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Albuquerque, New Mexico 87185

date: October 21, 2020

to: Leigh Anna Steele, MS-1455 (2556)

Digitally signed by Michael J. Kaneshige
Date: 2020.10.21 16:18:07 -06'00'

from: Michael Kaneshige, MS-1454 (2500)

subject: Safety Review Board review of explosive pressing initiation event

On June 30, 2020, a 0.87 gram PETN charge being pressed in the Rapid Prototyping Facility (RPF), room 1313 of the Explosive Components Facility (ECF; building 905), unexpectedly initiated, resulting in destruction of the pressing fixture but no injuries or facility damage[1,2]. In response to a request from Leanna Minier, manager of organization 2554 at the time, the Explosives Technologies Group (ETG) Safety Review Board (SRB) met on Aug. 13, 2020 and Oct. 1, 2020 to review information collected following the incident, consider likely direct causes, and form recommendations.

The SRB consisted of Michael Kaneshige (2500, chair), Duane Richardson (2554, ret.), David Rosenberg (2555), Mark Anderson (6647), and Jon Vasiliauskas (0622). The SRB review was supported by Rachel Carlson (2554), Cody Love (2552), Ryan Marinis (2554), Shane Snedigar (2554), Ed Finley (0634), Shelley Guard (2557), and Leanna Minier.

Background

RPF work request RPF-200625-01 called for pressing two different types of pentaerythritol tetranitrate (PETN) powder into Sandia Instrumented Thermal Ignition (SITI[3]) flanges using a V31516 (issue C) loading fixture[4]. As shown in Figure 1, the SITI Flange has a tube leading downward from the powder cavity. A steel Pin was placed in this tube to prevent powder from entering the tube. Prior to the initiation event, PETN had been pressed without incident into five other flanges under the same work request. Forty similar operations had been performed with PETN and CL-20 under previous work requests without incident.

[1]DOE Occurrence Report NA—SS-SNL-2000-2020-0002, "Inadvertent Reaction from Pressing Energetic Material," July 14, 2020.
[2]Minier, Leanna M.G.; Romero, Brittni; Braem, Maria; "Occurrence Causal Analysis Report: Inadvertent Reaction During the Pressing of Energetic Material", Sandia report SAND2020-8678R, Aug. 14, 2020.
[3]Drawings provided as attachments are modified versions of part numbers 2A2948 (FLANGE, 0.063 Ullage) and 2A2958 (TUBE FLANGE, 0.063 Ullage) with smaller cavities. A Tube Flange was involved in the initiation.
[4]The loading fixture in use was modified from issue B, except for the flats on the Rams (V31516-400 and V31516-600).

The pressing process begins with loose assembly of all the parts shown in Figure 1. In this configuration, the Ram extends 0.010" into the powder cavity and aligns the SITI Flange, Funnel, and Ram. At this point, the Cap, which is threaded onto the Base, is tightened, clamping the Funnel, Flange, Base, and Cap together. The Ram is withdrawn from the Funnel and powder is loaded into the Flange and Funnel. The Ram is then inserted back into the Funnel and a 0.010" thick shim is placed between the Ram and Funnel so that the resulting pressed powder bed is flush with the top of the Flange (other shim thicknesses are used to achieve desired pressed bed height). The fixture is placed under the ram of a press, in this case a Schmidt pneumatic press with 10,000 lbf capacity, and the operator actuates the press by pushing two buttons outside a shield. This shield is rated for 2.5 g TNT equivalent.

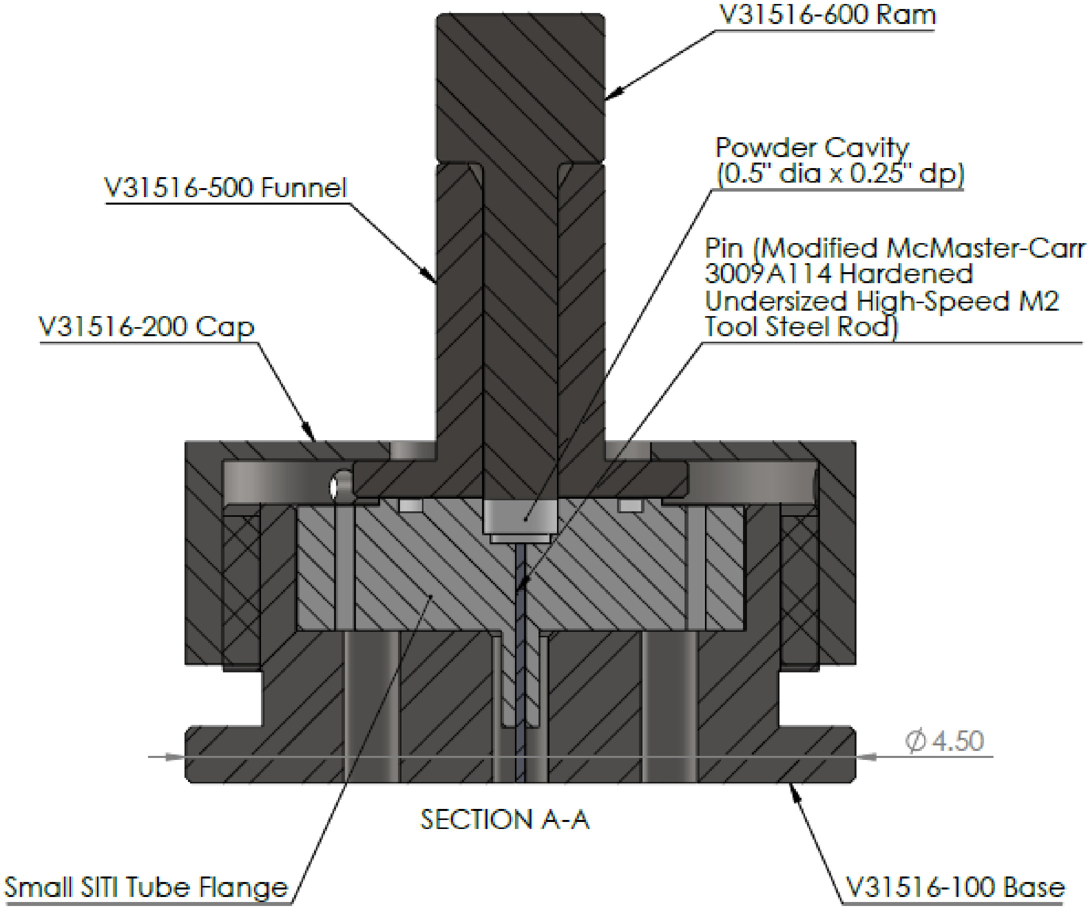


Figure 1. Cross-sectional illustration of a small SITI Tube Flange in a V31516 Loading Fixture.

As described by the operator, the press ram descended onto the loading fixture, the shim moved slightly, a "tink" noise was heard, and the PETN initiated resulting in a loud report, bright flash, and smoke. A safety monitor in the nearby assembly room and a technologist in a neighboring lab heard the event and came to check on the operator, who was startled but not injured. Figure 2 shows the workstation after the event. The loading fixture was externally intact and the shield was undamaged.

Investigation

The SRB and RPF staff identified several hypotheses to guide investigation and analysis including: contamination or unusual sensitivity of the PETN, failure of the press, friction, and misalignment of the loading fixture. Following is discussion of what we found regarding these hypotheses.

The PETN being pressed was from Trackable Unit (TU) 102434, which had previously undergone a battery of analyses (particle size and morphology, surface area, chemical purity, NOx content, and IR/Raman spectroscopy) prior to being pressed. These analyses showed that the material was consistent in all ways with pristine “RR5K”, as expected based on labels and Sandia’s Explosive Inventory System (EIS) description. Although details of the material provenance and pedigree are not known, EIS records indicates that it was received in 1988, and container labels indicate that it was produced in 1971.

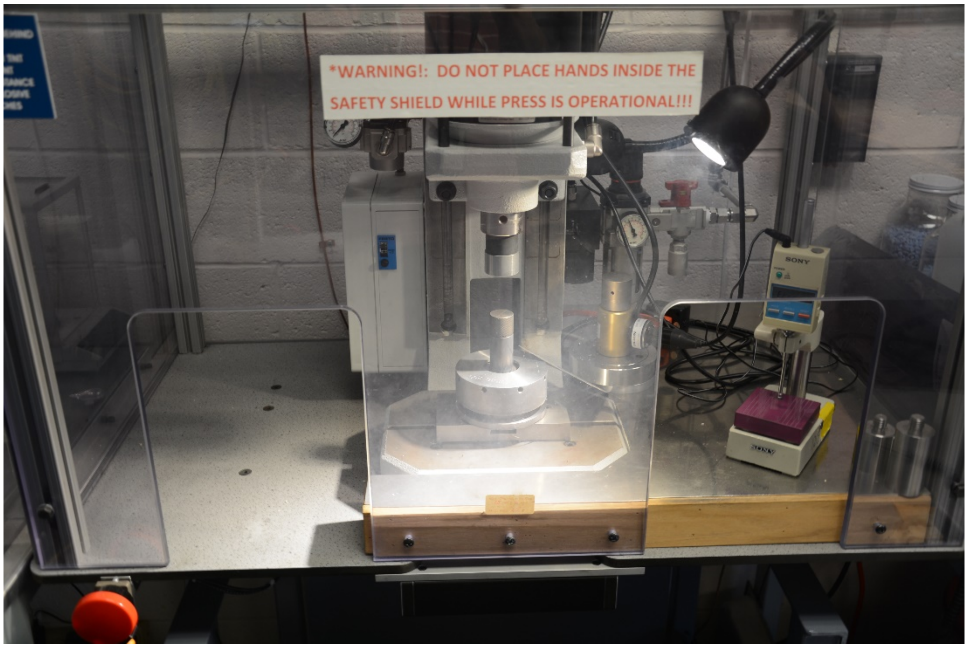


Figure 2. Pressing workstation following the initiation event.

To determine if this PETN is more sensitive than usual, it was submitted to Sandia’s Small-Scale Sensitivity Test (SSST) lab for friction and impact testing. Modified Bureau of Mines (MBOM) impact tests using Type-12 tooling and a 2.5 kg impactor and BAM friction tests were performed on PETN from TU 102434, and Mil-Spec PETN for comparison. As the results in Table 1 and Table 2 indicate, it was found to be somewhat less sensitive to impact than Mil-Spec material, and markedly more sensitive to friction[5]. Baseline sensitivity data for RR5K PETN were not available to the SRB. Significant variability in SSST results is typical, however these results indicate that TU 102434 is notably sensitive to friction.

[5] Jason J. Phillips, “Sandia National Laboratories Small-Scale Sensitivity Testing (SSST) Report: SNL-SSST-20200722, RR5K PETN”, July 22, 2020.

Table 1. MBOM impact sensitivity test results and conditions - Table 3 from Ref. 5.

Material	Test Date	H_{50} (cm)	Temp. (°C)	RH (%)
PETN (mil-spec)	7/22/20	9.6 ± 1.2	22.7	56.0
RDX (mil-spec)*	Multiple	23.3 ± 1.2	21.4	30.6
RR5K PETN	7/22/20	21.9 ± 1.8	22.4	53.7

***Results averaged from multiple test series**

Table 2. BAM friction sensitivity test results and conditions - Table 4 from Ref. 5.

Material	Test Date	TIL, 0 of 20 (N)	Temp. (°C)	RH (%)
PETN (mil-spec)	7/22/20	40	22.6	54.0
RDX (mil-spec)*	Multiple	164	21.6	30.1
RR5K PETN	7/22/20	24	22.4	53.9

***Results averaged from multiple test series**

Some discoloration of the PETN submitted for SSST characterization was noted but not considered by the press operator to be unusual. Contamination (Figure 3), consistent with fibrous filter media and frequently found in explosive powders, was also noted.

Figure 3. Contaminants removed from the RR5K PETN. Fig. 2 from Ref. 5.

The operator reported that the press behaved normally before the incident. Following the incident, the press was evaluated for function and no signs of malfunction or damage were identified as the press continued to reach expected forces with no discernable change in stroke rate. Between the report from the operator and the post-event inspection there is no indication that the press malfunctioned or failed during the operation.

Friction is a concern when pressing energetic materials, so steps are taken to prevent particles from being entrained between sliding surfaces and to reduce the likelihood of initiation of those that are. These include small clearances between Ram and Funnel, smooth surface finishes, cleaning of surfaces to remove residual powder between pressing cycles, and pressing slowly. For instance, the diametral clearance between the V31516-600 Ram and V31516-500 Funnel is 0.0005” to 0.0025” with surface finishes of 16 microinches. Operating procedure ETG-OP-0257, Issue K[6], specifies that powder contact surfaces are wiped before assembly and loading for one press within the RPF, but not two others. Within the RPF, pressing speeds are adjusted to be slow, but not to specific limits.

In order to assess possible misalignment of the loading fixture components and other possible causes of the initiation, the SRB coordinated with RPF staff to disassemble and inspect the fixture. The disassembly process was planned to preserve and capture information regarding orientation, interference, deformation, unreacted PETN, and foreign object debris. The following observations were made during disassembly:

1. The shim had a pattern of soot marks indicating that it was on top of the loading fixture Cap, rather than between the Funnel and Ram, when the initiation occurred (Figure 4).
2. The Cap was visibly bowed upward (Figure 5).
3. Two pieces broke off the Funnel (Figure 6).
4. The Pin was in at least eight pieces inside the powder cavity and on the surface of the SITI Flange (Figure 7).
5. No unreacted PETN was visible.

Figure 4. Shim during disassembly showing soot marks corresponding to spanner wrench holes in the Cap.

[6] Rachel Carlson, “Energetic Powder Pressing Operations,” Explosives Technologies Group operating procedure ETG-OP-0257, Issue K, July 16, 2019.

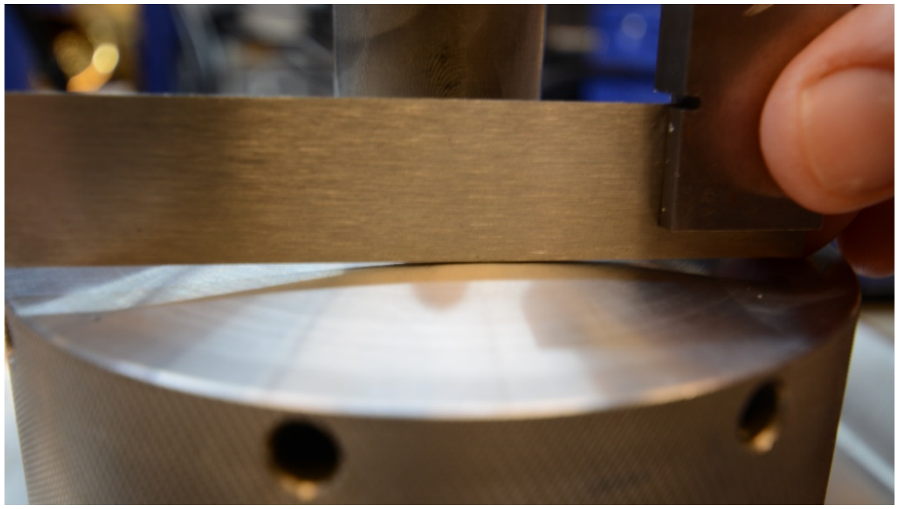


Figure 5. Loading fixture Cap showing curvature resulting from explosion.

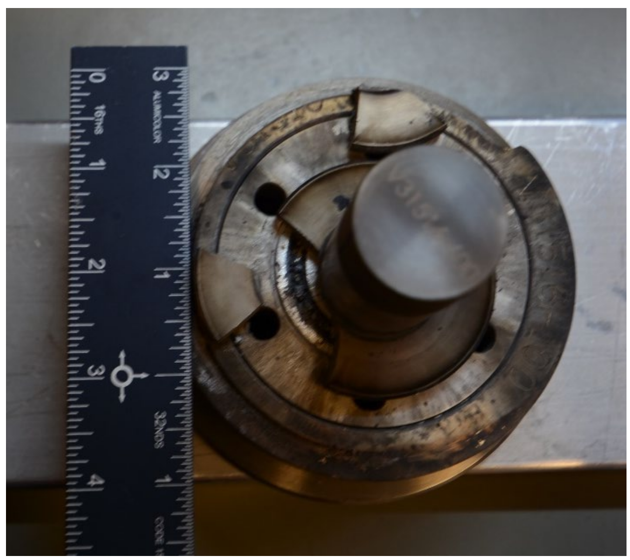


Figure 6. Loading fixture Base, Funnel, and Ram and SITI Flange showing broken Funnel.

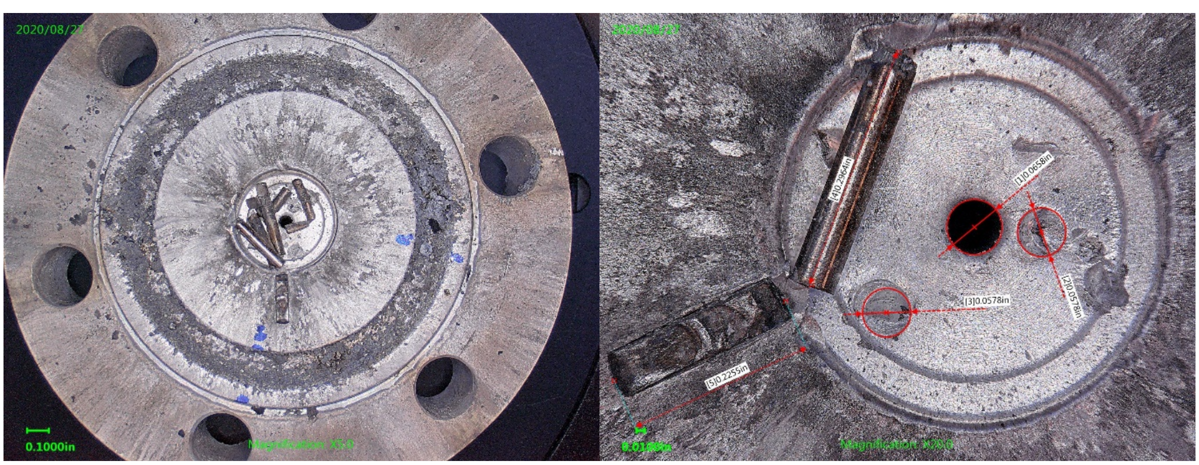


Figure 7. SITI Flange showing pieces of the Pin in the powder cavity and on the surface (left) and indentations in the bottom of the powder cavity (right).

Assessment

The direct cause of the PETN initiation was apparent after disassembly. Finding the broken Pin inside the SITI Flange and between the Flange and Funnel indicated that it was in the powder cavity during the pressing operation rather than in the Flange tube. Apparently, upon compression by the Ram it broke into multiple pieces and created the indentations seen in the bottom of the cavity. The fracture of the Pin likely caused the "tink" noise heard by the operator just before the initiation. The exact mechanism is not known, but initiation of the PETN powder may have occurred when the Pin broke releasing elastic energy, by friction between the Pin and other surfaces, by local heating when the Pin and fragments indented the Flange, or a similar mechanism. In general, foreign object debris (FOD) in a pressing cavity, particularly large metal fragments, is likely to create favorable conditions for initiation.

The SRB considered contributing factors that caused the Pin to inadvertently be inside the powder cavity during pressing. The most likely cause was suction created when the Ram was withdrawn from the Funnel after alignment. While this had not been observed in previous iterations, several factors can affect whether it happens in a particular instance:

1. Rate of withdrawal of the Ram. The faster the Ram is pulled out of the Funnel, the more suction is created due to restricted air flow into the Funnel and SITI Flange around the Ram and Pin. Since this is a manual operation, the rate varies and can increase over time with operator familiarity.
2. Pin clearance. While clearance around the Ram is intentionally small as described above, and consistent, clearance around the Pin is relatively variable. The Pin diameter has a tight tolerance (0.0002" total), but the Flange hole diameter does not (0.010" total), and the fit has been found to vary significantly. Variations in clearance with different Flanges will result in variations in air flow, suction, and likelihood of the Pin being pulled up into the powder cavity.
3. Tape on the bottom of the fixture. In previous series, adhesive tape was applied to the bottom of the loading fixture to prevent the Pin from falling out during movement, and this may have also prevented it from being sucked up into the cavity. Tape was not used during the series that led to the incident.
4. Lack of flats on the Ram. Issue C of V31516 added three "flats" on the sides of the Ram to reduce air flow resistance when the Ram was inserted or withdrawn from the Funnel. When other modifications were made to the hardware, the flats were deferred and were not added before the incident. They could have reduced the amount of suction and prevented the Pin from being pulled up when the Ram was removed.

In addition, we note that the lack of a positive control on the position of the Pin created the possibility of it being pulled into the cavity. If the Pin was constrained, the contributing factors described above would not have mattered.

Prior to disassembly, misalignment of the Funnel and Flange was considered a likely contributing factor. Interference between the Ram and SITI Flange would result in sliding friction, plastic deformation, or fracture of the aluminum flange resulting in local heating. Alignment relies on 0.010" of engagement between the Ram and SITI Flange and clamping force between the threaded Cap and Base. Review of the SITI Flange drawings found that the edge of the powder cavity is specified to be broken (chamfered) between 0.005" and 0.010". This reduces the effectiveness of the alignment process. However, misalignment resulting from this broken edge will not cause interference between the Ram and SITI

Flange. Furthermore, the shim prevents the Ram from extending past the Funnel and interfering with the SITI Flange. Therefore, in order for the Ram to interfere with the SITI Flange, more than one of the following must happen: alignment is not performed, the Cap is not tightened sufficiently onto the Base allowing the Funnel to move, or the shim is not between the Ram and Funnel at the end of the press stroke.

Conclusions

The primary conclusion of the SRB is that the direct cause of the initiation of PETN was the presence of FOD (the Pin) inside the Funnel and SITI Flange during pressing.

While design changes and administrative controls can be implemented to prevent this in the future, the energy involved in pressing makes elimination of the risk of initiation impossible. The Sandia Explosives Safety Manual (6.4.1) includes pressing as an example Class I activity, requiring "protection to prevent serious personal injuries to personnel performing the activity and personnel in other occupied areas. This protection can be achieved by controlling blast and debris through suppression, containment, or establishing an exclusion area with positive access control."[7] That is, operators must be protected from the consequences of initiation, regardless of the likelihood because the likelihood cannot be made negligible. Identification and elimination of likely causes of this incident should contribute to safer and more efficient future operations but engineered controls such as shielding and two-hand press controls are necessary to mitigate the effects of inadvertent initiations.

Recommendations

Following are recommendations to the RPF for potential improvements to the operation that the SRB believes will decrease the likelihood of a similar event. These recommendations are specifically applicable to the V31516 Loading Fixture, but may also be beneficial to some other applications.

1. Provide and use a mechanism for repeatable alignment of the Loading Fixture under the Press. Although misalignment is not believed to have contributed to this incident, it can lead to uneven force, damage to fixture components, or the fixture "kicking out" from under the press.
2. Use a spanner wrench to tighten the Cap during alignment. This will help prevent the Funnel from moving relative to the Flange after alignment.
3. Create and use an Alignment Ram, similar to but longer than the pressing Ram (V31516-600) to provide greater engagement with the SITI Flange. One flat extending to the end will prevent suction when the Alignment Ram is removed.
4. Modify the pressing Ram design by removing the flats and changing the surface finish from 16 to 4 microinches. The flats are unnecessary if the Alignment Ram is used, and a finer surface finish will reduce friction and facilitate cleaning.
5. Fabricate and use "Donut" Shims in place of the U-shaped shims used previously. By capturing the Ram, these Shims will not be able to fall off the fixture.
6. Replace the constant diameter Pin with a Step Pin with a larger diameter below the SITI Flange tube. Such a Step Pin cannot be pulled into the powder cavity.
7. Control the SITI Flange tube inside diameter to a precision similar to that of the Pin for a consistent close fit. In addition to maintaining consistent air flow characteristics around

[7] Danton Humphries, Sandia MN471011, Explosives Safety Manual, Issue R-2, Dec. 21, 2016.

the Pin, this will consistently prevent powder from entering the gap around the Pin where it could be initiated by friction when the Pin is removed.

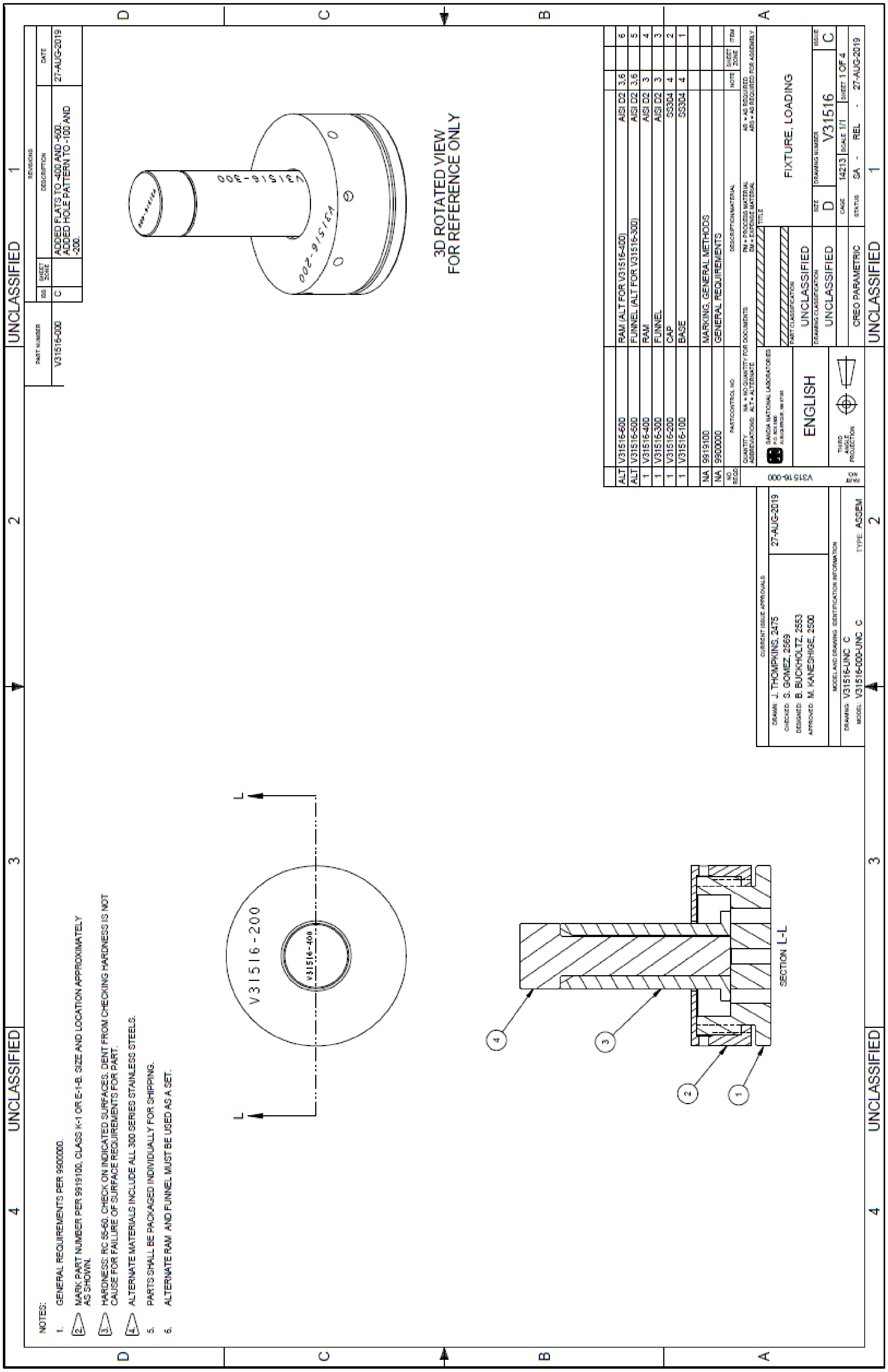
8. Visually inspect the powder cavity for FOD before loading powder. This can be accomplished with a borescope or similar device and will be effective for any type of FOD or gross misalignment in many pressing fixtures, not only the V31516 Loading Fixture.
9. Modify ETG-OP-0257 to specify cleaning of pressing fixture powder contact surfaces before each use. This will reduce the likelihood of friction initiation by removing residual powder.

Attachments:

V31516, “Fixture, Loading”, Issue C

ibFlange drawing

ibTube Flange drawing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NOTES:
1. GENERAL REQUIREMENTS PER 9900000.
2. MARK PART NUMBER PER 9919100, CLASS K-1 OR E-1-B. SIZE AND LOCATION APPROXIMATELY AS SHOWN.
3. HARDNESS: RC 55-60. CHECK ON INDICATED SURFACES. DENT FROM CHECKING HARDNESS IS NOT CAUSE FOR FAILURE OF SURFACE REQUIREMENTS FOR PART.
4. ALTERNATE MATERIALS INCLUDE ALL 300 SERIES STAINLESS STEELS.
5. PARTS SHALL BE PACKAGED INDIVIDUALLY FOR SHIPPING.
6. ALTERNATE RAM AND FUNNEL MUST BE USED AS A SET.
V31516-200
V31516-400
SECTION L-L
3D ROTATED VIEW
FOR REFERENCE ONLY
PART NUMBER V31516-000
ADDED FLATS TO -400 AND -600. ADDED HOLE PATTERN TO -100 AND -200.
27-AUG-2019
ALT V31516-600 RAM (ALT FOR V31516-400) AISI D2 3,6 6
ALT V31516-500 FUNNEL (ALT FOR V31516-300) AISI D2 3,6 5
1 V31516-400 RAM AISI D2 3 4
1 V31516-300 FUNNEL AISI D2 3 3
1 V31516-200 CAP SS304 4 2
1 V31516-100 BASE SS304 4 1
NA 9919100 MARKING, GENERAL METHODS
NA 9900000 GENERAL REQUIREMENTS
DRAWN: J. THOMPKINS, 2475
CHECKED: S. GOMEZ, 2569
DESIGNED: B. BUCKHOLTZ, 2553
APPROVED: M. KANESHIGE, 2500
27-AUG-2019
SANDIA NATIONAL LABORATORIES
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DRAWING NUMBER V31516
ISSUE C
CAGE 14213
SCALE 1/1
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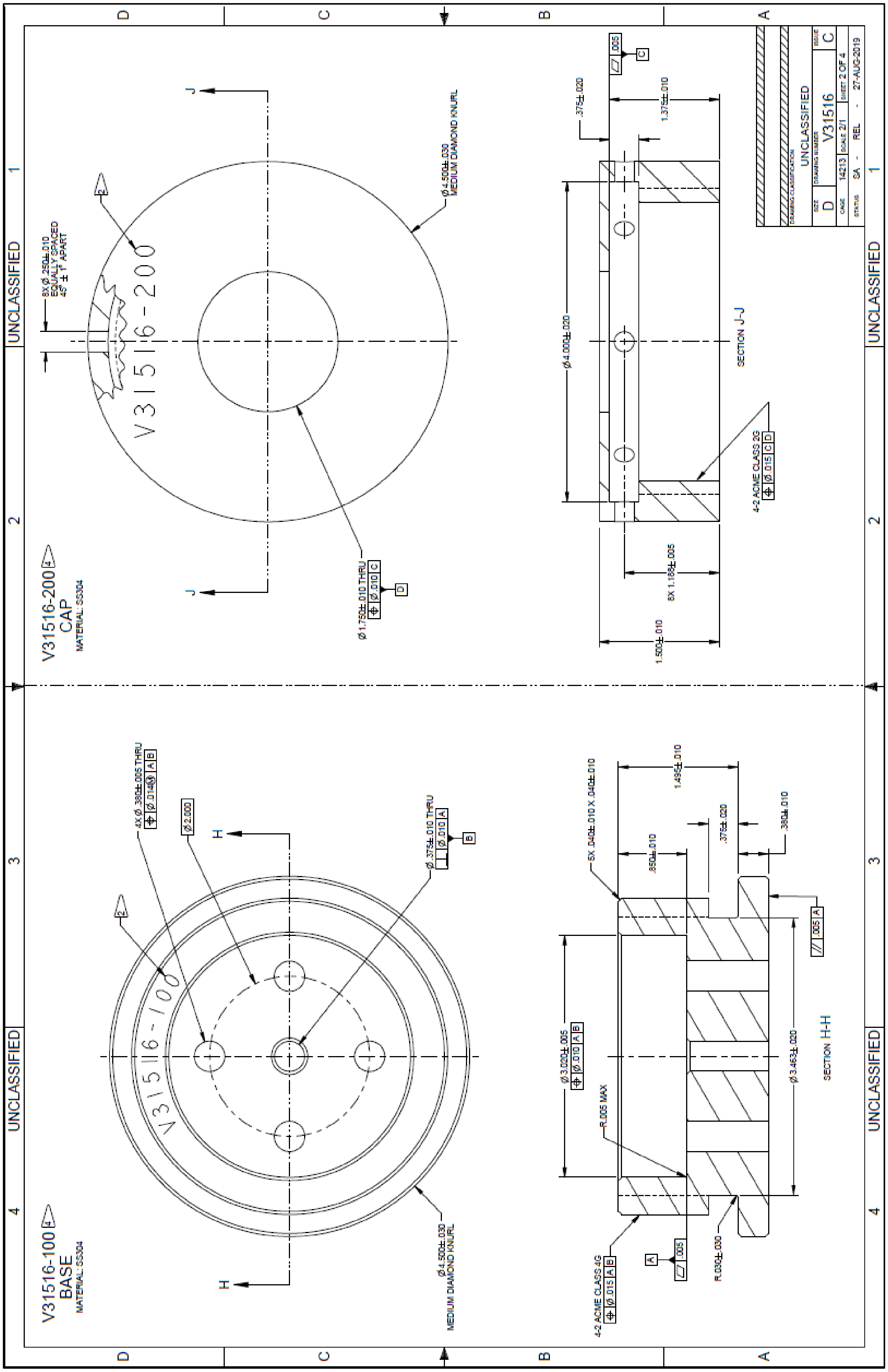
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14213
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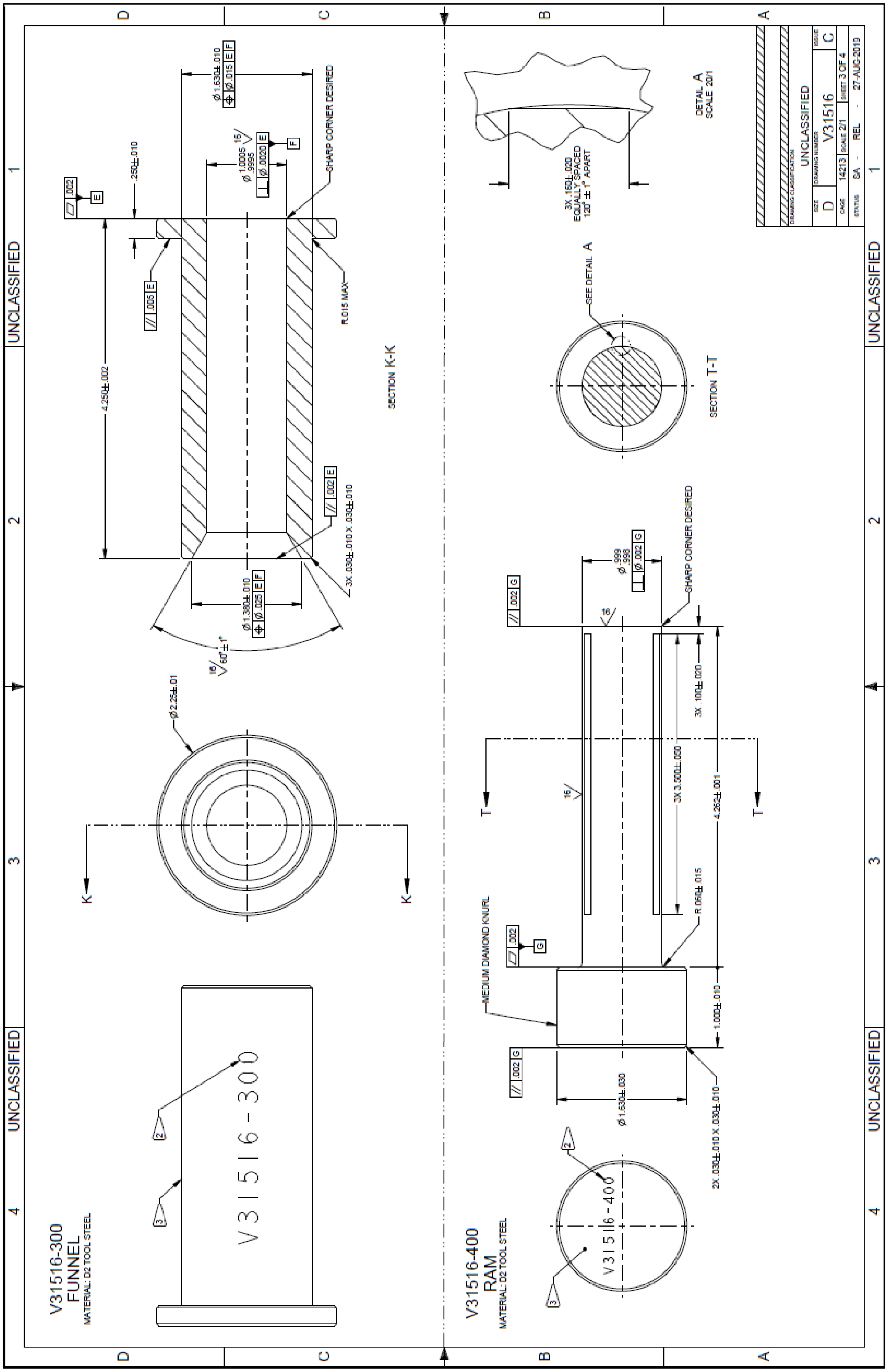
27-AUG-2019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V31516-400
RAM
MATERIAL: D2 TOOL STEEL
V31516-400
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SECTION T-T
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DETAIL A
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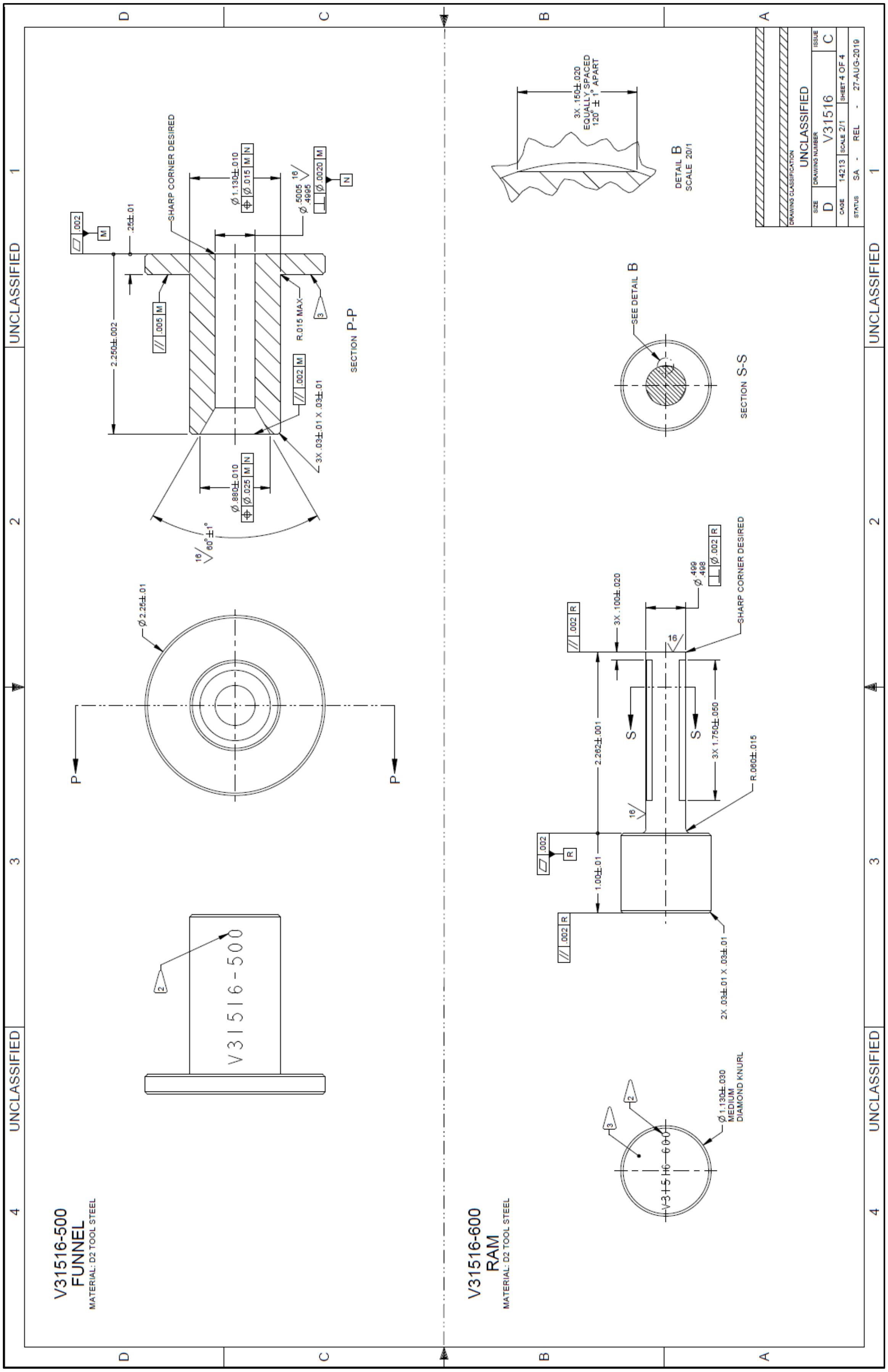
27-AUG-2019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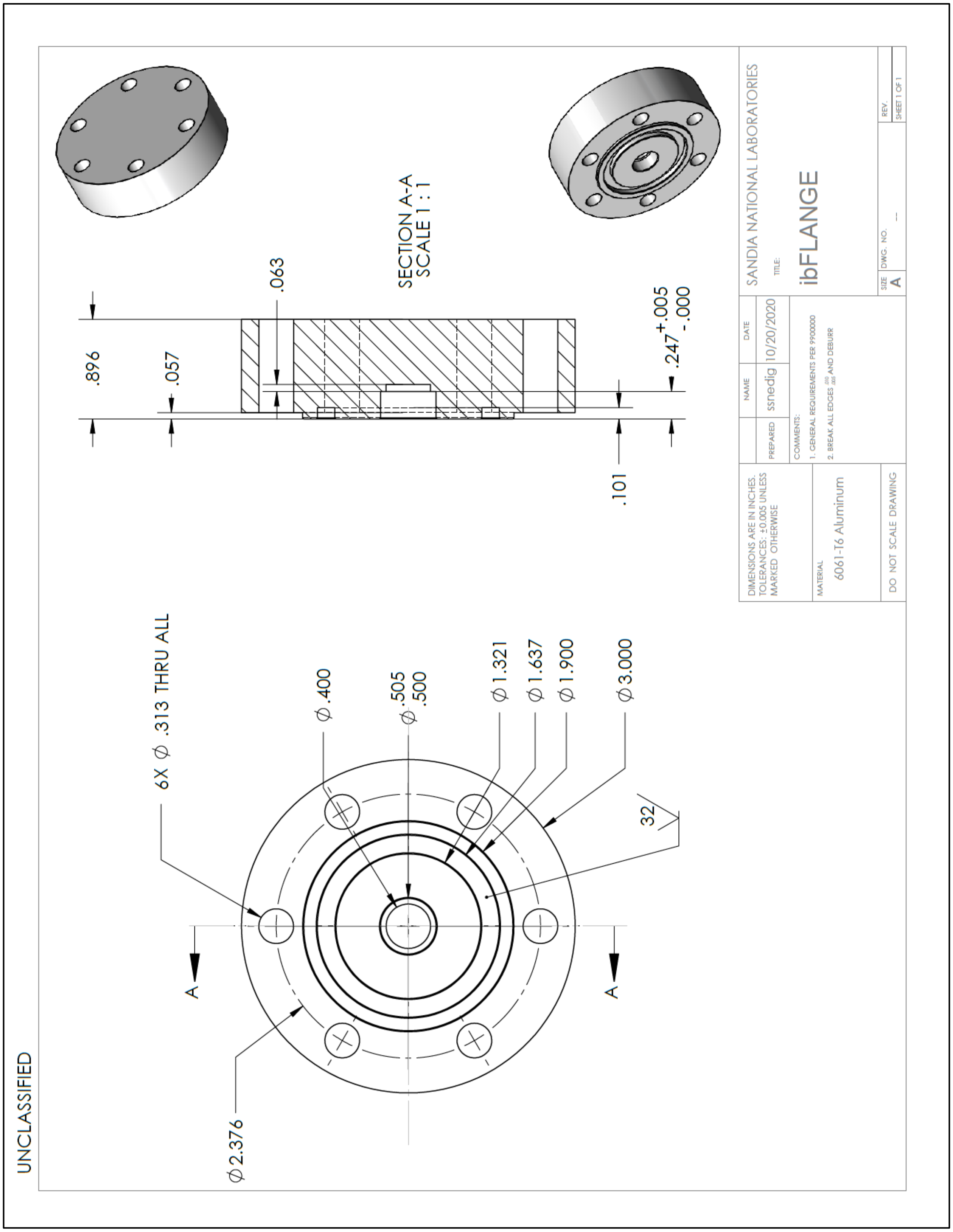
27-AUG-2019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∅ 1.900
∅ 3.000
∅ 2.376
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SANDIA NATIONAL LABORATORIES
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ssnedig
10/20/2020
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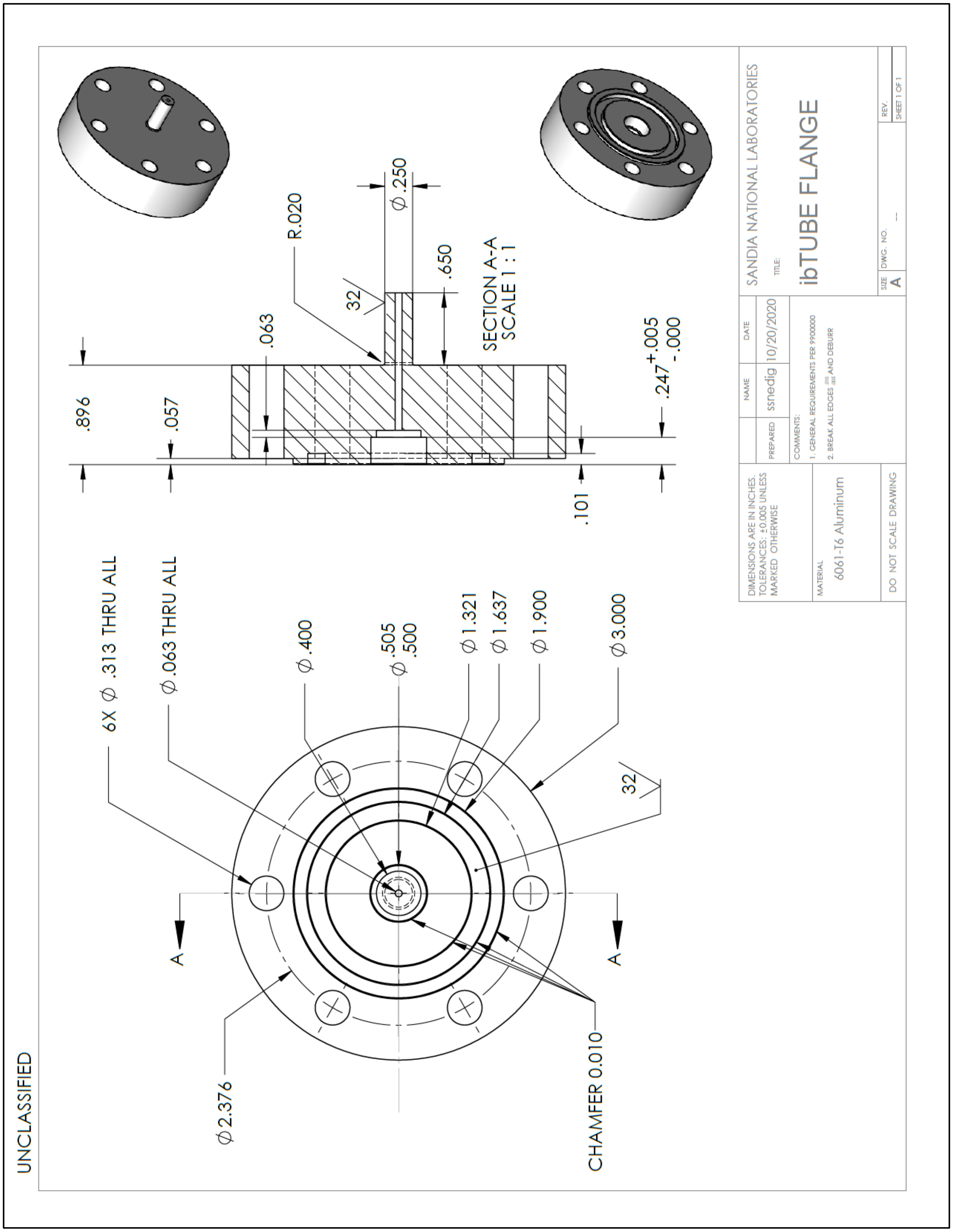
REV.
SHEET 1 OF 1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