximum damage was evident (Fig. 27). The lathe adaptor was shattered quite extensively leaving no discernible pattern.

It was suspected that the lack of a significant lathe bed crater might have resulted from the absence of a wet pan which should have provided a better mechanical linkage between the billet and lathe bed and provided a missile source. The possibility was also considered that the wet pan support locations on the lathe bed might have been instrumental in determining the crater position. In Tests 2 through 5 a simulated wet pan, 36 x 48 x 0.15 cm steel plate, set on two steel support bars 1.3 x 5.1 x 35.6 cm were used. A steel wet pan was used instead of aluminum even though the original wet pan was aluminum because efforts were being made to find the fragments of the aluminum vacuum holding fixture and the addition of other aluminum sources could have been confusing.

In Test No. 1 the simulated cam lock, lathe adaptor, and vacuum holding fixture were held to the simulated lathe using a solid shaft whereas the corresponding shaft in the incident lathe was hollow for the application of vacuum. Since the damage to the simulated lathe adaptor was unlike that of the incident adaptor it was decided to change the mounting shaft to a hollow shaft for future tests.

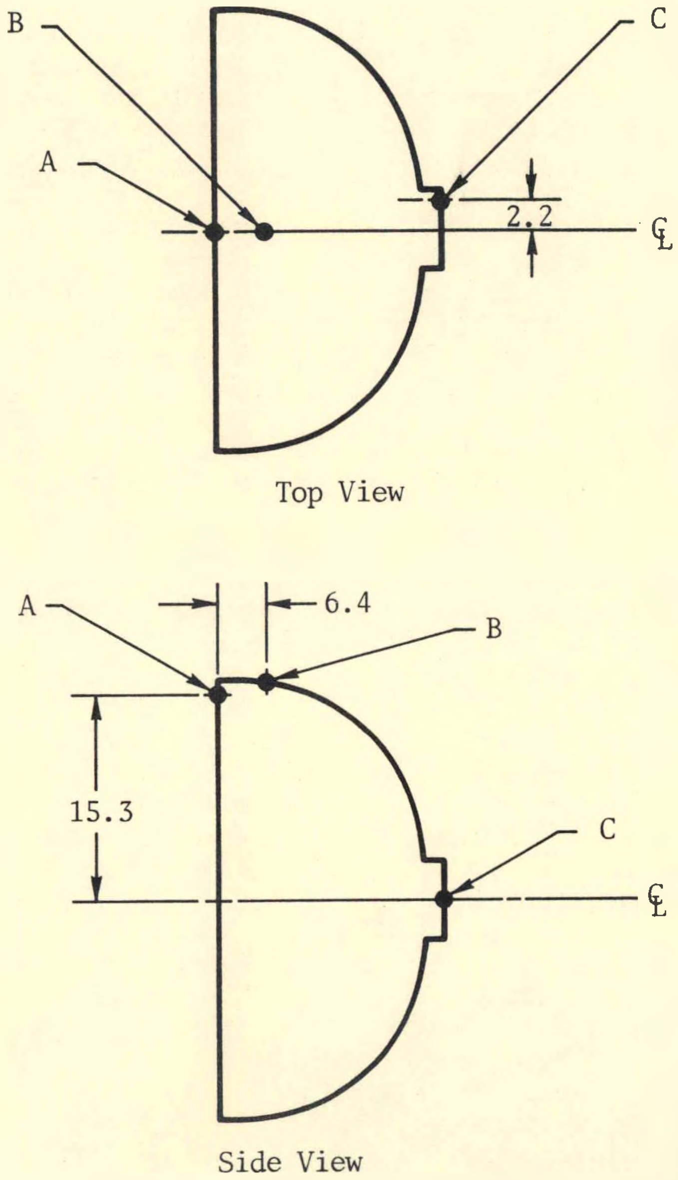

Fig. 24. Points of Initiation

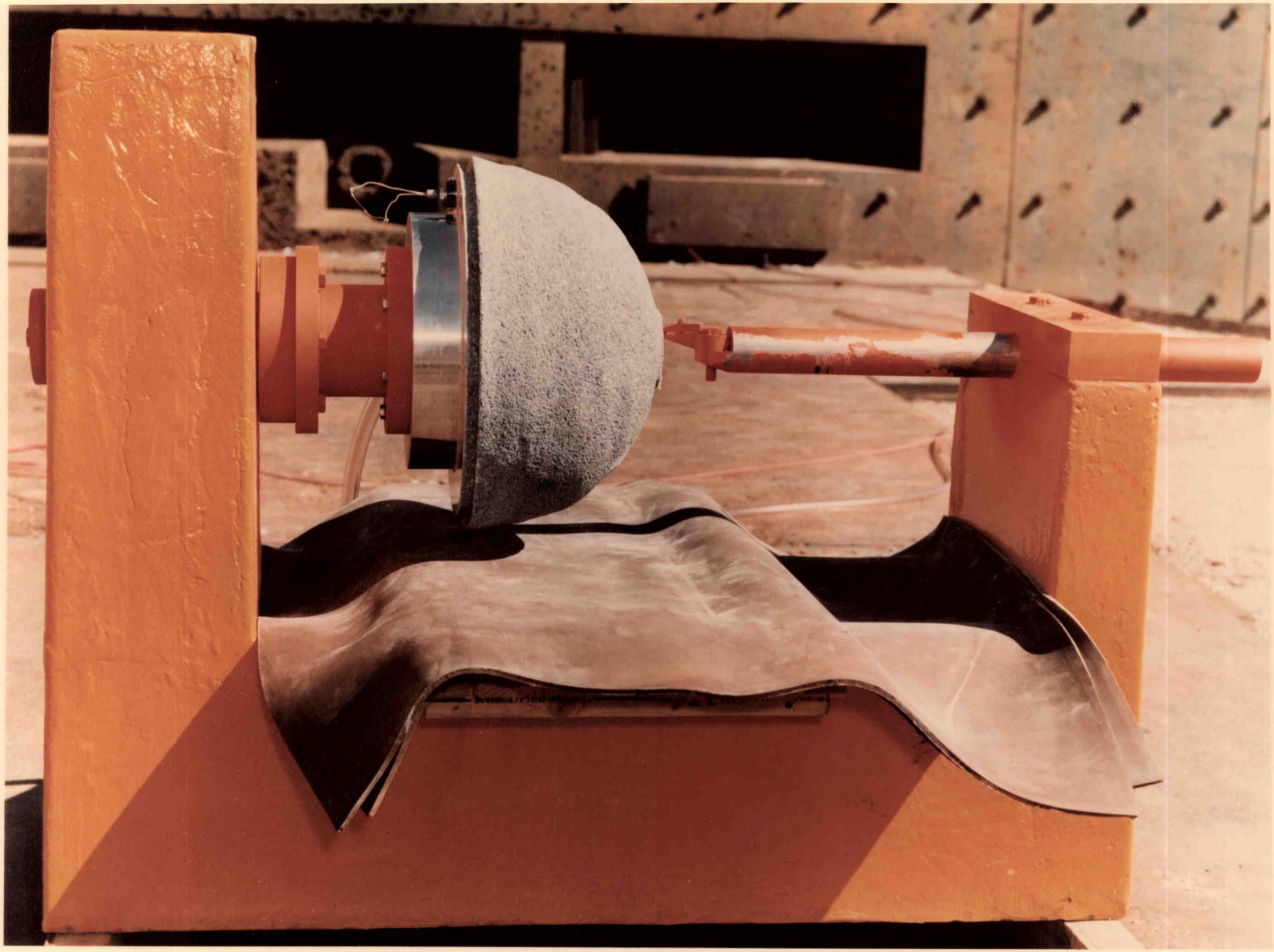

Fig. 25. Typical Test Fire Setup

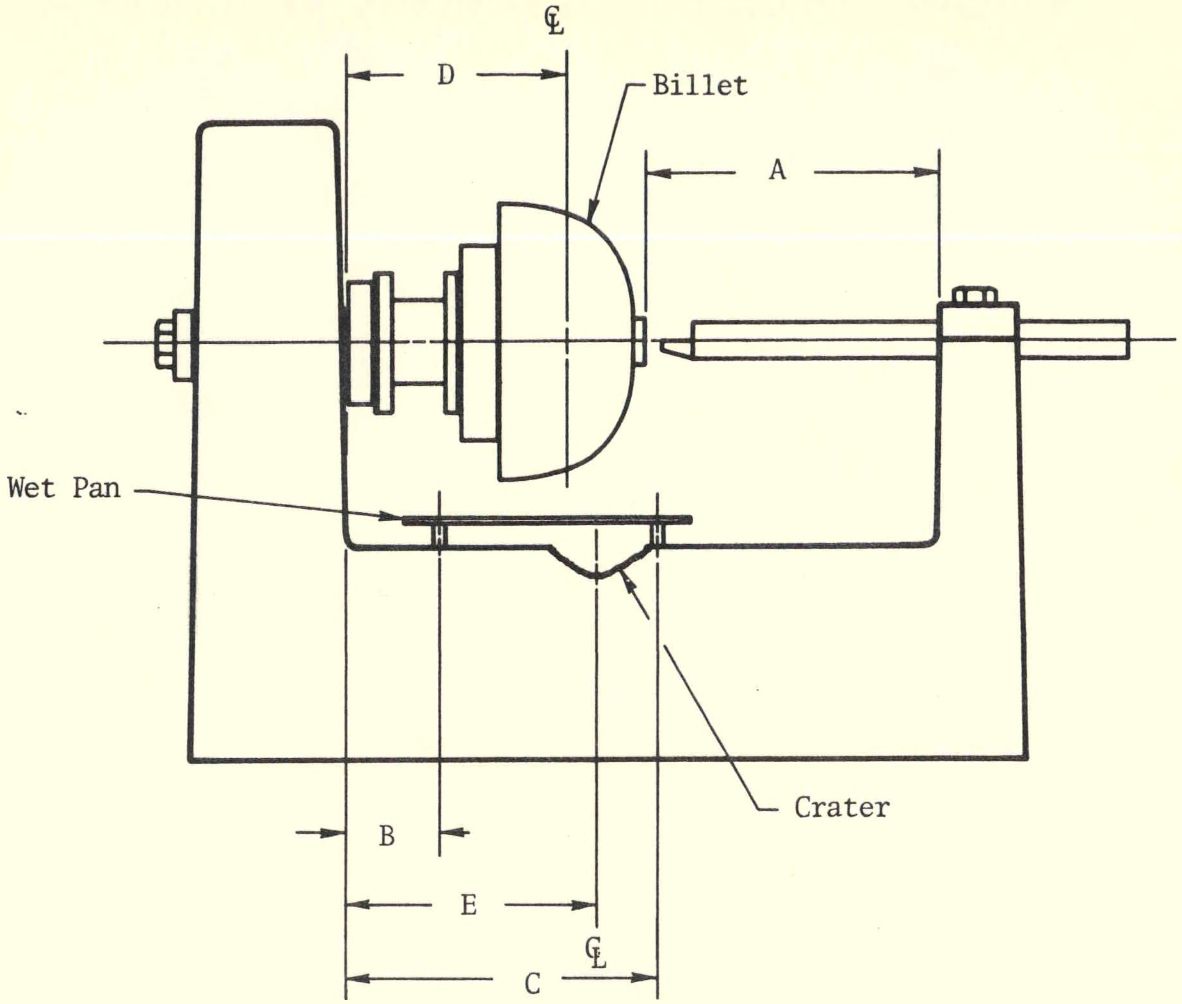

Fig. 26. Pre and Post Shot Dimensions

Table IV. Pre and Post Shot Dimensions

Shot No.	Point of Initiation	Billet (cm)		Set-Up Dimensions (cm)				Post Shot Dimensions		
		Diameter	Height	A	B	C	D	E(cm)	E-D* (cm)	Deflection** (deg)
Incident	N/A	36.2	21.3	36.4	N/A	N/A	53.2***	55.9***	2.7	5.8
1	A	39.4	22.9	40.6	N/A	N/A	32.4	32.7	0.3	2.0
2	B	39.4	22.9	39.7	14.0	44.5	32.4	33.8	1.4	1.6
3	A	39.1	25.4	39.1	12.7	43.2	33.7	34.6	0.9	1.7
4	C	40.6	22.9	40.0	17.8	48.3	32.4	34.3	1.9	3.2
5	B	39.4	21.0	42.5	10.2	40.6	31.5	33.7	2.2	1.9

**Crater displacement from billet centerline toward boring bar end.*

***Angle of Boring Bar - The difference in the angle of deflection of the incident versus tests suspected to be due to the simulated holder which was apparently too weak and broke in all test fires.*

****Point of reference as shown in Fig. 13. Does not correspond to test shots.*

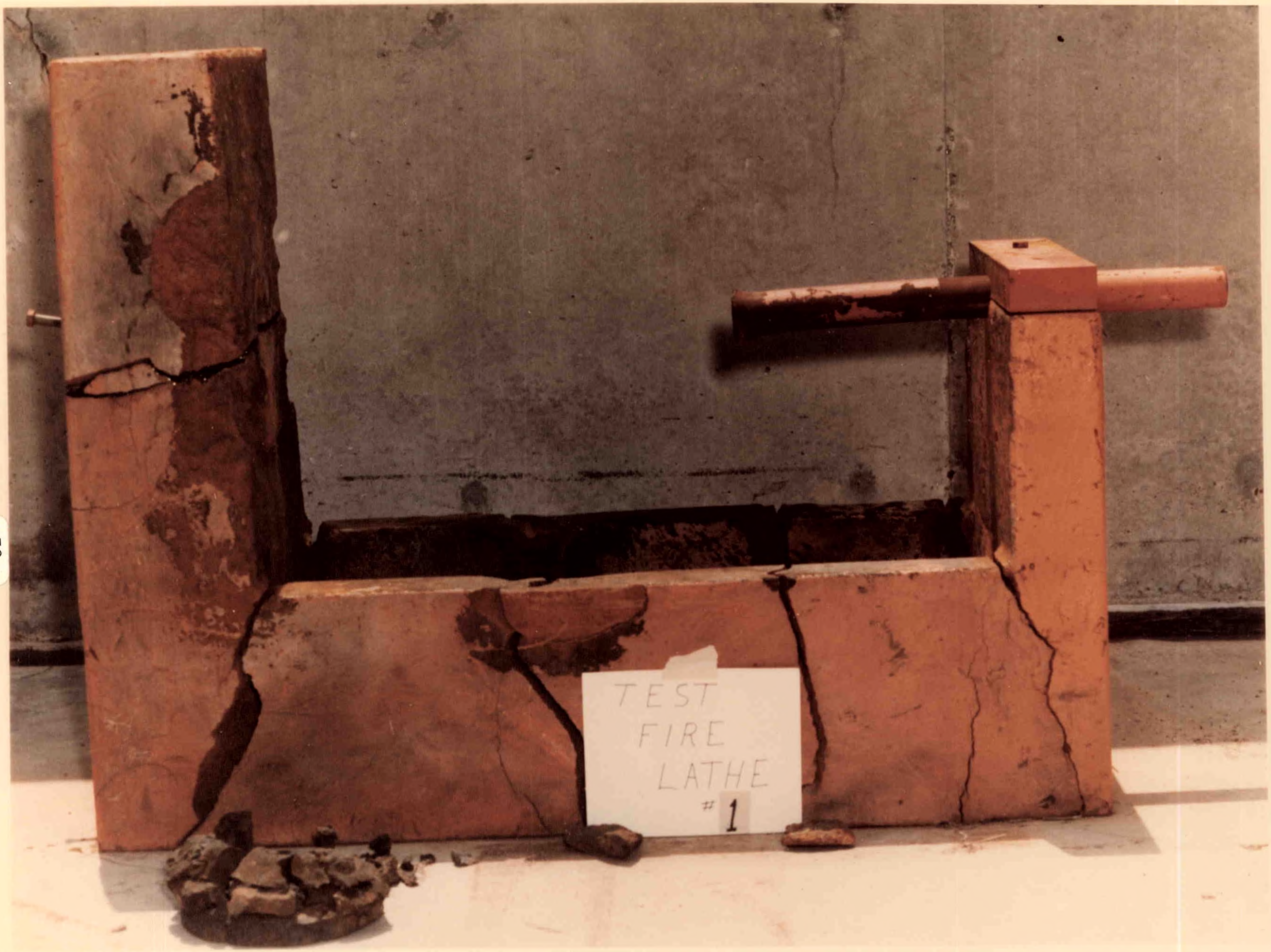

Fig. 27. Crater Produced without Wet Pan

Test No. 3 was a repeat of No. 1 from the standpoint of point of initiation but included the above wet pan addition and mounting shaft modification. More cratering resulted (Fig. 28, typical of all tests with wet pans). Addition of the simulated wet pan did result in more extensive cratering but changes in wet pan location did not seem to affect the crater position. Without exception, all craters were displaced from the billet centerline towards the cutter just as in the incident lathe. Damage to the lathe adaptor was the same as in Test No. 1, again not like the incident, indicating that position A was not the point of initiation in the incident and the hollow shaft was not a significant change. As before the boring bar was bent down but less than in the incident.

Test No. 4 was initiated from position C. Again the boring bar was bent down only slightly and significant cratering occurred using the wet pan. In this test the lathe adaptor was deformed in a generally symmetrical fashion as in the incident but the maximum metal erosion occurred generally in the second quadrant toward the top as shown in Fig. 29 rather than the bottom as in the incident. Considering the point of initiation, the metal erosion area was basically across the billet from the detonator, as one might expect as shown in Fig. 30. In order to move the erosion area on the adaptor to the bottom while initiating from the pole of the billet it would appear necessary to move the initiating point above the center horizontal plane of the billet. However, the cutter (the probable source of initiation in the pole area) is fixed in its horizontal plane. In order for the cutter to be located on the upper half of the billet the billet itself would have to move down or release from the vacuum holding fixture. However, the symmetry of damage to the lathe adaptor would tend to preclude this.

Another sequence of events considered consistent with the damage pattern would require the start of a low order reaction on billet centerline at the cutter followed by rotation of the billet 1/8 to 1/4 revolution before buildup to the explosion making the point of initiation appear to be generally on the top. From the lathe reconstruction, the maximum speed if turning was 140 rpm. At this speed it would take 107 ms for a 1/4 revolution or 54 ms for 1/8 revolution. From skid tests the time lag from initiation to final reaction is approximately 1 ms. It appears highly unlikely that any appreciable rotation could occur before final reaction thereby eliminating this possibility.

Test Nos. 2 and 5 (the second to insure reproducibility) were initiated from position B. Results of the two tests were the same. Again the boring bar was bent down slightly and with the addition of the wet pan significant cratering of the lathe bed occurred. The lathe adaptor deformation was generally symmetrical and the maximum metal erosion areas were on the bottom (Figs. 31 and 32) as in the incident. A general relationship between the point of initiation and the area of maximum metal erosion for Tests 2 and 5 is schematically shown in Fig. 33.

For comparison purposes, all lathe adaptors and boring bars are shown in Figs. 34 and 35, respectively.

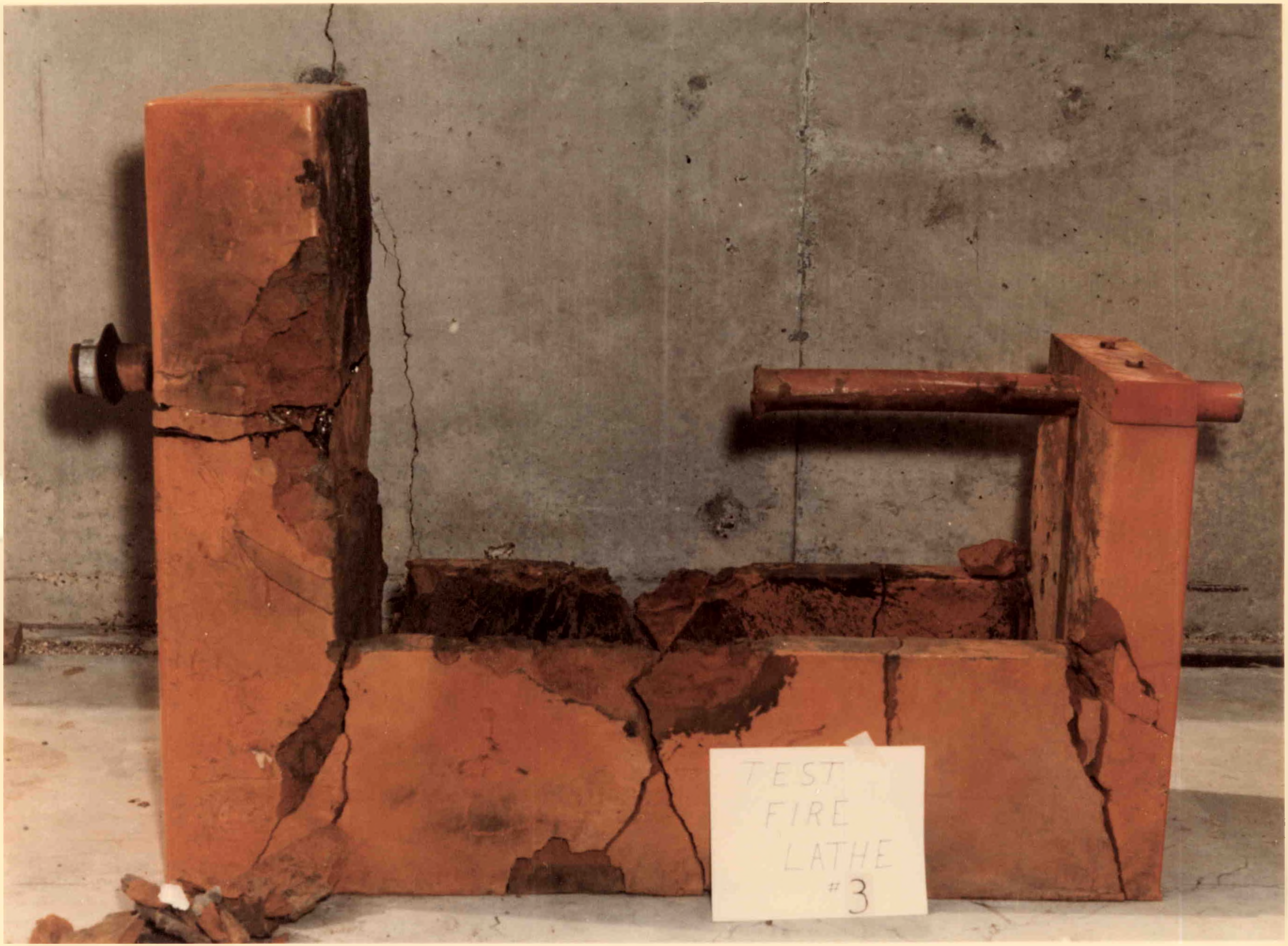

Fig. 28. Crater Produced with Wet Pan

Fig. 29. Test No. 4 Lathe Adaptor (Cutter Initiation Point)

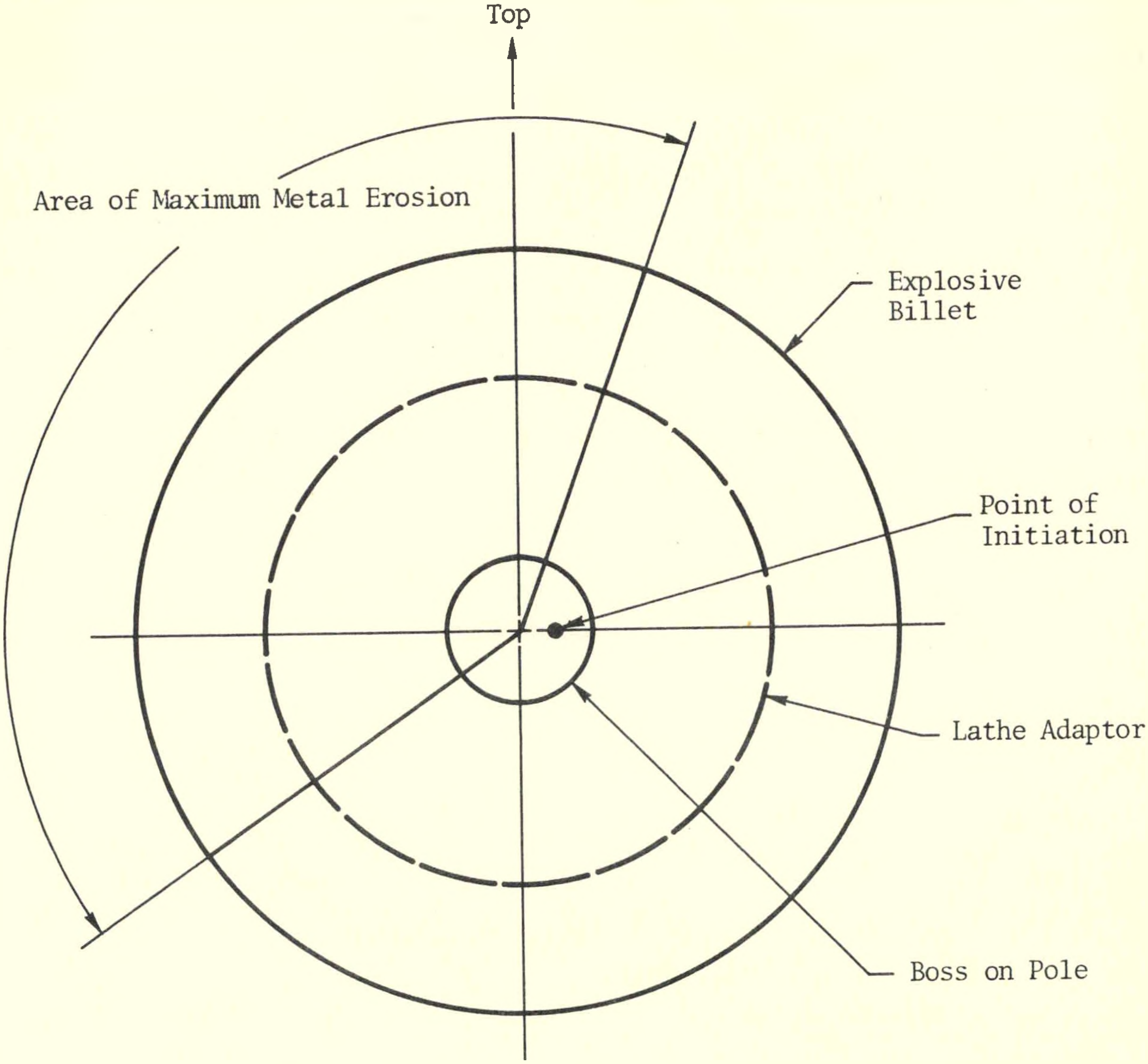

Fig. 30. Test No. 4 Lathe Adaptor and Initiation Point

Fig. 31. Test No. 2 Lathe Adaptor (Mallet Initiation Point)

Fig. 32. Test No. 5 Lathe Adaptor (Mallet Initiation Point)

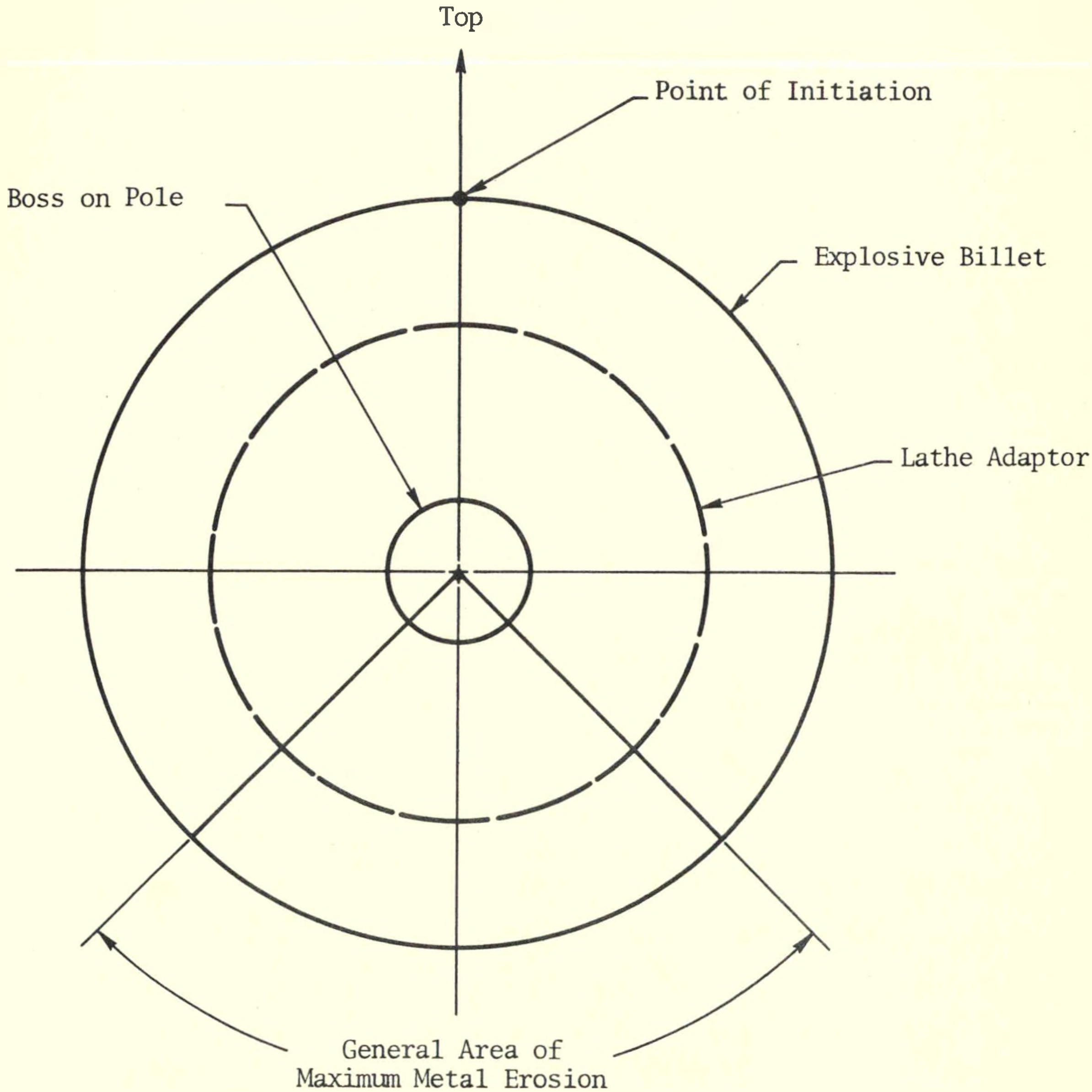

Fig. 33. Test No. 2 and 5 Lathe Adaptor and Initiation Point

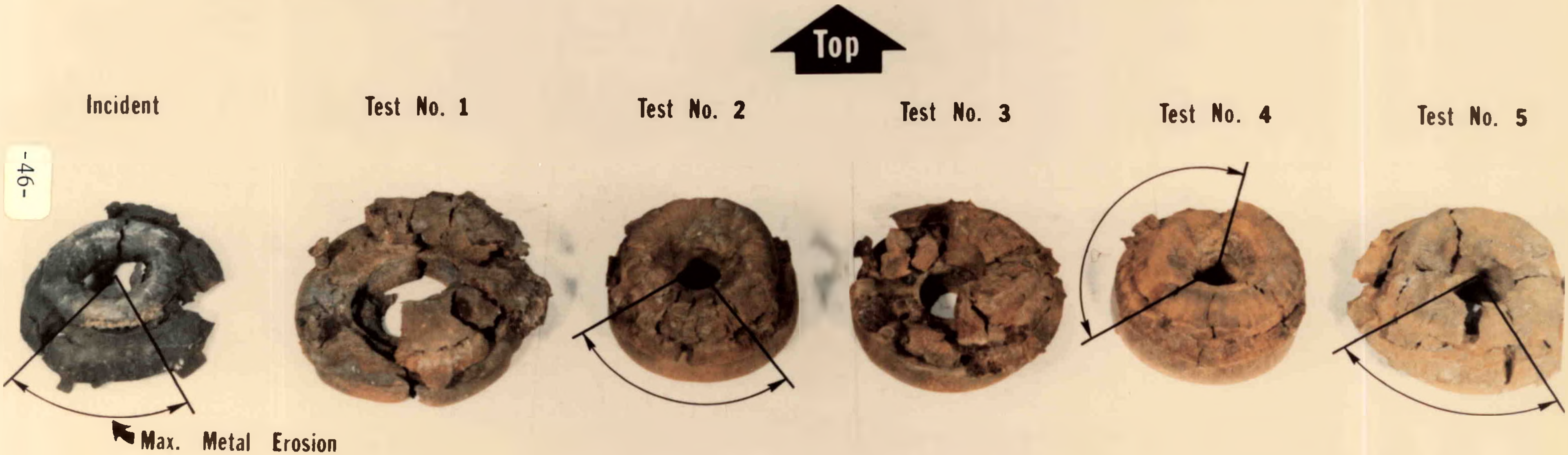

Fig. 34. Lathe Adaptors Comparison

Incident

No. 1 Vacuum Holding Fixture

No. 2 Mallet

No. 3 Vacuum Holding Fixture

No. 4 Cutter

No. 5 Mallet

Fig. 35. Lathe Boring Bars Comparison

CONCLUSIONS

From the results of the lathe simulation test fire series relative to the three damage areas of concern it appears that the lathe adaptor was the most enlightening. All boring bars were bent down slightly regardless of the point of initiation, none as much as in the incident, but because of possible unknown or uncontrollable differences between the simulation and actual incident the exact extent of damage was not considered as important as the general type of damage or damage pattern. All lathe bed craters were displaced slightly from billet center line towards the cutter as in the incident and though the extent of cratering was found to be dependent on the presence of a wet pan the location of the crater was independent of wet pan location. The best duplication of incident lathe adaptor/cam lock damage resulted from the simulation billet initiated at the top circumferential position which is concluded to be the area of initiation in the incident. This conclusion eliminates those possibilities considered requiring initiation on the vacuum holding fixture surface or the cutter position at the billet pole.

Reviewing the original eight possibilities considered during the ERDA investigation and this investigation only three remain that are consistent with the facts developed thus far. These are

1. Initiation during centering of the billet with a mallet.

2. Adjustment of the cutter in close proximity to the billet with explosive in the threads and/or socket of the socket head cap screw being initiated causing subsequent initiation of the billet.

3. Impact of the billet by falling overhead objects.

None of these three possibilities can be eliminated unequivocably. Falling objects are considered highly improbable and beyond the scope of this investigation. Cutter adjustments would require an inadequate concern for cleanliness to allow explosive accumulations in screw heads and/or threads. But mallet impact during centering operations was a standard procedure and hence is considered the most likely of these three, particularly if combined with friction.

Why after so many years of using mallets with explosives would this particular operation result in initiation? The nature of explosives, particularly near threshold, is such that reaction or nonreaction is highly dependent on differences too small to measure. In fact, many sensitivity test results are expressed in terms of probabilities.

Two other tests, the instrumented mallet test and "as-pressed" skid test, were started as a result of this incident. Preliminary results of the instrumented mallet test(*1*), though as yet inconclusive, indicate that the forces generated manually with a mallet are at least in the range of possibilities for causing initiation if additional frictional forces are

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(1) G. T. West, Mallet Impact Test, MHSMP-78-38 (September 1978).

involved, such as a glancing blow or rotation of the billet at the time of impact. The "as-pressed" skid test series still being conducted preliminarily indicates that billets with "as-pressed" surfaces may be more sensitive than machined surfaces making initiation by mallet impact on an "as-pressed" surface a distinct possibility.

Hence, the strongest conclusion considered justifiable from this investigation is that initiation occurred somewhere on the top circumferential surface of the LX-09 billet. Less definitive is the cause for this initiation. But of the three possibilities for initiation on this portion of the billet, mallet impact during centering is considered the most probable cause.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to the numerous contributors to this investigation, particulary those efforts of H. B. Swenson.