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SUMMARY OF GRANULATION MATRIX TESTING FOR THE PLUTONIUM IMMOBILIZATION PROGRAM (U)

September 21, 2001

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INTRODUCTION

In FY00, a matrix for process development testing was created to identify those items related to the ceramic process that had not been fully developed or tested and to help identify variables that needed to be tested. This matrix, NMTP/IP-99-003, was jointly created between LLNL and SRTC and was issued to all affected individuals. The matrix was also used to gauge the progress of the development activities. As part of this matrix, several series of tests were identified for the granulation process. This summary provides the data and results from the granulation testing. The results of the granulation matrix testing were used to identify the baseline process for testing in the PuCTF with cold surrogates in B241 at LLNL.

BACKGROUND/GRANULATION OBJECTIVES

The granulation step in the plutonium immobilization process is being performed to agglomerate the fine particles of ceramic oxides and actinide oxides that have been milled and blended in the attritor. Through granulation, the fine particles are agglomerated into larger clusters to improve powder properties. Most important of these are improved flowability, decreased dustiness, and increased powder bulk density. These properties are important for ensuring that die filling is reproducible and for minimizing the amount of dust released into the glovebox since the powders are not contained during pressing. For the granulation matrix testing, these properties were considered in measuring the success of the test variable.

POWDER PREPARATION

LLNL procedure TIP-PD-02, "Fabricating Surrogate Plutonium Ceramic Pucks – Plant Prototypical Process", was used to fabricate the batches of material. Each batch of material fabricated was documented on a batch data sheet. The batches were fabricated in individual 1.5-kg precursor lots and lots were combined as needed to produce the nominal feed batch. All precursors were wet ball milled, dried, size-reduced, and then calcined. If the granulation test required the addition of a binder to the precursors, it was added using wet ball milling. The powder was then again dried and size-reduced. The precursors were then blended in the attritor with the appropriate amount of cerium oxide or the appropriate amounts of cerium and uranium oxides. If the granulation test required the addition of the binder during mixing/blending, it was added to the attritor with the other feed materials. Acrawax C was used when a dispersant was necessary in the attritor.

In some cases, the granulation gave very poor results and the powder was re-used in another test to minimize material and labor costs. If water was the binder added during granulation, then the powder was dried and re-attritored to break up the particles. If an organic binder was added during granulation, then the powder was heated in the calcine oven to a minimum of 450°C to ensure that the binder had burned off and the powder was re-attritored to break up the particles. When these powders were used and gave spurious results, testing was repeated as necessary with fresh powder to verify results since a slight difference in powder behavior is seen because of the smaller particle sizes and slight binder residue.

GRANULATION TESTING

Granulation matrix testing was performed using the baseline production process with cerium oxide as a surrogate for the plutonium and uranium oxides. Verification testing was also performed with uranium to confirm and further optimize the processing parameters. The 10.5 wt% plutonium composition was used in the testing since the studies were initiated before the formulation was officially changed. The matrix given in document NMTP/IP-99-003 was used to provide the guidance for the parameters and variables to be tested.

Most of the granulation testing was performed in the research and development labs in B241 at LLNL using the laboratory-scale 8-quart GEMCO granulator. However, testing that was performed to determine the optimal batch sizing used the larger PuCTF granulator. Copies of the granulation data sheets will be stored in a three ring binder labeled "Granulation Matrix Data Sheets", which will be archived with other data from the program.

Parameters Tested

Parameters investigated for this study included the following:

- Binder type, amount, and addition point;
- Maximum capacity of the granulator;
- Use of the Agitator;
- Lubricant type and amount; and
- Necessity for drying.

As these parameters were tested, they were verified with the nominal batch size and with powders containing uranium oxide. Uranium containing powders had previously been shown to behave differently during granulation; thus, verification of the parameters was considered essential. Originally, it was planned to use manganese oxide for some of the verification testing, but due to the disposal problems of this material, the use of uranium oxide was considered adequate.

Other parameters that were investigated during the study but that were not completely resolved included the following:

- Type and size of nozzle;
- Nozzle position;
- Rate of binder addition;
- Vessel speed;
- Process time; and
- Powder temperature.

Since these parameters were felt to be equipment size dependent, they could not be finalized until testing with full-scale equipment was performed. The studies documented here give a synopsis of the optimum parameters for the lab-scale equipment, which should serve as the starting point for the development of the parameters for the full-size equipment.

Appendix A is an excerpt from the overall process development matrix, but contains a status of the granulation matrix parameters only. This matrix provides a concise summary of the studies performed.

Binder Type, Amount, and Addition Point

A total of seven different binders were selected for the granulation matrix testing. The binder type was selected based on the results from Test #9 and #10 of the Form & Process Development Task Plan (PIP-TP-98-001), which was performed at LLNL. Although seven different binders were selected, the number of tests was much larger due to the additional variables of the amount of binder (both binder concentration and actual addition amount), addition point for the binder, and the combination of binders. Forty-five different variables were tested with respect to the binder parameter. Appendix B gives a summary of the combinations tested, along with the precursor / powder batch ID.

In these original binder tests, the same nozzle size and pattern was used throughout; however, spraying water used a different size nozzle than organic binder. The agitator arm was not used and process time was kept constant at 30 minutes.

As mentioned earlier, uranium oxide was used for verification testing. Binder combinations / concentrations that seemed promising were tested with uranium oxide, and Appendix C identifies those binders and precursor / powder batches that were tested with uranium.

Maximum Capacity

The larger-scale PuCTF granulator was used to perform a series of test to determine the maximum capacity of the granulator. The PuCTF granulator is nominally rated for 10-kg (or ~10 liters) processing but will accommodate much larger quantities. Batch size was increased in 2-kg increments up to 18-kg to determine an optimal and maximum batch size from a processing perspective. The same performance measures investigated for the binder testing were used to ascertain the quality of the product produced.

Use of the Agitator

The GEMCO tumble granulator selected for lab-scale and PuCTF testing came equipped with an agitator bar to help with mixing of the powder being processed. Preliminary studies showed that use of the agitator during binder addition helped to disperse the binder. However, the use of the agitator presented additional maintenance issues because of the extra seal required and additional support equipment. Therefore, one of the parameters examined was whether the agitator was beneficial to processing. The agitator was only investigated for use during binder addition. The same performance measures investigated for the binder testing were used to ascertain the quality of the product produced. It was determined that the agitator gave no significant advantages to powder processing during granulation and its use was discontinued.

Lubricant Type and Amount

When the process development matrix was created, it was not certain whether a lubricant would be necessary during pressing to avoid creating undue stress on the pucks. Lab-scale studies to date had shown that some of the binders would require the addition of a lubricant, while others would not and nothing was known about the effect in the fully-automatic press. With each binder system tested, pressing was evaluated to determine if lubricant would be necessary. However, no extensive testing with lubricants was performed because the more optimal binder systems did not require any additional lubricant to be added. Should a lubricant prove to be necessary in the future, the results from Test #15 of the Form & Process Development Task Plan (PIP-TP-98-001) showed that a small amount (<1 wt% total) of Acrawax C added to the powder would greatly reduce the stresses created during ejection of the puck from the press.

Necessity for Drying

An additional option for the GEMCO granulator is a heated shell to dry the product. In this configuration, the GEMCO is called a "Formulator" and product can be heated to drive off any excess moisture. This equipment was tested at the vendor and in early development studies. However, as testing with the normal configuration progressed, the need for drying the granulated product was eliminated because of the acceptable product obtained.

Other Parameters

Most of the testing performed for this matrix used a nozzle with a fan spray pattern with two different size openings. The size selected gave the lowest hold-up and best granulated product for the nozzles tested. Some preliminary testing was performed with the use of a cone-shaped nozzle, but problems with over-spray were seen with binder solutions. However, the limited testing did indicate that water spray with the cone-shaped nozzle was effective. The nozzle type and size is one of the parameters that will be spray arm location dependent and also very dependent on the binder solution; therefore, the final selection should be performed with equipment that is representative of the plant-size, process, and configuration.

As alluded to in the previous paragraph, the nozzle position will also strongly impact the hold-up and resulting granulated product. For the granulation matrix testing, very little work was performed with changing the nozzle position. For the lab-scale granulator (i.e., nominal 8 qt working volume), the nozzle arm was slightly off of center such that the powder was sprayed before the tumbling process was initiated. The nozzle position is another parameter that should be tested in the plant-prototypical equipment.

The rate of binder addition was kept fairly constant within binder concentrations tested, but was varied with the different binder types and amounts to try to optimize the spray pattern. It was mainly controlled through the setting of the pump, however, in plant production, this should be controlled using a metered rate. Rates of binder addition are

given for the different tests. However, this is another parameter that will have to be optimized with the plant-prototypical equipment.

The initial vessel speed was kept at a maximum from test to test and during binder addition. The speed of tumbling was varied with different binders because of the flow characteristics of the powder depending on the binder. The vessel speeds for the lab-scale test unit were used to calculate the vessel speeds for the PuCTF unit and should also be used as a starting reference for the plant-prototypical equipment.

Initial process time was 30 minutes for all testing. However, after a significant portion of the testing was performed, it was determined that shorter process times would result in less hold-up in the vessel and less degradation of the soft granules. Using the acrylic lid, it was observed that the powder reached an optimal characteristic and then the material would start clinging to the sides of the vessel with additional tumbling time. Therefore, the process time was reduced such that the process was ended after the powder appeared to be fully granulated and before the material started accumulating on the sides of the vessel. For the lab-scale unit, this was about 10 minutes of total process time, while the PuCTF unit required about 20 minutes of process time. This of course will have to be optimized with the plant-scale unit.

Powder from the attritor has an elevated temperature due to the high-energy exerted on the powder during milling/blending. Some of the tests used powder that was directly transferred from the attritor into the granulator. With some of the binders, this resulted in excessive hold-up in the vessel due to steam generation in the vessel. For the matrix testing, the powder used was at room temperature to eliminate this variable. Limited testing in the PuCTF granulator was performed to try to determine the maximum processing temperature. However, these studies were not completed and additional testing will have to be performed in the plant-prototypical equipment to determine the upper temperature limit for powder processing.

Granulated Powder Testing

Powders produced were compared based on the flow and dust characteristics, the particle size distribution (including general product appearance), the puck quality, and Powder Test Center data. The methods used for the comparison are described below, along with discussion of the results. Although not directly related to powder properties, the amount of hold-up left in the vessel was also a critical parameter evaluated for each test. Some discussion on this also follows.

Summaries of the powder and puck testing results and general observations about the granulation tests performed with cerium are given as Appendix D and with uranium are given as Appendix E. The “Matrix Test #” refers to the test number and the amount of binder added during the granulation process. A description of the binder type, amount, and addition point being tested in the individual tests was given in Appendix B and this is what was referred to as the test number. An example of a “Matrix Test #” would be “GA-4-

10%." The "GA-4" refers to a test in which 6% Airvol 21-205 is added to the powder before mixing and the "-10%" refers to 10 weight percent of water that was added during granulation.

Flow

One of the key reasons for performing the granulation step is to produce a powder that more evenly flows into and fills the press die cavity. The general flow characteristics of the granulated powders were evaluated by transferring some of the granulated product into a 1" opening stainless steel funnel and determining how the material flowed. Each product was rated on its general flow behavior through the funnel. The test was repeated by packing the powder into the funnel and then observing the flow behavior for a second time. Observations are recorded in Appendix D and E. Powders were rated from "poor" to "very good" with respect to flow. Binder combinations that produced powders with less than "ok" flow were eliminated from further consideration.

In general, the binders had an optimal addition amount during granulation with too low or too high additions producing non-flowable powder. A nominal addition range was 10 to 12 weight percent. PEG and HPMC, especially when used together, tended to produce powders with good flow. Certain combinations or addition methods of Airvol and Duramax also produced good flowing powder.

In addition to this visual test, a larger-scale flow-meter was also constructed so the angle of repose for the granulated powders could be measured. This device used approximately 500-1000 g of powder and then the slide gate was removed and the resulting angle was measured using a protractor. The test was performed a minimum of three times with each powder and then the average was reported. This test was not performed for all of the powders because the apparatus was not ready for testing at the start of the study. The results from this testing are also reported in Appendix D. Unfortunately, no general trends could be gleaned from the data.

For the maximum capacity testing, flow was an important decision factor. Many problems were seen when emptying the granulator if the powder amount was much greater than the nominal capacity. Therefore, 10 kg was considered to be the nominal capacity from a flow perspective.

Dust

Another strong objective of performing granulation is to reduce the dust that is generated during the pressing process since this is the primary point in the ceramic fabrication process where the powders are not contained. A quantitative measurement of the dust associated with each powder was not performed. The amount of small particles (<150 μm) is also reported in the Particle Size Distribution subsection. A general comment on the overall dusting behavior of the powders from a strictly visual observation is reported in Appendix D and E. Binder combinations that resulted in powders that were "dusty" or "very dusty" were not considered for further testing.

General observations about dusting included the following: dust was minimal with binder additions above 10 weight percent during granulation; sprayed binders tended to reduce dusting more than water additions; PEG / HPMC combined solutions required higher concentrations to reduce dusting; and uranium powders tended to have less dust than the equivalently processed cerium powders.

Particle Size Distribution

Approximately 500 grams of each powder was characterized using sieve analyses to determine the particle size of the product ranging from 75 μm to 1 mm, as well as the associated level of fines (i.e., material less than 106 μm). The general size of each powder is reported in Appendix D. In general, this data was used to determine the amount of fines associated with each product and to obtain a general idea of the packing efficiency associated with the particles. Binder combinations that produced fines greater than 20% were not considered for further testing.

Observations about the particle size included: spraying water produced small particles (150 μm) except at high water addition levels on powders containing high levels of binder; spraying PEG solutions on the powders tended to produce a lot of fines except at high concentrations or when the solution was combined with HPMC; spraying Duramax solutions tended to greatly reduce the amount of fines; and spraying PEG or Airvol solutions on powders containing Airvol resulted in large sized particles being formed. In general, particle sizes were in the range of 75 to 300 μm.

This was also an important criteria for determining the maximum capacity. When the granulator was over-filled, the binder did not seem to get evenly distributed on the powder. Very large granules formed in the higher powder loading tests in the path of the binder spray.

Puck Quality

After granulation, a small amount of powder from each batch was pressed using the laboratory Carver press to obtain a general idea of green puck quality. The remaining powder was archived for pressing using the PuCTF Best press. After pressing, the pucks were sintered at 1350°C for 4 hours using a programmed heat-up and cool-down. The temperature used for the binder burn-out hold depended on the particular binder type being used. Pressing information and puck measurements were recorded on puck data sheets per the requirements of TIP-PD-02. A summary of the puck measurement data is given as Appendix F and density data is plotted in Figure 1a and Figure 1b of this appendix. The puck data sheets from the pucks pressed in the Carver press will be stored in the three ring binder labeled “Granulation Matrix Data Sheets”, while the puck data sheets from the PuCTF Best press will be archived in the “Best Press” puck data sheet binder. Both of these binders are being archived with other data from the program.

General observations about the quality of the pucks produced from the powders and puck densities are given in Appendix D and E. Theoretical densities were assumed to be 5.20

g/cc for hafnium/cerium/cerium pucks and 5.71 g/cc for hafnium/cerium/uranium pucks. For the PuCTF pressed pucks, an average of the densities from all pucks pressed is reported. Small cracking that was attributed to gradients introduced by problems with the press dies were considered acceptable whereas significant cracking associated with binder burn-out or pressing in general were not. The powders were also evaluated for the need for lubrication during the pressing operation with those not requiring lubrication considered more favorable. For puck density, the target density was greater than 92% of theoretical but densities of greater than 90% were considered acceptable.

Observations about puck quality and pressing behavior included the following:

- Less pressure was required in the Best Press than in the laboratory Carver press. For equivalent pressures in the Best Press, a lot of lamination cracking in the puck was seen. The Best Press pucks also tended to have higher densities, which can be attributed to the dual-action pressing that should have resulted in fewer density gradients in the green puck.
- Die filling problems were seen when the binder amounts were too high (powder too moist).
- Airvol powder/crystals added to the attritor resulted in puck sintering problems.
- Adding PEG to the powders before granulation or spraying PEG solutions to non-binder containing powders during granulation resulted in pucks with lamination cracks and poorly lubricated powders when pressed.
- Spraying combinations of PEG and HPMC also had inconsistent results with regards to sintered puck quality and need for lubrication, but, when 8% HPMC solution was combined with 20% PEG solutions, the pucks were generally of good quality.
- Duramax, in general, produced good pucks but some problems were seen with cracking when pressure was too great and density problems were seen when the pressure was too low.
- Some radial cracking was seen in the pucks containing Airvol, which was attributed to the alignment problem with the dies.
- Airvol and PEG combinations produced good pucks but needed additional lubrication to minimize ejection pressure.
- When a large amount of granules >1 mm were present, they tended to remain intact after pressing and sintering but had no apparent affect on density.
- With uranium, combinations of Airvol in the powder with Airvol sprayed during granulation produced the best quality pucks.

No examination of the pucks was performed using microscopy, since all of the binders and the granulation methods had previously been shown to have no affect on product mineralogy.

Powder Test Center Data

Samples of the powders were subjected to Powder Test Center (PTC) testing to help determine the physical properties of the powders. A summary of the data is given as Appendix G. Important graphs associated with the data are given as figures in the

appendix. Due to the suspension of the program, testing on all of the powders was not completed. Therefore, only the results of the powders tested are provided.

Both the bulk and tap densities were measured on the powders and are plotted in Figure 1 of Appendix G. The bulk density is also referred to as the apparent density. It ranged from 1 to 1.7 g/cc for the powders measured. In general, powders with higher apparent densities are preferred because they are less difficult to press. The tap density is the density of a loose powder subjected to a number of prescribed tappings. The tap density represents the highest packing density possible for a powder without the application of pressure. The tap density provides useful information on the packing of the loose powder during transportation and when it is in a container on a press before die filling. It varied from 1.1 to 1.9 g/cc. The tap density to bulk density ratio was also calculated for each sample. The ratio of the tap density to the bulk density gives a signature characteristic of the interparticle friction, and is called the Hausner ratio, useful in categorizing relative interparticle friction. For a spherical powder, the tap to bulk ratio will be slightly above unity. More irregular particle shapes undergo a larger density increase with vibration, resulting in a higher Hausner ratio. In general, more irregular particle shapes give lower packing densities. The ratios are plotted in Figure 2 of Appendix G. In general, the granulated powders produced using Duramax 1023 in the blended powder and adding water during granulation had the highest densities, along with spraying 5 or 10% Airvol solutions during granulation. Hausner ratios varied from 1.04 to 1.19. No general trends for the particular binders or in percent additions were seen.

Information on flow as visually quantified and as measured with the fabricated flow apparatus was reported above. The angle of repose was also measured as part of the standard suite of tests with the Powder Test Center. The angle of repose is accepted in the powder processing industry as the standard measure of powder flowability. It represents the ability of the powder to uniformly fill a die cavity, with lower angles representing more flowable powder. Typically, an angle of 30° is a good measure of powder flowability. The results are plotted in Figure 3 of Appendix G. Duramax 1023 in the powder or spraying Airvol during granulation produced the most flowable powders. This was consistent with visual observations discussed earlier.

The slide coefficient is a measure of the frictional interactions between powder particles and die walls during compaction. For many materials, frictional effects at the die walls dominate during compaction. In some cases, the friction is the leading problem in dry pressing, resulting in poor or non-uniform green density, die sticking, and puck lamination and end capping. For a given powder and a given die material, the slide coefficient varies slightly with green density. The magnitude extends from 0 (infinite friction) to 1 (no friction) and relates directly the friction forces to the pressing forces. A value around 0.7 is considered moderate, with higher values indicating good or very good compaction properties and lower values suggesting a difficult compaction process. Difficult compaction results in relatively large frictional forces, which can lead to large density variations and, ultimately, large shrinkage variations. A plot of the slide coefficients for the

various powders compacted at 2 and 5 ksi is given as Figure 4 in Appendix G. None of the powders were above the target value of 0.7. Generally, the results indicated that spraying Airvol during granulation or water on Duramax 1023 containing powders had the highest slide coefficients. Higher green densities represented by higher compaction pressures increased the coefficient as expected but still were below the target.

The compactability coefficient is a material constant characterizing the ability of a powder to densify and represents interactions between powder particles during compaction. Powders with high coefficients are compacted to high densities with relatively little pressure. Compactability is also referred to as compressability. It can be defined for full-size pucks by the compression ratio, which is the volume of the loose powder compared to the volume of the compacted powder or the green puck density compared to the apparent density. A plot of the compactability coefficients for compacts pressed at 2 and 5 ksi using the PTC is given as Figure 5 in Appendix G. Trends were consistent with the slide coefficient data. In general, there was very little scatter in the data and the results were relatively the same.

The ejection pressure was measured on the small compacts made with the PTC. The ejection pressure reported is the compact ejection pressure averaged over the first 2.54 mm of compact travel in the PTC die after the starting pressure overshoot needed to initiate the movement of the compact. The data is plotted in Figure 6 of Appendix G for compaction pressures of 2 and 5 ksi. In general, powders containing Duramax or PEG had higher ejection pressures. The PEG results were consistent with observations made during actual pressing, where it was obvious that additional lubrication was needed. A significant increase in ejection pressure was seen with higher compaction pressures.

The PTC was used to determine the axial strength of the compacts. The axial strength of the green PTC compacts is measured by crushing the compacts along the pressing face. For these tests, it gives a rough measure of the green strength of the puck during handling but gives a better measure of the strength during ejection from the press. High values for axial strength are desired since it should correlate to good green strength of the puck and gives a relative measure of the likelihood of cracking due to stress induced during the ejection of the puck. Figure 7 of Appendix G contains the available data. The data for the powders was inconsistent when comparing within a binder test. Therefore, no general trends could be discerned. For the most part, strength increased with increasing pressure as expected.

The cohesiveness of the green compact represents a ratio between the axial green strength of the compact and the maximum friction pressure between the compact and die walls. This parameter is directly related to cracking and lamination resistance during compact ejection. When less than one, the compacts will likely develop cracks during ejection unless special care is implemented. If above 1, cracking during removal from the die should not occur under normal conditions. The cohesiveness was measured using the PTC, and the data is plotted in Figure 8 of Appendix G. About half of the binder systems

produced powders with acceptable cohesiveness. Some scatter was seen in the data so generalizations could not be made.

Hold-Up

A significant concern with the granulation process for plant production is the amount of hold-up in the vessel since this clean-up operation will have to be performed remotely. The amount of hold-up for each test was measured and is reported in Appendix D and E. Target hold-up was considered to be less than 5%. General observations about hold-up included the following: spraying PEG solutions increased the amount of hold-up; spraying PEG combined with HMPC had inconsistent results with test using 8% HPMC / 20% PEG solution producing very little hold-up; spraying Duramax solutions resulted in minimal hold-up; and spraying Airvol or PEG solutions on Airvol containing powders resulted in low hold-up amounts. Limited testing was performed to determine whether the hold-up continued to build-up at a constant rate or whether it would reach a saturation limit as seen with the attritor. The preliminary results showed that hold-up continued to accumulate; however enough repetitions were not done to determine whether a saturation limit could be or had been reached due to the suspension of the program.

Hold-up also played a considerable role in the determination of the maximum capacity. As mentioned earlier, significant problems were seen with flow of the powder with higher powder amounts. Transfer of the powder out of the vessel was hampered by the large amount of powder; thus, hold-up was very high. The data reported in Appendix D does not properly reflect the amount of hold-up in the vessel with respect to free-released powder. After initial attempts to freely transfer the powder, the sides of the vessel were agitated to help with removal of the powder. The amount of powder remaining after that step is what is reflected in Appendix D.

The use of the agitator impacted the hold-up seen in the vessel. The amount was slightly higher and the hold-up was harder to remove. This was likely due to the amount of binder and powder that were thrown at the sides of the vessel at a higher velocity, thus creating more hold-up.

CONCLUSIONS

Based on the results of the granulation matrix testing, the following observations and conclusions were made:

- 8 wt% Airvol 21-205 added to the precursors followed by spraying a 10% Airvol solution on the powder during granulation was the optimal binder system based on all of the data. The higher Airvol 21-205 addition to the precursors gave better results than the 6 wt% addition, and the higher concentration solution also seemed to produce better results than the 5% Airvol solution.
- Good powders and pucks were produced when Duramax 1023 was added to the precursors and water was added during granulation, but this product is no longer available. Duramax 1020 did not have the same qualities. Solutions of Duramax 1020,

when added during granulation, did result in good powders and pucks, but several problems were seen with pumping this solution because of the solids content.

- The maximum capacity was determined to be consistent with the vendor recommendations.
- The agitator was determined to be unnecessary to produce adequate powders and furthermore resulted in additional hold-up, so it was removed on March 14, 2000.
- Additional lubricants were not needed with the recommended binder system (i.e., Airvol), but would be required with some of the other binder systems (e.g., PEG).
- Drying was determined not to be necessary because the flowability and pressing characteristics of the powder were considered acceptable without ancillary drying.
- As with previous uranium testing, uranium powders had better flow properties and lower dust levels but possibly had higher hold-up. The optimal binder system (i.e., Airvol in the powder and Airvol sprayed on the powder) had equivalent hold-up when tested with uranium.

FUTURE CONSIDERATIONS

The following items should be considered in any future plant-scale testing:

- Nozzle pattern was not well tested and should be re-visited to minimize maintenance and over-spray problems during plant operation. A fan shaped nozzle was used throughout the testing; however, it has to be operated in a specific direction for effective granulation to occur. This could create a problem for maintenance in the plant and increases the potential for upsets. Preliminary testing with a cone-shaped nozzle while spraying water gave good results and should provide better binder distribution and less potential for upset.
- The spray arm location and nozzle position should be further evaluated in the larger-scale equipment since this greatly affects granule formation and the amount of hold-up. It needs to be optimized for the vessel size.
- The binder rate of addition needs to be optimized to the pump system used in the plant. Nominal addition rate for the lab-scale testing was 80 g / min to 100 g / min but will depend on the binder and spray nozzle design.
- The optimal vessel speed, along with process limits, need to be defined for the plant-scale system. Data from the lab-scale and the PuCTF testing should be used as a starting point.
- The optimal processing time, along with the process limits, need to be defined for the plant-scale system. Data from the lab-scale and the PuCTF testing should be used as a starting point.
- The maximum powder processing temperature needs to be defined after mixing in the plant-scale attritor. This was not thoroughly examined in the matrix testing but was shown to have an effect on steam generation and product hold-up in the granulator.
- The rate of accumulation / hold-up in the granulator needs to be defined for plant prototypical processing conditions. This will allow for a general idea of the required maintenance and will help define the extent of engineering that needs to be performed to define the cleaning equipment / process for the granulator.

- The granulation equipment has not been tested with plutonium. However, uranium testing has shown promising results with the equipment, and similar tumble granulation methods have been used in the past to make full-scale plutonium pucks in the Pu Facility at LLNL.
- Once parameters are optimized for the baseline formulation, a suite of impurity tests needs to be done to further evaluate the effects of impurities on granulation (e.g., effects of hygroscopic impurities).

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APPENDICES

A Synopsis from Process Development Matrix for FY00 – Status as of April 2001
B Granulation Test Series A – Binder Type, Amount, and Addition Point
C Granulation Test Series B – Binder Type, Amount, and Addition Point with Hf/Ce/U Formula
D Summary of Cerium Granulation Test Parameters and Product Data
E Summary of Uranium Granulation Test Parameters and Product Data
F Puck Data for Granulation Matrix Testing
G Powder Test Center Data for Granulation Matrix Testing

Appendix A - Synopsis from Process Development Studies for FY00 - Status as of April 2001

Test Series	Parameter Studied	Variable/Test	Responsible Site	Target Completion Date	Material	Acceptance Criteria	Status
GA	Binder Type, Amount, and Addition Point (3 kg Batch)	PEG 8K	LLNL	Complete	Hf/Ce/Ce	Formation of granules, sieve classification, powder test center analyses, and flow and dust testing. Pucks as applicable for green strength, handling, cracking, and density.	Testing has shown that the following binders (with addition point listed) produce acceptable granulated material without impacting the process: 3% PEG - Prec.; 20% PEG Solution - Gran.; 4.5 to 6% Airvol - Prec.; 5 or 10% Airvol Solution - Gran.; 8 - 10% HPMC solution - Gran.; 10 - 20% PEG solution - Gran.; 3 & 5% Duramax - Prec.; and 5 & 10% Duramax solution - Gran. Airvol in precursors with additional airvol added during granulation was deemed the baseline process from this testing. Results will be documented during closeout.
		Airvol 21-205	LLNL		Hf/Ce/Ce		
		Airvol 205	LLNL		Hf/Ce/Ce		
		PEG 8K/HPMC E-5	LLNL		Hf/Ce/Ce		
		PEG 8K/Airvol 21-205	LLNL		Hf/Ce/Ce		
		PEG 8K/Airvol 205	LLNL		Hf/Ce/Ce		
		Maltrin M-150	LLNL		Hf/Ce/Ce		
		Duramax	SRTC/LLNL		Hf/Ce/Ce		
		Added to Precursors	LLNL		Hf/Ce/Ce		
		Sprayed during Granulation	LLNL		Hf/Ce/Ce		
		Added to Attritor	LLNL		Hf/Ce/Ce		
	Full Batch	Verify Best of Binders	LLNL		Hf/Ce/Ce		
GB	Hf/Ce/U Verification	Verify Best of Binders	LLNL	Complete	Hf/Ce/U	Acceptable granules & pucks.	Consistent results with GA testing.
GC	Hf/Ce/Mn Verification	Verify Best of Binders	LLNL	Not performed	Hf/Ce/Mn	Acceptable granules.	Not performed.
GD	Maximum Capacity	8, 12, vs 16 qt	LLNL	Complete	Hf/Ce/Ce	Formation of granules, sieve classification, powder test center analyses, and flow and dust testing. Pucks as applicable. Vessel hold-up.	Current size ratio seems optimal. However, larger size batches were shown to also produce acceptable product. Biggest problem was discharge.
GE	Agitator	No Agitator	LLNL	Complete	Hf/Ce/Ce	Formation of granules, sieve classification, powder test center analyses, and flow and dust testing. Pucks as applicable. Vessel hold-up.	Baseline process established without use of agitator.
		During binder addition	LLNL	Complete			With the agitator, larger and harder granules were produced and additional hold-up was seen.
GF	Binder/Water Addition	Type/Size of Nozzle	LLNL/SRTC	On-going	Hf/Ce/Ce	Formation of granules, sieve classification, powder test center analyses, and flow and dust testing. Pucks as applicable. Vessel hold-up.	Preliminary nozzles, position, and rate of addition have been defined. However, the final decision will be based on full-plant size equipment. Additional optimization will be necessary.
		Nozzle Position	LLNL/SRTC	On-going			
		Rate of Addition	LLNL/SRTC	On-going			
		Verify with Uranium	LLNL	On-going	Hf/Ce/U	Acceptable Granules & Pucks	
GG	Lubricant type and amount	No Additional	LLNL/SRTC	Complete	Hf/Ce/Ce	Flow and dust testing, Powder test center analyses, puck ejection force, and acceptable pucks.	No additional lube was deemed necessary after pressing in the PuCTF press with baseline powders.
		EBS, Ca Stearate, others	LLNL/SRTC	Not performed			
		dry vs liquid	LLNL/SRTC	Not performed			
		Verify with Uranium	LLNL	Complete	Hf/Ce/U		U results were similar for Carver press.
GH	Drying Necessity	Formulator	LLNL	4/30/00	Hf/Ce/Ce, Hf/Ce/U	Formation and flow of granules, acceptable pucks.	The baseline process produced acceptable results that made drying unnecessary.
		Vacuum (air)	LLNL	Not performed			

Appendix A - Synopsis from Process Development Studies for FY00 - Status as of April 2001

Test Series	Parameter Studied	Variable/Test	Responsible Site	Target Completion Date	Material	Acceptance Criteria	Status
GI	Vessel Speed (min, max)	During binder addition	LLNL	5/31/00	Hf/Ce/Ce	Formation of granules, sieve classification, powder test center analyses, and flow and dust testing. Pucks as applicable. Vessel hold-up.	Vessel speed has been defined for the current scale equipment, will have to be further optimized for the plant-scale equipment when testing is performed.
		During tumbling	LLNL	Complete			
		Determine Operating Limits	LLNL/ SRTC	On-going			
		Verify with Uranium	LLNL	Complete	Hf/Ce/U	Acceptable Granules & Pucks	Results similar to Ce.
GJ	Time of Tumble (min, max)	During binder addition	LLNL	Complete	Hf/Ce/Ce	Formation of granules, sieve classification, powder test center analyses, and flow and dust testing. Pucks as applicable.	Process time has been defined for the current scale equipment, will have to be further optimized for the plant-scale equipment when testing is performed.
		During tumbling	LLNL	Complete			
		Determine Operating Limits	LLNL/ SRTC	On-going			
		Verify with Uranium	LLNL	Complete	Hf/Ce/U	Acceptable Granules & Pucks	Results similar to Ce.
GK	Powder Temperature	Impact on Process	LLNL/ SRTC	On-going	Hf/Ce/Ce	Formation of granules.	Need to evaluate maximum temperature allowed to make acceptable product and minimize hold-up.

Appendix B - Granulation Test Series A - Binder Type, Amount, and Addition Point

Test #	Binder Type	Binder Amount (Based on Total Feed)	Addition Point	Batch ID
GA-1	Airvol 21-205	4.5 wt% liquid (~21% solids)	Precursors	112499
GA-2		6 wt% liquid (~21% solids)		112299, 030800
GA-3	Airvol 21-205	5% Solution	Granulation	112399
GA-4		10% Solution		111599-0 to -2, 092899-0 &-1, 113099-0 & -4, 011100-0 & -2, 031500-2, 020400-0 & -1, 032000-0 & -1
GA-5		15% Solution		113099-2 & -3, 021100-0&-1, 022800-0, 111799, 032100-4, 032000-0 & -3, 031500, 022500-5, 022900-3
GA-6	Airvol 205	1 wt% dry	Attritor	NA
GA-7		2 wt% dry		111899-0 & -1, 121499-0
GA-8		3 wt% dry		120799-0 & -1, 121499-3
GA-9		4 wt% dry		120799-3
GA-10		5 wt% dry		NA
GA-11	PEG 8K	4 wt%	Precursors	121399-0 to -2
GA-12		5 wt%		NA
GA-13		3 wt%		122299-0 & -1, 122799-0 & -1
GA-14	PEG 8K	10% Solution	Granulation	120899-0 & -1
GA-15		20% Solution		120899-2 to -4, 010400-0
GA-16		30% Solution		010400-1 & -3
GA-17		25% Solution		010500-0
GA-18		15% Solution		122799-1, 011100-2 & -3
GA-19	Duramax 1020 or 1023	3 wt% liquid	Precursors	011000-0 to -3
GA-20		5 wt% liquid		011800-0 & -2, 022500-0 & -1
GA-21		7 wt% liquid		022500-3 & -4
GA-22	Duramax 1020	5% Solution	Granulation	121799-1 to -3
GA-23		10% Solution		111799-1 & -2, 010400-0, 021700-5, 011100-2, 020100-0 to -3, 010500-1 & -3, 120899, 011800-0, 012500-0, 020700-0, 021100-1, 030300-3, 031500-0, 040300-0 & -1
GA-24		15% Solution		1207990, -2 & -3, 111899-1, 032100-0, -1, & -4, 032000-3 & -4
GA-25	PEG 8K / HPMC E-5	5% HPMC Sol'n / 10% PEG Sol'n	Granulation	010500-1 & -3
GA-26		10% HPMC Sol'n / 10% PEG Sol'n		010400-2, 120899-1, 011100-0
GA-27		5% HPMC Sol'n / 20% PEG Sol'n		NA
GA-28		8% HPMC Sol'n / 20% PEG Sol'n		120799-1, 111899-0, 121499-1 & -3, 010500-0 & -2, 032100-2 & -3, 010400-1 & -3, 113099-2, 121799, 100799-3
GA-29	Airvol 21-205	4.5% Airvol liquid / 5% Sol'n	Precursors / Granulation	011800-5, 112499-1
GA-30		4.5% Airvol liquid / 10% Sol'n		011900-0 to -2, 020400-2 & -3
GA-31		6% Airvol liquid / 5% Sol'n		012500-0, -1, -2, & -4
GA-32		6% Airvol liquid / 10% Sol'n		013100-0 to -3, 020700-2 &-3, 030800-1 to -4
GA-33	PEG 8K / Airvol 21-205	2 wt% PEG / 4 wt% Airvol liquid	Precursors	020100-0 to -3
GA-34	PEG 8K / Airvol 21-205	4.5 wt% liquid Airvol / 20% PEG Solution	Airvol to Prec. / PEG in Gran.	020400-0 & -1
GA-35		6 wt% liquid Airvol / 20% PEG Solution		020700-0 & -1

Appendix B - Granulation Test Series A - Binder Type, Amount, and Addition Point

Test #	Binder Type	Binder Amount (Based on Total Feed)	Addition Point	Batch ID
GA-36	PEG 8K / Airvol 21-205	2 wt% PEG / 10% Airvol sol'n	PEG to Prec. / Airvol in Gran.	021400-1 & -2
GA-37		3 wt% PEG / 10% Airvol sol'n		122999-1, 021700-0 & -1, 122799-1
GA-38	Maltrin M-150	3 wt%	Precursors	021100-0 & -1
GA-39	PEG 8K / HPMC E-5	2 wt% PEG dry / 5% HPMC Sol'n	PEG to Precursors / HPMC in Granulation	021800-1 to -3
GA-40		2 wt% PEG dry / 8% HPMC Sol'n		021800-4, 122299-0
GA-41		3 wt% PEG dry / 10% HPMC Sol'n		030200-0, -1, -3 & -4
GA-42		3 wt% PEG dry / 8% HPMC Sol'n		022900-3, 122999-0, 022800-4
GA-43	Duramax 1020	3wt% Duramax / 10% Duramax Solution	Precusors / Granulation	022800-0
GA-44	Duramax 1020 / HPMC E-5	3 wt% Duramax / 8% HPMC Solution	Precusors / Granulation	22800
GA-45	Airvol 21-205	4.5% Airvol liquid / 15% Solution	Precusors / Granulation	020400-0 & -1, 011900-3, 011100-2

Appendix C - Granulation Test Series B - Binder Type, Amount, and Addition Point with Hf/Ce/U Formula

Test #	Binder Type	Binder Amount (Based on Total Feed)	Addition Point	Batch ID
GB-1	HPMC E-5/PEG 8K	8% HPMC Solution/20% PEG Solution	Granulation	021100-3, 030300-2
GB-2	PEG 8K	20% PEG Solution	Granulation	021100-5
GB-3	Airvol 21-205	6% Airvol	Precursors	021400-3
GB-4	Airvol 21-205	6% Airvol/10% Airvol Solution	Precursors/Granulation	021400-5, 031400-0 & -2
GB-5	Duramax 1020	10% Duramax solution	Granulation	030300-0
GB-6	PEG 8K/Airvol	4% PEG/10% Airvol Solution	Precursors/Granulation	030300-3
GB-7	PEG 8K/HPMC E-5	4% PEG/8% HPMC Solution	Precursors/Granulation	030300-5
GB-8	Duramax 1020	6.8% Duramax	Precursors	030900-0 & -1
GB-9	Duramax 1020/HPMC E-5	6.8% Duramax/10% HPMC Solution	Precursors/Granulation	030900-3

Appendix D - Summary of Cerium Granulation Test Parameters and Product Data

Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-1-0%	N/A	112499	4.5% Airvol in Powder	None	N/A	N/A	Poor	Very dusty	Most 106 um, 15% fines	Powder	N/A	Broke during pressing	96.63% 1775	N/A	N/A
GA-1-4%	G1214-0	112499-0	4.5% Airvol in Powder	Water	90 Hz-30 min	66.7 g/min, setting 6	Poor	Some reduction	Mostly 150 um, 15% fines	Not granulated	82.1 g	Good Puck	93.74% 1505	N/A	N/A
GA-1-8%	G1214-1	112499-1	4.5% Airvol in Powder	Water	90 Hz-4.33 min, 60 Hz-3.67 min, 40 Hz-22 min	88.9 g/min, setting 6	Poor	Better than 4%	~60% 150 um, 5% fines	Small & few large granules	123.1 g	Broke in 3 pieces	NA 1500	N/A	N/A
GA-1-12%	G1215-0	112499-2	4.5% Airvol in Powder	Water	90 Hz-5 min, 40 Hz-25 min	96 g/min	Flowable	Minimal	Mostly 106-150 um, 15% fines	Small granules	42.0 g	Broke in 2 pieces	NA 1499	Good pucks, no problems. (9.5 ton)	93.22%
GA-1-14%	G1217-0	112499-3	4.5% Airvol in Powder	Water	90 Hz-6 min, 40 Hz-1 min, 30 Hz-23 min	84 g/min, setting 6	Flowable	Minimal	Mostly <150 um, 15% fines	Granules starting to form	126.8 g	Gradient crack along centerline	NA 1507	Pucks were delaminating after pressing (9.5 ton).	93.03%
GA-2-0%	N/A	112299	6% Airvol in powder	None	N/A	N/A	Poor	Very dusty	Mostly <106 um	Some agglomerates	N/A	Faint crack near centerline	95.84% 1776	Cracking problems when pressure was <15 tons. Sintered pucks -faint lam & radial cracks.	96.55%
GA-2-4%	G1215-1	112299-0	6% Airvol in powder	Water	90 Hz-4.8 min, 60 Hz-28.2 min	150 g/min, setting 6	Ok	Some reduction	Mostly 106-150 um, 3% fines	Very small granules	36.6 g	Good Puck	94.40% 1506	Some problems with delamination until fill height adjusted. Faint cracking on	94.27%
GA-2-6%	G1217-1	112299-3	6% Airvol in powder	Water	90 Hz-3.5 min, 60 Hz-1.92 min, 40 Hz-22.5 min	72 g/min, setting 6	With assist	Slightly dusty	Mostly 150 um, 3% fines	Small granules, less dust than 4%	29.7 g	Good Puck	93.73% 1503	Good pucks, no problems. (9.5 ton)	94.56%
GA-2-8%	G1215-2	112299-1	6% Airvol in powder	Water	90 Hz-3.7 min, 60 Hz-1.47 min, 50 Hz-24.83 min	88.9 g/min, setting 6	With assist	Slightly dusty	~60% 150 um, 2% fines	Very small granules	31.5 g	Good Puck	94.39% 1504	Good pucks produced with some fine lamination cracking due to press chattering. (14 ton)	95.62%
GA-2-10% Full Batch	G0314-0	030800-1, 030800-0	6% Airvol in powder	Water	90 Hz-8.67 min, 50 Hz-21.33 min	78.3 g/min, setting 33	With assist	Minimal	N/A	Slightly granulated, looks like powder	~84 g	N/A	N/A	N/A	N/A
GA-2-10% Full Batch	G0314-1	030800-3, 030800-4	6% Airvol in powder	Water	90 Hz-6.12 min, 50 Hz-23.88 min	97.55 g/min, setting 38	Poor	Minimal	N/A	Same appearance as G0314 0, vessel not cleaned in between, used valve to discharge	~240 g	N/A	N/A	N/A	N/A
GA-2-10% Full Batch	G0315-0	030800-1, 030800-0, re-used	6% Airvol in powder	Water	90 Hz-6.2 min, 50 Hz-23.8 min	96.77 g/min, setting 38	With assist	Minimal	N/A	Same appearance as G0314 0, vessel not cleaned in between, used valve to discharge	~1274 g	N/A	N/A	N/A	N/A
GA-2-12%	G1215-3	112299-2	6% Airvol in powder	Water	90 Hz-5.2 min, 60 Hz-1.13 min, 40 Hz-23.67 min	85.7 g/min, setting 6	With assist	Minimal	Mostly 106-150 um, 8% fines	Small granules with a few large ones	77 g	Good Puck	93.68% 1498	Some problems with filling, good pucks with the exception of a faint radial crack. (10 ton)	94.30%
GA-3-6%	G0104-1	112399-2	None	5% Airvol Solution	90 Hz-2.58 min, 20 Hz-27.42 min	102.8 g/min, setting 20	Ok	Slightly dusty	Most 106 um, 28% fines	Very small granules	81.7 g	Circum. & radial cracking	92.51% 1515	Some faint radial and lamination cracking (10 ton).	93.73%
GA-3-10%	G0103	112399-3	None	5% Airvol Solution	90 Hz-3.92 min, 20 Hz-26.08 min	109.1 g/min, setting 20	Good	Slightly dusty	Most 106-212 um, 28% fines	Very small & small granules	97.7 g	Density Gradient Cracks	93.19% 1510	N/A	N/A
GA-3-12%	G0104-2	112399-0	None	5% Airvol Solution	90 Hz-4.33 min, 20 Hz-25.67 min	100 g/min, setting 20	Ok	Dusty	Most 106-212 um, 20% fines	Some small granules	152.7 g	Density Gradient Cracks	92.82% 1514	Press was chattering (10 ton). Pucks had a couple of radial & circum. cracks which resulted in some pucks breaking in two.	94.09%
GA-3-14%	G0104-0	112399-1	None	5% Airvol Solution	90 Hz-5.17 min, 20 Hz-24.83 min	105 g/min, setting 20	Good	Minimal	Most 106-212 um, 14% fines	Lot of hold-up, lots of small granules	479.2 g	Density Gradient with radial Crack	93.74% 1516	No problems pressing, pucks had faint lamination cracks. (10 ton)	93.44%

Appendix D - Summary of Cerium Granulation Test Parameters and Product Data

Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-4-6%	G0105-0	092899-0	None	10% Airvol Solution	90 Hz-2.42 min, 20 Hz-27.58 min	126.8 g/min, setting 20	Ok	Very dusty	Most 106 um, 17% fines	Very little granulation	14.5 g	Density Gradient Cracks	93.27% 1518	No problems pressing, pucks had a couple of faint radial & lam. cracks. (10 ton)	94.02%
GA-4-8%	G0106-2	111599-1	None	10% Airvol Solution	90 Hz-3.92 min, 20 Hz-26.08 min	82.19 g.min, setting 21	Good	Dusty when poured	7% 1 mm, most 106-300 um, 18% fines	Small and medium granules	183 g	Density Gradient Cracks that broke puck	NA 1511	No problems pressing (10 ton). Pucks had up to 2 radial cracks & some faint lam. cracking.	93.97%
GA-4-10%	G0105-1	092899-1	None	10% Airvol Solution	90 Hz-3.72 min, 20 Hz-26.28 min	110.3 g/min, setting 20	Ok	Minimal	Some 1mm, most 150-300 um, 13% fines	Small granules	9.3 g	Density Gradient Cracks	92.21% 1512	No problems pressing (10 ton). Some of the pucks had radial cracks with faint lam. cracking.	93.47%
GA-4-10% Repeat	G0321-2	011100-0	None	10% Airvol Solution	90 Hz-7.5 min, 20 Hz-22.5 min	100 g/min, setting 35	Ok	Slightly dusty	N/A	Looks like sand, warm powder gave bigger heal than previous batch.	~196 g	N/A	N/A	N/A	N/A
GA-4-10% Repeat	G0321-3	011100-2	None	10% Airvol Solution	90 Hz-4 min, 20 Hz-26 min	100 g/min, setting 35	Poor	No dust	N/A	Few very small granules. Clean vessel	~31 g	N/A	N/A	N/A	N/A
GA-4-10% Repeat	G0322-0	032000-0	None	10% Airvol Solution	90 Hz-3.75 min, 20 Hz-26.25 min	109 g/min, setting 35	Good	Dusty	N/A	Small granules. Hold-up increased over previous batch.	est. 210 g	N/A	N/A	N/A	N/A
GA-4-10% Repeat	G0322-1	032000-1	None	10% Airvol Solution	90 Hz-3.75 min, 20 Hz-26.25 min	109 g/min, setting 35	Good	Dusty	N/A	Small granules. Hold-up increased over previous batch.	est. 354 g	N/A	N/A	N/A	N/A
GA-4-10% (Full Batch)	G0107-1	113099-0, 113099-4	None	10% Airvol Solution	90 Hz-7.17 min, 20 Hz-22.83 min	99.4 g/min, setting 17	Good	Slightly dusty	Most 106-300 um, 20% fines	Small granules.	222.7	Gradient crack with few radial cracks	93.55% 1533	Combined with smaller batch, G0105-1	
GA-4-12%	G0107-0	111599-2	None	10% Airvol Solution	90 Hz-4.5 min, 60 Hz-25.5 min	102.9 g/min, setting 17	Good	Minimal	18% 1mm, most 106-300 um, 10% fines	Various sized granules	155 g	Cracked in Half along radial direction	NA 1517	Powder had good flow & low dust to press. Pucks had up to three radial cracks & some faint lam. cracking. (10 ton)	93.77%
GA-4-12% Full	G0320-0	031500-2	None	10% Airvol Solution	90 Hz-2 min, 80 Hz-5min, 20 Hz-23 min	111.3 g/min, setting 35	Good (62)	Dusty	Most 75-300 um, 23% fines	Various sized granules formed. Hot powder used.	~343.4 g	N/A	N/A	N/A	N/A
GA-4-12% Full	G0321-1	020400-0, 020400-1, re-used	None	10% Airvol Solution	80 Hz-7.67 min, 20 Hz-82.33 min	104.3 g/min, setting 35	Ok	Minimal	N/A	Various sized granules up to 1/4". Powder left coating.	~477 g	Crack along gradient with some radial off.	94.25% 2089	N/A	N/A
GA-4-14%	G0105-2	111599-0	None	10% Airvol Solution	90 Hz-5.22 min, 20 Hz-24.78 min	99.5 g/min, setting 17	Flowable	No dust	35% 1mm, some 212-300 um, 5% fines	Various sized granules	194 g	Density Gradient Cracks	93.62% 1513	Powder had good flow & low dust to press. Pucks had up to two radial cracks & some faint lam. cracking. (10 ton)	93.35%
GA-5-6%	G0106-0	113099-3	None	15% Airvol Solution	90 Hz-3.53 min, 20 Hz-26.47 min	71.1 g/min, setting 21	Flowable	Dusty	Most 106 um, 15% fines	Solution flow problems, some granules	101.5 g	Gradient crack & few radial	93.11% 1532	N/A	N/A
GA-5-10%	G0106-1	113099-2	None	15% Airvol Solution	90 Hz-4.4 min, 20 Hz-25.6 min	88.2 g/min, setting 21	Flowable	Dusty	Most 106-300 um, 19% fines	Some nice granules	146.6 g	Gradient crack & a radial	92.04% 1536	N/A	N/A
GA-5-10%	G0518-1	022500-5 re-used	None	15% Airvol Solution	90 Hz-3.58 min, 20 Hz-6.42 min	115.1 g/min, setting 34	Poor	Dusty	N/A	Partially granulated	35.3 g	N/A	N/A	N/A	N/A
GA-5-12% (full)	G0427-0	031500 re-used	None	15% Airvol Solution	80 Hz-5 min, 25 Hz-4 min	180.6 g/min, setting 39	Ok to good flow with assist	Minimal	N/A	Good product, but appears to be damp	19 g	N/A	N/A	N/A	N/A
GA-5-12% (full)	G0427-1	032000-3, 032100-4, re-used	None	15% Airvol Solution	80 Hz-6.1 min, 25 Hz-13.9 min	143.9 g/min, setting 39	Ok to good flow with assist	Minimal	N/A	Good product, ran for 10 additional minutes, product looked a little better but some increased hold-up	64 g	N/A	N/A	N/A	N/A

Appendix D - Summary of Cerium Granulation Test Parameters and Product Data

Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-5-12% (full)	G0427-4	021100-0, 021100-1, re-used	None	15% Airvol Solution	80 Hz-6 min, 25 Hz-14 min	142.0 g/min, setting 39	Ok to good flow with assist	Minimal	N/A	Acceptable product, also run for 10 extra minutes	54.9 g	N/A	N/A	N/A	N/A
GA-5-12% (full)	G0427-5	111799-, 032000-0, re-used	None	15% Airvol Solution	80 Hz-6.1 min, 25 Hz-3.9 min	116.6 g/min, setting 39	Ok	Minimal	N/A	Good granules	103 g	N/A	N/A	N/A	N/A
GA-5-12%	G0517-0	022800-0, re-used	None	15% Airvol Solution	90 Hz-4.48 min, 20 Hz-5.52 min	111.8 g/min, setting 34	Good	Minimal	32% 1 mm, 18% fines	Various sized granules, appears to be error in heal amount	51 g	N/A	N/A	N/A	N/A
GA-5-12% (full)	G0518-0	022900-3, re-used	None	15% Airvol Solution	90 Hz-4.32 min, 20 Hz-5.68 min	114.3 g/min, seting 34	Tapped needed assist, good otherwise	No dust	N/A	Good granules, Changed nozze to 75 degrees	29.5 g	N/A	N/A	Good pucks, faint lamination crack on puck pressed below 6 tons	94.48%
GA-7-4%	G1216-0	111899-0	2% Airvol in Attritor	Water	90 Hz-2.53 min, 60 Hz-27.47 min	78.4 g/min, setting 6	With assist	Slightly dusty	N/A	Some small granules	33 g	N/A	NA	N/A	N/A
GA-7-8%	G1216-1	111899-1	2% Airvol in Attritor	Water	90 Hz-3.67 min, 60 Hz-26.33 min	89.9 g/min, setting 6	Worse than 4%	Slightly dusty	N/A	A lot of small granules	46 g	N/A	NA	N/A	N/A
GA-7/4-10%	G0107-3	121499-0	2% Airvol in Attritor	10% Airvol Solution	90 Hz-5 min, 20 Hz-25 min	92.6 g/min, setting 17	Ok	Slightly dusty	16.5% 1mm, 19% 300 um, 9% fines	Various sized granules	170.7 g	Lot of lamination cracking, surfacer defects	85.86% 1528	N/A	N/A
GA-8-4%	G1216-2	120799-0	3% Airvol in Attritor	Water	90 Hz-2.33 min, 60 Hz-27.67 min	90.3 g/min, setting 6	Poor	Dusty	N/A	No real granules	117.2 g	N/A	NA	N/A	N/A
GA-8/4-10%	G0107-2	121499-3	3% Airvol in Attritor	10% Airvol Solution	90 Hz-4 min, 20 Hz-26 min	107.6 g/min, setting 17	Good	Minimal	25% 1 mm, rest 106-150um, 3% fines	Various sized granules	41.4 g	Minor surface cracking & laminar cracking	89.90% 1527	N/A	N/A
GA-8/4-12%	G0121-0	120799-0	3% Airvol in Attritor	10% Airvol Solution	90 Hz-4.67 min, 20 Hz-25.33 min	100.8 g/min, setting 20	Ok to good with assist	Minimal	12% 1 mm, rest 106um, 15% fines	Various sized granules	18.8 g	Gradient crack at centerline	91.99% 1624	N/A	N/A
GA-8-8%	G1216-3	120799-1	3% Airvol in Attritor	Water	90 Hz-3.5 min, 60 Hz-26.5 min	96.0 g/min, setting 6	Wost of all Airvol	Minimal	N/A	Some small granules, clumpy	219.1 g	Broke green	NA	N/A	N/A
GA-9-8%	G1220-0	120799-3	4% Airvol in Attritor	Water	90 Hz-3.92 min, 60 Hz-26.08 min	82.3 g/min, setting 6	Poor	Very dusty	40% 106 um, 10% fines	Some larger granules, but mostly very small.	339.7 g	Uneven color & surface, circum-ferential cracking.	90.43% 1508	N/A	N/A
GA-11-6%	G1221-0	121399-2	4% PEG in Powder	Water	90 Hz-4.33 min, 20 Hz-25.67 min	81.8 g/min, setting 6	Ok	More than 8%	Most between 300 um and fines	Very small granules	67.8 g	Small Cracks	95.54% 1502	N/A	N/A
GA-11-8%	G1220-1	121399-1	4% PEG in Powder	Water	90 Hz-4.08 min, 20 Hz-25.92 min	77.9 g/min, setting 6	Ok	Slightly dusty	14% 1mm & 15% 150 um, 16% fines	Small to medium size granules, mostly small	359.8	Crack in radial & circum. direction.	95.14% 1501	N/A	N/A
GA-11-10%	G0110	121399-0	4% PEG in Powder	Water	90 Hz-4.83 min, 20 Hz-25.17 min	78.3 g/min, setting 27	Flowable	Minimal	~17% 1mm, rest 75-300 um, 16% fines	Various sized granules	123.0 g	Gradient crack & several radial	93.39% 1531	Delamination cracking from pressing & some radial cracks after sintering. (8.5 & 9.5 ton)	93.69%
GA-13-6%	G0112-0	122299-0	3% PEG in powder	Water	90 Hz-3.5 min, 20 Hz-26.5 min	72.0 g/min, setting 25	Poor	Some reduction	Most 75-212um, 18% fines	More 105 than 10%, small granules	32.0 g	Density gradient crack & few radial	94.46% 1538	N/A	N/A
GA-13-10%	G0112-1	122299-1	3% PEG in powder	Water	90 Hz-4.75 min, 20 Hz-25.25 min	100.0 g/min, setting 29	Ok	Some reduction	Most 75-212um, 14% fines	Very small granules with a few about 400 um	27.8 g	Broke in several pieces	NA	N/A	N/A

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Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-13-12%	G0120-2	122799-1	3% PEG in powder	Water	90 Hz-4.63 min, 20 Hz-25.37 min	99.2 g/min, setting 22	Needs assist	No dust	~18% 1mm, some 106-212um, 5% fines	Large agglomerates, looks like it needs drying	127.0 g	Laminar cracking due to problems during ejection	93.2% 1623	Problems with chattering and cracking upon ejection (10 ton). All pucks had radial & lam. cracks after sintering.	93.28%
GA-13-14%	G0113	122799-0	3% PEG in powder	Water	90 Hz-4.42 min, 20 Hz-25.58 min	117.3 g/min, setting 25	Poor	No dust	~18% 1mm, some 75-150um, 12% fines	Various sized granules	91.7 g	Laminar cracking due to gradient and sticking to upper punch	92.55% 1540	N/A	N/A
GA-14-10%	G0110-1	120899-1	None	10% PEG Solution	90 Hz-4.08 min, 20 Hz-25.92 min	97.4 g/min, setting 25	Good	Very dusty	29% 106um, rest <500um, 15% fines	Small granules	105.6 g	Gradient crack & several radial	92.36% 1530	N/A	N/A
GA-14-14%	G0110-2	120899-0	None	10% PEG Solution	90 Hz-4.67 min, 20 Hz-25.33 min	114.4 g/min, setting 25	Good	Dusty	most 75-300 um, 29% fines	Bigger & more granules than 10%	241 g	Density gradient crack & few radial	93.06% 1535	N/A	N/A
GA-15-10%	G0111-0	120899-2	None	20% PEG solution	90 Hz-4.13 min, 20 Hz-6.87 min, 30 Hz-19 min	95.8 g/min, setting 20	Good	Some reduction	most 75-300 um, 29% fines	Very small granules	70.8 g	Density gradient crack & a radial	92.37% 15.34	A few pucks cracked upon ejection (10 ton). All pucks had radial and lamination cracks after sintering.	92.90%
GA-15-12%	G0113-0	010400-0	None	20% PEG solution	90 Hz, 20 Hz	setting 25	Good	Very little	N/A	Small granules	145.6 g	N/A	N/A	N/A	N/A
GA-15-14%	G0111-1	120899-4	None	20% PEG solution	90 Hz-5 min, 20 Hz-25 min	105.0 g/min, setting 20	Good	Minimal	15% 1mm, some 106-300 um, 10% fines	Various sized granules	118.7 g	Cracking in radial & circum. direction	93.04% 1529	Problems with cracking upon ejection (10, 15, & 20 ton). Radial and lamination cracks present after sintering.	92.69%
GA-15-15%	G0111-2	120899-3	None	20% PEG solution	90 Hz-5.58 min, 20 Hz-24.42 min	101.5 g/min, setting 20	Good	Slightly dusty	15% 1mm, some 106-300 um, 8% fines	Large and small granules	386.3 g	Circum. & radial cracking	92.12% 1537	N/A	N/A
GA-16-8%	G0118-0	010400-1	None	30% PEG Solution	90 Hz-3.78 min, 20 Hz-26.22 min	86.3 g/min, setting 17	Poor	Dusty	Mostly 150um, 11% fines	Very fine granules	337.0 g	Problems ejecting, lot of cracking	93.8% 1618	N/A	N/A
GA-16-14%	G0118-1	010400-3	None	30% PEG Solution	90 Hz-4.75 min, 20 Hz-17.25 min, 30 Hz-8 min	192 g/min, setting 17	Adequate	Dusty	Mostly 106-150um, 11% fines	Very small granules and some small agglomerates	237.8 g	Problems ejecting, lot of cracking	95.1% 1615	N/A	N/A
GA-17-10%	G0119-0	010500-0	None	25% PEG solution	90 Hz-4 min, 20 Hz-3 min, 30 Hz-23 min	100 g/min, setting 20	Adequate	Minimal	~37% 106 um, 18% fines	Very small granules	238.2 g	Cracking due to ejection green.	89.79% 1544	N/A	N/A
GA-18-10%	G0120-3	122799-1	None	15% PEG Solution	90 Hz-3.8 min, 20 Hz-26.2 min	107.1 g/min, settong 22	Poor, ok with assist	Dusty	Mostly 75-150 um, 16% fines	Few very small granules	210.0 g	Gradient cracks with radial cracks	92.53% 1619	N/A	N/A
GA-18-12%	G0120-4	011100-3	None	15% PEG Solution	90 Hz-4.17 min, 20 Hz-25.83 min	113.7 g/min, setting 20	Ok	Minimal	Mostly 75-212um, 30% fines	Some very small granules.	211.9 g	Gradient cracks with radial cracks	92.28% 1620	N/A	N/A
GA-18-14%	G0120-5	011100-2	None	15% PEG Solution	90 Hz-4.92 min, 20 Hz-25.08 min	107.0 g/min, setting 20	Good	Slightly dusty	Mostly 75-212um, 28% fines	Various sized granules	201.0 g	Gradient cracks with radial cracks	93.78% 1616	N/A	N/A
GA-19-4%	G0119-1	011000-0	3% Duramax 1023	Water	90 Hz-2.28 min, 60 Hz-1.72 min, 40 Hz-26 min	101.4 g/min, setting 22	Poor	Very dusty	~32% 106 um, 9% fines	A few small granules	42.2 g	Circum. & radial cracking	94.10% 1543	N/A	N/A
GA-19-8%	G0119-2	011000-1	3% Duramax 1023	Water	90 Hz-3.33 min, 20 Hz-26.67 min	103.0 g/min, setting 20	Adequate	Very dusty	19% 500um, most 75-106um, 4% fines	Very fine granules	36.2 g	Good Puck	94.97% 1621	N/A	N/A
GA-19-10%	G0124-2	011000-1 re-used	3% Duramax 1023	Water	90 Hz-3.97 min, 20 Hz-26.03 min	101.0 g/min, setting 25	Good	Minimal	5% 1 mm, some 75-150um, 35% fines	Various sized granules, with some >1mm	150.3 g	Crack starting at gradient and some radial	N/A	No problems pressing (10 ton). Faint lamination cracks present on sintered pucks.	93.87%

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Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-19-10% Repeat	G0208-1	011000-0 re-used	3% Duramax 1023	Water	90 Hz-4.10 min, 20 Hz-25.90 min	83.5 g/min, setting 34	Ok to good with assist (76)	Dusty	4% 1 mm, some 75-150um, 41% fines	Various sized granules with some large agglomerates	365.7 g	Good puck	94.42% 1662	N/A	N/A
GA-19-12%	G0120-0	011000-2	3% Duramax 1023	Water	90 Hz-5 min, 20 Hz- 25 min	94.0 g/min, setting 22	Good	Minimal	~30% 106 um, 18% fines	Many granules	11.7 g	Circum. & radial cracking, ok puck	93.54% 1541	No problems pressing (10 ton). Faint lamination cracks present on half of sintered puck.	94.22%
GA-19-14%	G0120-1	011000-3	3% Duramax 1023	Water	90 Hz-5.17 min, 20 Hz-24.83 min	100.8 g/min, setting 22	Good	No dust	23% 1mm, rest 75-300 um, 18% fines	Various sized granules	137.0 g	Few lamination cracks, good otherwise	94.75% 1622	Lamination cracks developed in green pucks after pressing at 10 tons. Good sintered pucks otherwise.	94.59%
GA-20-0%	N/A	N/A	5% Duramax 1023	None	N/A	N/A	Poor	Very dusty	N/A	Powder	N/A	Slight lamination cracks near top	98.23% 1642	Lamination cracks from pressing, radial & surface cracks after sintering.	96.38%
GA-20-4%	G0124-0	011800-0	5% Duramax 1023	Water	90 Hz-2.25 min, 40 Hz-27.75 min	96.0 g/min, setting 25	Poor	Very dusty	N/A	Not much different than raw powder	33.5 g	N/A	N/A	N/A	N/A
GA-20-8%	G0124-1	011800-2	5% Duramax 1023	Water	90 Hz-3.83 min, 20 Hz-26.17 min	84.8 g/min, setting 25	Ok to good with assist	Dusty	43% fines, rest 75 300 um	Very small granules.	37.9 g	Good puck, cracked in half cold.	93.56% 1626	Lamination cracks developed in green pucks after pressing at 10 tons. Good sintered pucks otherwise.	96.31%
GA-20-8%	G0301-3	022500-1	5% Duramax 1020	Water	90 Hz-3 min, 60 Hz- 2 min, 20 Hz-25 min	120 .0g/min, setting 38	Poor	Very dusty	N/A	Looks like powder. 1020 behaves differently than 1023	48 g	N/A	N/A	N/A	N/A
GA-20-10%	G0217-0	011800-0 re-used	5% Duramax 1023	Water	90 Hz-3.55 min, 60 Hz-5.45 min, 20 Hz-21 min	102.0 g/min, setting 38	Poor (58)	No dust	Most 75-212 um, 25% fines	Fluffy with sand appearance, sticky, may work better with UO2.	266.1 g	Good puck	93.34% 1771	Lamination cracks developed in green pucks after pressing at 10 tons. Good sintered pucks otherwise.	94.78%
GA-20-10%	G0301-1	022500-0	5% Duramax 1020	Water	90 Hz-3.72 min, 20 Hz-26.28 min	110.3 g/min, setting 38	Poor	Dusty	N/A	Unacceptable, Powder like, not as good as 1023 binder.	507 g	N/A	N/A	N/A	N/A
GA-20-12%	G0125-0	011800-0 re-used	5% Duramax 1023	Water	90 Hz-4.22 min, 20 Hz-25.78 min	111.8 g/min, setting 22	Poor, ok with assist	No dust	Most 150-300um, 2% fines	Granulated but wet looking.	1149.6 g	Crack starting at gradient and some radial.	93.91% 1627	N/A	N/A
GA-21-8%	G0302-2	022500-3	7% Duramax 1020	Water	90Hz-6.42 min, 60 Hz-23.58 min	87.3 g/min, setting 35	Poor	Very dusty	N/A	Looks like powder.	249 g	N/A	N/A	N/A	N/A
GA-21-12%	G0302-3	022500-4	7% Duramax 1020	Water	90 Hz-4.17 min, 20 Hz-25.83 min	113.6 g/min, setting 33	Poor	Minimal	N/A	Looks like wet powder.	786 g	N/A	N/A	N/A	N/A
GA-22-10%	G0125-1	121799-2	N/A	5% Duramax 1020 Solution	90 Hz-4.17 min, 20 Hz-25.83 min	94.7 g/min, setting 24	Adequate	Minimal	Most 75-212 um, 14% fines	Very small granules.	9.3 g	Good puck, slight gradient evident.	91.81% 1628	Lamination cracks developed in green puck after pressing at 10 tons. Good sintered pucks otherwise.	95.39%
GA-22-12%	G0125-3	121799-1	N/A	5% Duramax 1020 Solution	90 Hz-5.83 min, 20 Hz-24.17 min	98.1 g/min, setting 24	Adequate to Good (61)	Minimal	Most 75-212 um, 9% fines	Small granules. Binder not started until 2.17 minutes into process.	14.0 g	Good puck that broke cold	N/A	Some lamination cracks with pucks pressed above 7 tons. Others good pucks green and sintered.	94.21%
GA-22-12% Full	G0229-1	121399-1, 121399-2	N/A	5% Duramax 1020 Solution	90 Hz-8.28 min, 60 Hz-21.72 min	98.9 g/min, setting 35	Poor (61)	Minimal	Most 75-300 um, 3% fines	Very small granules.	20.8 g	Good puck that broke in half cold.	92.98% 1834	Combined with smaller batch	

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GA-22-14%	G0125-2	121799-3	N/A	5% Duramax 1020 Solution	90 Hz-5min, 20 Hz-25 min	115.0 g/min, setting 24	Good	Minimal (least of 22s)	Most 75-212 um, 23% fines	Small granules with a few >600 um.	48.0 g	Good puck	93.28% 1630	Lamination cracks developed in green pucks after pressing at 10 tons. Good sintered pucks otherwise.	93.74%
GA-23-6%	G0224-4	021700-5	N/A	10% Duramax 1020 Solution	90 Hz-5.8 min, 60 Hz-24.2 min	38.9 g/min, setting 35	Ok with assist (64)	Slightly dusty	Most 75-212 um, 7% fines	Very small granules. Undershot binder addition, clogging	93.9 g	Crack starting at gradient and 2 radial.	90.28% 1832	No problems pressing (8 & 10 ton). Pucks had a couple of radial cracks after sintering.	92.71%
GA-23-8%	G0126	111799-1 re-used	N/A	10% Duramax 1020 Solution	90 Hz-3.97 min, 40 Hz-26.03 min	80.8 g/min, setting 20	Poor	Minimal	Most 75-212 um, 10% fines	Small granules	4.0 g	Good puck that broke cold.	N/A	No problems pressing (10 & 12 ton). Pucks had a couple of radial and lamination cracks after sintering.	93.32%
GA-23-10%	G0126-2	111799-2 re-used	N/A	10% Duramax 1020 Solution	90 Hz-4.17 min, 20 Hz-25.83 min	94.6 g/min, setting 20	Poor	Minimal	Most 75-150 um, 4% fines	Small granules	10.0 g	Good puck that broke cold, gradient crack	N/A 1632	No problems pressing (7 ton). Good pucks but 2 broke cold.	91.17%
GA-23-10%	G0225-2	011100-2	N/A	10% Duramax 1020 Solution	90 Hz-4.17 min, 60 Hz-25.83 min	94.6 g/min, setting 35	Ok with assist	No dust	Most 75-150 um, 6% fines	Small granules	5.2 g	N/A	N/A	N/A	N/A
GA-23-12%	G0126-1	010400-0	N/A	10% Duramax 1020 Solution	90 Hz-4.83 min, 40 Hz-25.17 min	94.0 g/min, setting 20	Very good (66)	Minimal	Most 75-300 um, 5% fines	Very small granules.	2.5 g	N/A	N/A	No problems pressing up to 7.4 tons, chatter above. Combined with G0306-2 powder.	91.31%
GA-23-12% Full	G0229-2	020100-1, 020100-3, re-used	N/A	10% Duramax 1020 Solution	90 Hz-7.33 min, 60 Hz-22.67 mim	115.5 g/min, setting 35	Ok, poor when tapped (66)	Minimal	Most 75-300 um, 4 % fines	Very small granules, hold-up on bar and nozzle.	23 g	Good puck	88.76% 1835	Good pucks but some brownish color after sintering.	88.43%
GA-23-12% Full	G0306-0	020100-0, 020100-2	N/A	10% Duramax 1020 Solution	90 Hz-10.75 min, 60 Hz-19.25 min	73.8 g/min, setting 29	Poor to ok with assist (64)	Minimal	Most 75-300 um, 1% fines	Small granules, looked like powder.	~6.9 g	Broke in half cold at a piece of media, good otherwise.	91.56% 1934	See G0126-1	
GA-23-12% Full	G0306-1	011100 re-used	N/A	10% Duramax 1020 Solution	90 Hz-8.55 min, 60 Hz- 21.45 min	109.9 g/min, setting 32	Poor to ok with assist (68)	Minimal	Most 75-300 um, 3.5% fines	Small granules, hold-up in non-powder flow region (had about 7 g hold-up before starting).	34.5 g	Broke in 3 pieces cold, good otherwise.	N/A 1935	N/A	N/A
GA-23-12% Full	G0306-2	010500-1, 010500-3 re-used	N/A	10% Duramax 1020 Solution	90 Hz-3.85 min, 50 Hz-26.15 min	252.6 g/min, setting 70	Poor to ok with assist	No dust	Most 75-300 um, 2.5% fines	Small granules, changed to larger nozzle size, need to slow down during binder addition with large	18.8 g	Broke in 3 pieces cold, good otherwise.	N/A 1936	No problems pressing up to 7.4 tons, chatter above.	91.31%
GA-23-12% Full	G0316-0	120899, 011800-0	N/A	10% Duramax 1020 Solution	90 Hz-6.68 min, 50 Hz-23.32 min	setting 70, pump problem	Needs assist (76)	No dust	Most 75-212 um, 2.5% fines	Still looks like powder, but has some very small to medium granules.	~14.1 g	Good puck	91.98% 1941	Good pucks for the most part, a couple cracked cold.	91.97%
GA-23-12% Full	G0316-1	012500-0, 020700-0 re-used	N/A	10% Duramax 1020 Solution	Not clean, 90 Hz-2.88 min, 50 Hz-27.12 min	600 g/min, setting 85	Ok (74)	Slightly dusty	Most 75-212 um, 2.5% fines	Various sized granules, hold-up mostly in valve neck.	~97.1 g	Good puck	91.83% 1943	N/A	N/A
GA-23-12% Full	G0317-0	021100-1	N/A	10% Duramax 1020 Solution	Not clean, 90 Hz-2.35 min, 50 Hz-27.65 min	533.3 g/min, setting 85	Poor	Minimal	N/A	Various sized granules, needed assist when dumped with the valve.	~121 g	N/A	N/A	N/A	N/A
GA-23-12% Full	G0317-1	030300-3, 111799	N/A	10% Duramax 1020 Solution	Not clean, 90 Hz-2.42 g/min, 50 Hz-27.58 g/min	482.4 g/min, setting 85	Poor	Minimal	N/A	Various sized granules, needed assist when dumped with the valve.	~191 g	N/A	N/A	N/A	N/A
GA-23-12% Full	G0317-2	031500-0	N/A	10% Duramax 1020 Solution	Not clean, 90 Hz-2.42 g/min, 50 Hz-27.58 g/min	531.7 g/min, setting 85	Poor	Dusty	N/A	Hot powder, still looks like powder, nothing came out when valve opened.	~523 g	N/A	N/A	N/A	N/A

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GA-23-12% Full	G0410-0	012500, 020700, re-used	N/A	10% Duramax 1020 Solution	90 Hz-3 min, 60 Hz-4 min, 40 Hz-1.92 min, 10 Hz-21.08 min	144.0 g/min, setting 34	Ok	Minimal	N/A	Small granules formed, hold-up was minimal in vessel.	est. 20 g	N/A	N/A	N/A	N/A
GA-23-12%	G0531-0	040300-0, 040300-1	N/A	10% Duramax 1020 Solution with dispersant	90 Hz-3.62 min, 20 Hz-1.48 min	130.9 g/min, setting 40	Good	Minimal	N/A	3% Dispersant D3021 added to prevent agglomeration, granulated, didn't help with clogging.	71.3g	N/A	N/A	N/A	N/A
GA-23-12%	G0531-1	040300-0, 040300-1 re-used	N/A	10% Duramax 1020 Solution with dispersant	90 Hz-2.92 min, 20 Hz-7.08 min	143.9 g/min, setting 40	Good	Minimal	N/A	3% Dispersant D3021 added to prevent agglomeration, small granules with some large agglomerates, didn't help with clogging.	172.1 g	N/A	N/A	N/A	N/A
GA-24-8%	G0224-0	111899-1, re-used	N/A	15% Duramax 1020 Solution	90 Hz-3.17 min, 20 Hz-26.83 min	110.6 g/min, setting 35	Poor to ok with assist (65)	Slightly dusty	Most 75-212 um, 6% fines	Very small granules	26.3 g	Good puck	90.85% 1826	No problems pressing (7 ton). Good pucks but 2 cracked in half cold.	88.27%
GA-24-10%	G0301-0	120799-0 re-used	N/A	15% Duramax 1020 Solution	90 Hz-3.73 min, 20 Hz-26.27 min	109.9 g/min, setting 35	Good (64)	Minimal	Mostly 75-300 um, 6% fines	Small granule	20 g	Cold cracks that broke puck in 3 pieces.	N/A 1836	No problems pressing (7 ton). 2 pucks cracked in half cold due to possible media contamination.	90.64%
GA-24-10%	G0323-0	032100-0, 032100-1	N/A	15% Duramax 1020 Solution	50 Hz-6.17 min, 20 Hz- 23.83 min	104.0 g/min, setting 33	Poor, but good with assist (64)	Minimal	Mostly 75-300 um, 19% fines	Small granules that look like sand	~216 g	N/A	N/A	N/A	N/A
GA-24-12%	G0224-1	120799-2	N/A	15% Duramax 1020 Solution	90 Hz-4.37 min, 60 Hz-25.63 min	106.8 g/min, setting 35	Good (69)	Slightly dusty	Most 75-212 um, 3% fines	Small granules	10.5 g	Good puck that cracked in half cold.	91.1% 1827	No problems pressing (7 ton). Good pucks but one slightly brown after sintering.	89.96%
GA-24-12%	G0324-0	032000-4	N/A	15% Duramax 1020 Solution	90 Hz-4.37 min, 60 Hz-25.63 min	111 g/min, setting 35	Adequate	Dusty	N/A	Very small granules, used metal cover and valve.	~347 g	N/A	N/A	N/A	N/A
GA-24-12%	G0324-1	032000-3	N/A	15% Duramax 1020 Solution	90 Hz-5 min, 60 Hz- 25 min	88.0 g/min, setting 35	N/A	N/A	N/A	Problems with prefilter pluggage.	~254 g	N/A	N/A	N/A	N/A
GA-24-12%	G0324-2	032100-4	N/A	15% Duramax 1020 Solution	90 Hz-5 min, 60 Hz- 25 min	83.0 g/min, setting 35	Good	Dusty	N/A	Problems with prefilter pluggage, but made acceptable powder.	~169 g	N/A	N/A	N/A	N/A
GA-24-14%	G0224-2	120799-3 re-used	N/A	15% Duramax 1020 Solution	90 Hz-4.9 min, 60 Hz-25.1 min	107.7 g/min, setting 35	Good (67)	Some reduction	Most 75-212 um, 2% fines	Very small granules	10.9 g	Good puck that cracked in half cold.	88.92% 1828	No problems pressing (7 ton). Good pucks but slightly brown after sintering.	88.28%
GA-25-10%	G0124-3	010500-1	N/A	5% HPMC/ 10% PEG	90 Hz-4.33 min, 20 Hz-25.67 min	90.0 g/min, setting 20	Good	Minimal	Most 75-212 um, 23% fines	Very small granules	200.3 g	Crack along gradient with some additional burnout cracking.	92.73% 1634	N/A	N/A
GA-25-14%	G0124-4	010500-3	N/A	5% HPMC/ 10% PEG	90 Hz-5 min, 20 Hz- 25 min	105.0 g/min, setting 20	Good	Minimal	Most 75-212 um, 27% fines	Various sized granules with large agglomerates.	264.2 g	Crack along gradient with some additional burnout cracking.	92.17% 1635	N/A	N/A

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Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-26-10%	G0204-0	010400-2	N/A	10% HPMC/ 10% PEG	90 Hz-3.88 min, 20 Hz-26.12 min	104.2 g/min, setting 34	Good (67)	Minimal	Most 75-212 um, 20% fines	Various sized granules with some large agglomerates.	308.3 g	Burn-out cracking in both radial & circumferential direction.	91.38% 1655	N/A	N/A
GA-26-14%	G0204-1	120899-1	N/A	10% HPMC/ 10% PEG	90 Hz-5.15 min, 60 Hz-24.85 min	101.2 g/min, setting 34	Very good (49)	No dust	Most 106-300 um, 9% 1 mm, 13% fines	Recycled Powder, small to medium sized granules.	53.8 g	Crack along gradient starting, cold crack broke in half.	92.2% 1653	N/A	N/A
GA-26-14%	G0204-2	011100-0	N/A	10% HPMC/ 10% PEG	90 Hz-4.65 min, 60 Hz-25.35 min	115.1 g/min, setting 34	Very good (44)	Minimal	Most 106-300 um, 18% fines	Fresh Powder, small to medium sized granules.	312.5 g	Crack along gradient with radial cracks also.	91.85% 1654	N/A	N/A
GA-28-10%	G0210-0	111899-0	N/A	8% HPMC/ 20% PEG	90 Hz-3.6 min, 20 Hz-26.4 min	116.2 g/min, setting 34	With assist (72)	Minimal	Some 300 um, most 75-212 um, 6% fines	Very small granules and some larger agglomerates.	33.2 g	Good puck	92.14% 1706	Some lam. cracks with pucks pressed above 7 tons. Others good green and sintered.	92.54%
GA-28-12%	G0210-2	121499-1	N/A	8% HPMC/ 20% PEG	90 Hz-4.33 min, 20 Hz-25.67 min	108.1 g/min, setting 34	Good (68)	No dust	Most 75-300 um, 6% fines	Various sized small granules with some larger agglomerates.	39 g	Good puck	91.60% 1707, 1712	Good pucks but some faint lamination cracking on up to 1/3 of puck.	93.15%
GA-28-12% (Full)	G0214-0	010500-0, 010500-2	N/A	8% HPMC/ 20% PEG	90 Hz-7.8 min, 20 Hz-22.2 min	105.9 g/min, setting 34	Good (73)	Minimal	19% 300 um, 29% 150 um, 8% fines	Small granules	248 g	3 radial cracks off gradient.	93.17% 1749	Pucks had a couple of radial cracks and some lamination cracks after sintering.	92.92%
GA-28-14%	G0210-1	120799-1 re-used	N/A	8% HPMC/ 20% PEG	90 Hz-4.63 min, 20 Hz-25.37 min	115.7 g/min, setting 34	Very good (61)	No dust	Most 75-300 um, 15% fines	Small granules	27.8 g	A radial crack	93.51% 1705	Pucks had a couple of radial cracks and some lamination cracks after sintering.	94.97%
GA-28-14%	G0331-0	032100-2	N/A	8% HPMC/ 20% PEG	90 Hz-5.17 min, 20 Hz-24.83 min	105.8 g/min, setting 34	Very good	Minimal	N/A	Various sized granules.	351 g	N/A	N/A	Lamination cracks from pressing, radial & surface cracks after sintering.	95.21%
GA-28-14%	G0331-1	032100-3	N/A	8% HPMC/ 20% PEG	90 Hz-5.17 min, 20 Hz-24.83 min	111.8 g/min, setting 34	Very good	Minimal	N/A	Various sized granules.	370 g	N/A	N/A	Radial cracks after sintering and lamination cracking on half of puck due to die problem.	95.11%
GA-28-14% (Full)	G0214-1	010400-1, 010400-3	N/A	8% HPMC/ 20% PEG	90 Hz-9.12 min, 20 Hz-20.88 min	103.4 g/min, setting 33	Very good (68)	No dust	13% 1mm, rest 75-300 um, 7% fines	Small granules	20.9 g	Good puck	92.53% 1750	Good pucks overall but had some lamination cracks on 1/2 of puck circumference.	93.74%
GA-28-14% (Full)	G0315-1	113099-2, 121499-3 re-used	N/A	8% HPMC/ 20% PEG	90 Hz-3.58 min, 20 Hz-26.42 min	329.1 g/min, setting 70	Very good (68)	No dust	45% 1mm, rest 75-300 um, 6% fines	Many granules up to 1/4", did not clean vessel, used valve to discharge.	est. 59 g	1 radial crack with gradient evident.	93.1% 1942	A radial crack on each puck and some lamination cracks after sintering.	94.04%
GA-28-14% (Full)	G0315-2	121799, 100799-3	N/A	8% HPMC/ 20% PEG	80 Hz-3.5 min, 20 Hz-26.5 min	334.0 g/min, setting 70	Good (61)	No dust	49% 1mm, rest 75-300 um, 9% fines	Many granules of up to 1/4", did not clean vessel, used valve to discharge.	est. 452 g	Couple of faint radial and lamination cracks.	94.67% 1940	Several radial cracks after sintering and some pucks had some brown after sintering. Overall pucks are acceptable.	92.83%
GA-29-8%	G0127-1	011800-3	4.5% Airvol in Powder	5% Airvol Solution	90 Hz-3.92 min, 60 Hz-26.08 min	82.2 g/min, setting 20	Poor	Some reduction	Most 75-150 um, 13% fines	Small granules	22.7 g	Good puck with gradient crack.	94.3% 1636	N/A	N/A
GA-29-10%	G0127-0	011800-5	4.5% Airvol in Powder	5% Airvol Solution	90 Hz-4.33 min, 20 Hz-2.5 min, 40 Hz-23.17 min	90.1 g/min, setting 20	With assist	Slightly dusty	Some 425 um, rest 75-150 um, 20% fines	Small granules	10 g	Good puck with faint gradient crack.	94.26% 1637	Lamination cracks developed green and radial cracks after sintering. Acceptable overall.	93.91%
GA-29-10%	G0203-0	112499-1	4.5% Airvol in Powder	5% Airvol Solution	90 Hz-4.58 min, 60 Hz-25.42 min	83.8 g/min, setting 34	Poor (77)	Minimal	13% 1 mm, rest 75-106 um, 18% fines	Small granules	22.2 g	Good puck with faint gradient cracks starting.	92.27% 1647	1-2 faint radial and lamination (1/4 to 1/3 circumference) cracks. Acceptable overall.	91.41%
GA-30-8%	G0202	011900-0	4.5% Airvol in Powder	10% Airvol Solution	90 Hz-4.3 min, 20 Hz-25.7 min	72.7 g/min, setting 32	Good (67)	Dusty	15% 1 mm, some 75-106 um, 33% fines	Various sized granules	21.0 g	Crack along gradient with some radial starting.	93.48% 1646	Lamination cracks on all pucks, with radial cracks on some.	94.64%

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GA-30-10%	G0202-2	011900-1	4.5% Airvol in Powder	10% Airvol Solution	90 Hz-4.28 min, 60 Hz-25.72 min	91.5 g/min, setting 32	Good (64)	Some, less than 8, more than 12	20% 1mm, some 75-106 um, 29% fines	Various sized granules with some >850 um.	14.8 g	Gradient crack and 1 puck broke in half cold, other puck some lam.	94.11% 1643, 2070	A faint radial crack on each puck, pressed fine and pucks good otherwise.	92.90%
GA-30-10% Full	G0223-2	020400-3, 020400-2	4.5% Airvol in Powder	10% Airvol Solution	90 Hz-6.23 min, 60 Hz-23.77 min	113.9 g/min, setting 35	Ok to good, very good with assist (70)	No dust	18% 1 mm, some 75-150 um, 14% fines	Small to medium size granules.	77.7 g	Faint crack on gradient, good otherwise.	93.12% 1788		
GA-30-12%	G0202-1	011900-2	4.5% Airvol in Powder	10% Airvol Solution	90 Hz-4.65 min, 60 Hz-25.35 min	98.6 g/min, setting 32	Good with assist (65)	Less dusty than 8	29% 1mm, some 75-106 um, 29% fines	Various sized granules with few >850 um.	17.5 g	Gradient crack with a radial also.	92.53% 1644	Some lamination cracks & radial cracks on a few pucks. All pucks acceptable.	94.33%
GA-31-8%	G0203-1	012500-2	6% Airvol in powder	5% Airvol Solution	90 Hz-3.25 min, 60 Hz-26.75 min	106.7 g/min, setting 34	Ok with assist (67)	Minimal	Most 75-150 um, 21% fines	Various sized granules.	52.5 g	Good puck with faint gradient crack starting.	93.83% 1648	Good pucks	95.17%
GA-31-10%	G0215-2	012500-1	6% Airvol in powder	5% Airvol Solution	90 Hz-3.75 min, 60 Hz-26.25 min	109.1 g/min, setting 34	Ok to good with assist (64)	Minimal	Most 75-150 um, 23% fines	Some granules formed.	58.1 g	Good puck	95.28% 1767	Good pucks	95.61%
GA-31-12%	G0203	012500-4	6% Airvol in powder	5% Airvol Solution	90 Hz-4.67 min, 60 Hz-25.33 min	98.1 g/min, setting 34	Ok to good with assist (71)	Minimal	12% 1 mm, rest 106um, 21% fines	Various sized granules with some > 1 mm.	45.1 g	Good puck with faint gradient crack starting.	94.18% 1645	Good pucks >6 tons, others had some radial cracks.	91.46%
GA-31-14%	G0209-0	012500-0	6% Airvol in powder	5% Airvol Solution	90 Hz-5.22 min, 60 Hz-24.78 min	99.5 g/min, setting 34	Poor (67)	Minimal	14% 1mm & 30% 150 um, 22% fines	Small granules, behavior of powder improved some after drying.	95.3 g	Puck cracked in half during sintering along gradient.	N/A 1704	N/A	N/A
GA-32-4%	G0207	013100-2	6% Airvol in powder	10% Airvol Solution	90 Hz-1.9 min, 60 Hz-28.1 min	133.3 g/min, setting 34	Poor to ok with assist (62)	Some reduction	Most 75-150 um, 15% fines	Small granules	31.8 g	Crack along gradient.	93.39% 1656	A radial crack on each puck and some lamination cracks after sintering. Acceptable.	95.46%
GA-32-8%	G0204-3	013100-3	6% Airvol in powder	10% Airvol Solution	90 Hz-3.9 min, 60 Hz-26.1 min	82.2 g/min, setting 34	Ok to good with assist (65)	Minimal	Most 75-150 um, 13% fines	Small granules	58.4 g	Radial crack that caused gap in puck.	92.27% 1657	Some radial and lamination cracks. Acceptable.	94.79%
GA-32-10% (full)	G0223-3	020700-2, 020700-3	6% Airvol in powder	10% Airvol Solution	90 Hz-6.35 min, 60 Hz-23.65 min	112.1 g/min, setting 35	Marginal, good with assist (64)	No dust	46% 1 mm, rest 75-150um, 15% fines	Various sized granules with a lot >1 mm.	79.6 g	Very small radial and gradient crack.	94.94% 1825	Some faint radial & lamination cracks. Acceptable.	93.99%
GA-32-10% (full)	G0418-2	030800-3, 030800-4 re-used	6% Airvol in powder	10% Airvol Solution	90 Hz-3.75 min, 80 Hz-1.1 min, 25 Hz-5.15 min	159.1 g/min, setting 39	Good flow with assist	Minimal	N/A	Various sized granules up to 1 mm.	97.5 g	N/A	N/A	N/A	N/A
GA-32-12%	G0204-4	013100-1	6% Airvol in powder	10% Airvol Solution	90 Hz-4.2 min, 60 Hz-25.8 min	112.5 g/min, setting 34	Ok to good with assist (66)	Minimal	16% 1 mm, some 75-150um, 19% fines	Various sized granules with some >850 um.	42.2 g	Puck cracked cold, good otherwise.	91.78% 1658	Radial cracks starting & faint lamination cracks. Acceptable.	93.88%
GA-32-14%	G0207-1	013100-0	6% Airvol in powder	10% Airvol Solution	90 Hz-5.08 min, 60 Hz-24.92 min	102.9 g/min, setting 34	Good (53)	No dust	43% 1 mm, 15% fines	Various sized granules with some >1 mm.	133.7 g	Crack on gradient starting along with some radials	94% 1661	N/A	N/A
GA-32-14%	G0407	030800-1	6% Airvol in powder	10% Airvol Solution	90 Hz-4.5 min, 80 Hz-0.83 min, 60 Hz-24.67 min	120 g/min, setting 34	Good	No dust	79% 1 mm, 8% fines	Various sized granules with many >1 mm. Hold-up increased after 16 minutes of processing.	~321 g	N/A	N/A	Still see granules, 1 radial crack on each puck and some lamination cracks, acceptable.	93.87%

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GA-32-16%	G0404-0	030800-2	6% Airvol in powder	10% Airvol Solution	90 Hz-5.5 min, 60 Hz-4.5 min	102.0 g/min, setting 34	Good (61)	No dust	64% 1 mm, rest <106 um, 7% fines	Various sized granules with a lot >1 mm. Hold-up started accumulating in powder path, so stopped after 10 min.	~62 g	Crack along gradient with a faint radial also.	93.32% 2088	N/A	N/A
GA-33-8%	G0208-0	020100-0	2% PEG & 4% Airvol in powder	Water	90 Hz-3.37 min, 60 Hz-26.63 min	101.3 g/min, setting 34	Poor to ok with assist (63)	Minimal	Most 75-150 um, 16% fines	Very small granules with some larger agglomerates.	45.4 g	Crack along gradient with some radial also.	94.48% 1659	N/A	N/A
GA-33-8% Repeat	G0209-0	020100-2	2% PEG & 4% Airvol in powder	Water	90 Hz-3.38 min, 60 Hz-26.62 min	100.7 g/min, setting 34	Ok to good with assist (61)	Some reduction	Most 75-150 um, 29% fines	Various sized granules with a few >700 um.	156.7 g	Radial crack and a crack along gradient starting.	94.14% 1708	N/A	N/A
GA-33-10%	G0209-1	020100-3	2% PEG & 4% Airvol in powder	Water	90 Hz-4 min, 60 Hz-26 min	100.0 g/min, setting 34	Ok to good with assist (71)	No dust	Most 75-300 um, 21% fines	Most of hold-up removed with tapping, small granules and some larger agglomerates.	1184.8 g	Radial crack and a crack along gradient starting.	94.28% 1709	N/A	N/A
GA-33-12%	G0208-2	020100-1	2% PEG & 4% Airvol in powder	Water	90 Hz-4.73 min, 60 Hz-1.22 min, 40 Hz-2.55 min, 60 Hz-21.5 min	131.9 g/min, setting 34	Powder tends to bridge, ok with assist (77)	No dust	8% 1 mm, rest 75-300 um, 2% fines	Various sized granules with some very large agglomerates; most of hold-up discharged with assist.	1401.0 g	Lamination cracks from pressing that remained after sintering.	92.57% 1660	N/A	N/A
GA-34-8%	G0211-0	020400-0	4.5% Airvol in Powder	20% PEG solution	90 Hz-3.75 min, 60 Hz-26.25 min	87.3 g/min, setting 37	Poor flow due to bridging (60)	Some reduction	Most 75-212um, 11% fines	Some very small granules.	63.8 g	Good pucks (needs lube)	94.01% 1751, 1781	N/A	N/A
GA-34-12%	G0211-1	020400-1	4.5% Airvol in Powder	20% PEG solution	90 Hz-4 min, 60 Hz-26 min	120.0 g/min, setting 37	Poor flow due to bridging (68)	Minimal	Most 75-212 um, 16% fines	Very small granules.	56.7 g	Gradient & radial cracking (needs lube).	94.53% 1752, 1780	N/A	N/A
GA-35-8%	G0211-2	020700-1	6% Airvol in powder	20% PEG solution	90 Hz-3.38 min, 60 Hz-26.62 min	100.8 g/min, setting 35	Poor to ok with assist (67)	Slightly dusty	Most 75-212 um, 8% fines	Small granules to fines.	15.0 g	1 radial crack off gradient crack.	93.42% 1753, 1778	N/A	N/A
GA-35-12%	G0211-3	020700-0	6% Airvol in powder	20% PEG solution	90 Hz-4.12 min, 60 Hz-25.88 min	115.4 g/min, setting 34	Poor to ok with assist (70)	Minimal	Most 75-212 um, 15% fines	Very small granules.	12.8 g	2 radial cracks and crack starting at gradient.	93.60% 1754, 1777	N/A	N/A
GA-36-8%	G0223-0	021400-1	2% PEG in powder	10% Airvol Solution	90 Hz-3.5 min, 60 Hz-26.5 min	96.0 g/min, setting 35	Good (71)	Dusty	11% 1 mm, rest 75-150 um, 11% fines	Various sized granules.	18.3 g	Radial cracks with a circumferential starting.	94.1% 1774	Radial & circumferential cracks. Acceptable.	92.44%
GA-36-12%	G0223-1	021400-2	2% PEG in powder	10% Airvol Solution	90 Hz-4.35 min, 60 Hz-25.65 min	107.5 g/min, setting 35	Good (54)	No dust	38% 1mm, 17% fines	Various sized granules with some 1 mm.	28.7 g	Few radial cracks with a faint lamination crack.	94.57% 1779	Several radial cracks and circumferential.	93.79%
GA-37-6%	G0225-1	021700-1	3% PEG in powder	10% Airvol Solution	90 Hz-2.58 min, 60 Hz-27.42 min	113.9 g/min, setting 35	Ok to good with assist (67)	Dusty	Most 75-212 um, 10% fines	Small granules	33.7 g	Crack along gradient with several radial off.	89.11% 1830	N/A	N/A
GA-37-8%	G0215-0	122999-1	3% PEG in powder	10% Airvol Solution	90 Hz-3.83 min, 60 Hz-26.17 min	87.3 g/min, setting 34	Good (65)	Minimal	25% 1 mm, rest 75-150um, 20% fines	Various sized granules	8.2 g	Crack along gradient with some radial also.	92% 1768	N/A	N/A
GA-37-10%	G0225-0	021700-0	3% PEG in powder	10% Airvol Solution	90 Hz-4.25 min, 60 Hz-25.75 min	92.3 g/min, setting 35	Ok to good with assist (48)	Minimal	35% 1 mm, 20% fines	Various sized granules up to 1 mm.	155.8 g	Crack along gradient with several radial off.	88.81% 1831	N/A	N/A

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GA-37-12%	G0215-1	122799-1	3% PEG in powder	10% Airvol Solution	90 Hz-4.63 min, 60 Hz-25.37 min	99.2 g/min, setting 34	Good (48)	No dust	46% 1 mm, rest 75-150um, 8% fines	Various sized granules	21.1 g	Cracking in radial & circum. direction.	90.53% 1769	N/A	N/A
GA-38-8%	G0218-0	021100-0	3% M-150	Water	90 Hz-3.48 min, 20 Hz-26.52 min	96.8 g/min, setting 38	Poor (68)	Dusty	Most 75-212 um, 11% fines	Small granules	59.0 g	Crack along gradient with radial cracks also.	94.77% 1770	N/A	N/A
GA-38-12%	G0218-1	021100-1	3% M-150	Water	90 Hz-4.47 min, 20 Hz-25.53 min	103.7 g/min, setting 38	Poor (66)	Minimal	Most 75-212 um, 14% fines	Some small granules	51.1 g	Faint cracks on gradient, good otherwise.	94.84% 1773	N/A	N/A
GA-39-10%	G0228-0	021800-1	2% PEG 8K	5% HPMC Solution	90 Hz-4 min, 20 Hz-26 min	100.0 g/min, setting 36	Good (66)	Slightly dusty	12% 1mm, rest 75-300 um, 15% fines	Small granules	59.0 g	Cracking along the gradient with radials off, moisture cracking.	94.82% 183	Faint lamination cracking and a few minor radial cracks. Acceptable.	94.03%
GA-39-12%	G0229-0	021800-3	2% PEG 8K	5% HPMC Solution	90 Hz-4.67 min, 20 Hz-25.33 min	98.1 g/min, setting 36	Ok, good with slight assist (63)	No dust	32% 1mm, 12% fines	Various sized granules	46.2 g	Couple of radial cracks & some top surface cracks.	94.45% 1838	Radial and circumferential cracks.	93.97%
GA-39-14%	G0228-1	021800-2	2% PEG 8K	5% HPMC Solution	90 Hz-5.55 min, 20 Hz-24.45 min	99.5 g/min, setting 35	Ok, good with slight assist (73)	Minimal	39% 1 mm, 5% fines	Various sized granules, hold-up is mostly granules.	100.0 g	Several circumferential cracks.	94.13% 1839	Couple of radial cracks in each puck, acceptable.	93.72%
GA-40-10%	G0302	021800-4	2% PEG 8K	8% HPMC Solution	90 Hz-3.07 min, 20 Hz-26.93 min	130.4 g/min, setting 37	Ok (61)	Minimal	Mostly 150um, rest 75-300 um, 9% fines	Various sized granules.	36.3 g	Gradient crack and couple radials.	95.3% 1840	A couple of radial and some circumferential cracks. Acceptable.	95.38%
GA-40-12%	G0302-1	122299-0	2% PEG 8K	8% HPMC Solution	90 Hz-4.23 min, 20 Hz-25.77 min	113.2 g/min, setting 35	Good (55)	No dust	34% 1mm, rest 75-300 um, 9% fines	Well granulated with various sized granules.	42.8 g	Gradient crack with some radials and top surface cracking.	93.56% 1841	Still see granules, several radial cracks, acceptable.	88.73%
GA-41-10%	G0309-0	030200-0	3% PEG 8K	10% HPMC Solution	90 Hz-4.22 min, 20 Hz-25.78 min	93.2 g/min, setting 35	Ok to good with assist (67)	Minimal	6% 1 mm, rest 75-300 um, 14% fines	Small granules	50.9 g	Broke at gradient.	N/A 1937	N/A	N/A
GA-41-14% (probably 10%)	G0309-1	030200-1	3% PEG 8K	10% HPMC Solution	90 Hz-4.67 min, 20 Hz-25.33 min	114.4 g/min, setting 35	Good (73)	Minimal	12% 1mm, rest 75-300 um, 20% fines	Various sized granules mostly <700 um.	124 g	Crack along gradient with some radials off of it.	94.55% 1938	N/A	N/A
GA-41-12.6%	G0310-0	030200-3	3% PEG 8K	8 & 10% HPMC Solution	90 Hz-4.5 min, 20 Hz-25.5 min	107.7 g/min, setting 35	Poor	No dust	N/A	Various sized granules.	265 g	Circumferential and radial cracks.	94.66% 2774	N/A	N/A
GA-41-14% (Full)	G0310-1	030200-4	3% PEG 8K	10% HPMC Solution	90 Hz-5.67 min, 20 Hz-24.33 min	89.9 g/min, setting 33	Needs assist	No dust	N/A	Various sized granules (hold-up was mostly granules).	133.2 g	Doesn't look compacted, several lamination cracks.	91.64% 2775	N/A	N/A
GA-42-10%	G0303-1	022900-3	3% PEG 8K	8% HPMC Solution	90 Hz-3 min, 20 Hz-27 min	150.0 g/min, setting 35	Poor	Dusty	N/A	Looked like powder, did not run further testing.	35 g	N/A	N/A	N/A	N/A
GA-42-14%	G0303-2	122299-0, 022800-4	3% PEG 8K	8% HPMC Solution	90 Hz-4.75 min, 20 Hz-25.25 min	110.9 g/min, setting 36	Ok (64)	No dust	34% 1mm, rest 75-300 um, 4% fines	Various sized granules, some of hold-up was granules.	99.2 g	Gradient cracks with top surface cracks also.	93.99% 1842	N/A	N/A
GA-43-10%	G0302-4	022800-0	3% Duramax 1020	10% Duramax 1020 Solution	90 Hz-3.75 min, 20 Hz-26.25 min	109.1 g/min, setting 33	Poor	Dusty	N/A	Still looks like powder, no improvement over plain Duramax 1020 powder.	699 g	N/A	N/A	N/A	N/A
GA-44-12%	G0303-0	22800	3% Duramax 1020	8% HPMC Solution	90 Hz-4.5 min, 20 Hz-25.5 min	102.9 g/min, setting 36	Needs assist (60)	Minimal	48% 150 um, rest 75-300 um, 15% fines	Small granules, hold-up in transition areas (mostly granules).	78.7 g	Couple of radial cracks on sides and top.	95.29% 1837	N/A	N/A

Appendix D - Summary of Cerium Granulation Test Parameters and Product Data

Matrix Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Vessel Parameters	Binder Addition	Flow	Dust	Particle Size	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density	Best Press Pucks	Average Arch. Density
GA-45-12% (full)	G0425-2	020400-0, 020400-1, re-used	4.5% Airvol in powder	15% Airvol Solution	80 Hz-5 min, 25 Hz-5 min	173.8 g/min, setting 39	Tapped needs assist	Dusty	N/A	Undersprayed during granulation, not good granulation.	132.3 g	N/A	N/A	Good pucks with some faint lamination cracking on front side (press die problem).	92.98%
GA-45-12% (full)	G0425-3	011100-2, 020400-0, re-used	4.5% Airvol in powder	15% Airvol Solution	80 Hz-6 min, 25 Hz-4 min	146.1 g/min, setting 39	Ok to good with assist	Minimal	N/A	Various sized granules.	3.3 g	N/A	N/A	N/A	N/A
GA-45-12%	G0426-0	011900-3, re-used	4.5% Airvol in powder	15% Airvol Solution	80 Hz-3.47 min, 25 Hz-6.53 min	148.3 g/min, setting 39	Good	Minimal	N/A	Some nozzle pluggage, but very good product.	47.4 g	N/A	N/A	All pucks had some radial cracks on 1/2 of puck (press die problem).	94.23%
GD-10	GT0628-1	60100	6% Airvol 21-205	Water	30 rpm-12.67 min, 10 rpm-11.4 min	137.7 g/min	Needed assist	Slightly dusty	Mostly 75-212 um, 9% fines	Small granules	628 g	Developed a radial crack that broke puck in half.	N/A 2836	N/A	N/A
GD-12	GT0622	051800, 060200	6% Airvol 21-205	Water	30 rpm-13 min, 10 rpm-7 min	95.3 g/min	Better than GD-18	Slightly dusty	Mostly 75-212 um, 9% fines	Very small granules. Powder needed help getting out of vessel corners.	130.9 g	N/A	N/A	N/A	N/A
GD-14	GT0628-0	051800, 060200	6% Airvol 21-205	Water	30 rpm-13 min, 10 rpm-11.12 min	59.6 g/min	Needed assist (77)	Minimal	Mostly 75-212 um, 7% fines	Small granules	55.7 g	A radial crack about 2/3 of diameter.	95.54% 2837	N/A	N/A
GD-16	GT0627-0	060100, 060200	6% Airvol 21-205	Water	30 rpm-13 min, 10 rpm-7 min	89.1 g/min, setting 32	Needed assist	Slightly dusty	Mostly 75-212 um, 7% 1mm & 10% fines	Large granules where spray pattern was going through powder.	52 g	Developed a radial crack that broke puck in half.	N/A 2834	N/A	N/A
GD-18	GT0620-0	60100	6% Airvol 21-205	Water	30 rpm-19 min, 10 rpm-6 min	100.0 g/min, setting 32	Not good out of vessel (63)	No dust	Mostly 75-212 um, 14% 1mm & 8% fines	Some very large granules where spray pattern was going through powder.	112.6 g	N/A	N/A	Acceptable pucks, some lamination cracking due to die problem. Also a few with radial cracks.	95.59%
GE-1	G0313-0	100799-1, 100799-2, re-used	None	20% PEG/ 8% HPMC	90 Hz-8 min, 20 Hz-22 min, agitator 22 Hz for 6.5 min, 30 sec before binder addition & during binder	125 g/min, setting 33, with agitator	Poor because of wetness	No dust	44% 1mm, some 212-450 um, no fines	Large granules, hold-up hard to remove, agitator bar used for binder addition.	134 g	Lamination cracks evident in green state, some radial after sintering.	94.74%	N/A	N/A

Appendix E - Summary of Uranium Granulation Test Parameters and Product Data

Test #	Gran. Batch #	Batch #	Binder Before	During Granulation	Granulation Parameters	Binder Addition	Flow	Dust	Appearance/ Comments	Hold-up	Carver Puck	Arch. Density
GB-1-12%	G0218-2	021100-3	N / A	8% HPMC / 20% PEG Sol'n	90 Hz-3.82 min, 20 Hz-25.18 min	112.1 g / min	Ok	Not too dusty	Small granules, but a lot of hold-up.	350.0 g	Some radial cracking.	92.17
GB-1-14%	GU0308-0	030300-2	N / A	8% HPMC / 20% PEG Sol'n	90 Hz-4.94 min, 20 Hz-25.06 min	104.1 g / min	Good	Some dust	Very small granules	489 g	A couple of radial cracks, some cracking on bottom.	92.26
GB-2-12%	G0228-2	021100-5	N / A	20% PEG Solution	90 Hz-5.7 min, 20 Hz-24.3 min	92.7 g / min	Ok for U	Minimal	Very small granules, all of binder didn't go in.	375 g	A couple of radial cracks, chattering when pressed.	92.45
GB-3-10%	G0229-3	021400-3	8% Airvol to Precursors	Water	90 Hz-3.9 min, 60 Hz-26.1 min	126.9 g / min	Ok to good	None	Very small granules (powder like) with some 3 / 4" agglomerates, some problems with binder pumping system.	1060.4 g	Good pucks except 1 radial crack on each.	93.36
GB-4-10%	G0301-2	021400-5	8% Airvol to Precursors	10% Airvol Solution	90 Hz-1.43 min, 60 Hz-28.57 min	709.8 g / min	Ok	Not too dusty	Some small granules.	52 g	Good pucks	92.74
GB-4-10%	GU0705	031400-2	8% Airvol to Precursors	10% Airvol Solution	90 Hz-5 min, 60 Hz-10 min	76.5 g / min	Good	Minimal	Well granulated	42.4 g	Faint crack along gradient, good otherwise.	93.14
GB-4-12%	GU0412-0	031400-0	8% Airvol to Precursors	10% Airvol Solution	90 Hz-5.85 min, 60 Hz-24.15 min	67.4 g / min	Good with assist	None	Small to large granules, a lot of hold-up. Powder seemed wet.	198 g	Lamination cracks upon ejection, additional radial and moisture cracking after sintering.	91.51
GB-5-12%	G0307-0	030300-0	N / A	10% Duramax 1020 Solution	90 Hz-4.96 min, 20 Hz-25.04 min	86.7 g / min	Good	Minimal	Small granules, but a lot of hold-up.	367 g	Faint circumferential cracking with a radial crack also.	92.23
GB-6-10%	GU0309	030300-3	4% PEG to Precursors	10% Airvol Solution	90 Hz-5.85 min, 60 Hz-24.15 min	64.1 g / min	Very good	No dust	Various sized granules up to 1 / 4"	656.7 g	1 puck broke, others had cracks along gradient with few radial cracks.	91.26
GB-7-12%	GU0315-0	0300-5	4% PEG to Precursors	8% HPMC Solution	90 Hz-4.8 min, 20 Hz-25.2 min	122.4 g / min	Good with assist	No dust	Various sized granules	336.7 g	All cracked during pressing	N / A
GB-8-0%	N / A	030900-0	6.8% Duramax 1020 to Precursors	N / A	N / A	N / A	Poor	Dusty	Powder	N / A	Lamination cracks upon ejection, additional radial cracking after sintering.	94.01
GB-8-10%	GU0315-1	030900-0, 030900-1	6.8% Duramax 1020 to Precursors	Water	90 Hz-4.7 min, 20 Hz-25.3 fin	83.8 g / min	Needs assist, better than Ce	Dusty	Looks like powder with very small granules.	224.2 g	A couple of faint radial and circumferential cracks.	93.41
GB-8-12%	G0321-0	30900	6.8% Duramax 1020 to Precursors	Water	90 Hz-4.96 min, 20 Hz-25.04 min	93.1 g / min	Good	No dust	Small granules, but a lot of hold-up. Powder is acceptble, but process is not.	1088.2 g	N / A	N / A
GB-9-12%	GU0323-0	030900-3	6.8% Duramax 1020 to Precursors	10% HPMC Solution	80 Hz-4.5 min, 20 Hz-25.5 min	102.9 g / min	Ok	No dust	Clumps of granules, hold-up is granules.	~1 kg	Some sticking to top punch, which developed radial cracks in sintered pucks. Good otherwise.	91.77

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-1-0%	1520	3.256	2.600	463.7	442.8	352.515	442.8	1.390	N/A	2.44	4.90	94.32	N/A	N/A	4.51	N/A	20.15	0.7
GA-1-0%	1775	3.256	2.575	499.7	472.5	375.762	469.8	1.424	1.140	2.57	5.02	96.63	4.86	93.37	5.44	49.92	20.92	0.4
GA-1-4%	1505	3.254	2.621	451.8	422.2	335.784	422.4	1.228	0.985	2.70	4.87	93.74	4.85	93.20	6.55	47.95	19.45	4.3
GA-1-8%	1500	3.254	N/A	454.6	N/A	N/A	N/A	1.203	N/A	2.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.0
GA-1-12%, CP	1499	3.254	N/A	451.9	N/A	N/A	N/A	1.171	N/A	2.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.6
GA-1-12% BP 2/24 9.5 ton	1795	3.504	2.852	461.6	393.3	312.827	393.7	0.983	0.797	2.97	4.86	93.52	4.71	90.62	14.80	46.28	18.61	10.6
	1796	3.503	2.841	475.4	407.6	324.083	407.6	1.004	0.808	3.00	4.88	93.85	4.85	93.36	14.26	47.06	18.90	10.6
	1797	3.503	2.836	452.1	387.6	308.178	388.4	0.962	0.776	2.98	4.83	92.92	4.82	92.76	14.27	47.12	19.04	10.6
	1798	3.503	2.843	504.6	432.6	343.446	432.8	1.065	0.862	3.00	4.84	93.10	4.82	92.75	14.27	46.68	18.84	10.6
	1799	3.503	2.847	502.9	431.3	342.064	431.3	1.057	0.861	3.01	4.83	92.95	4.80	92.32	14.24	46.19	18.73	10.6
	1800	3.503	2.847	436.8	374.5	297.336	374.8	0.923	0.745	3.00	4.83	92.97	4.82	92.64	14.26	46.68	18.73	10.6
GA-1-14%, CP	1507	3.253	N/A	466.5	N/A	N/A	N/A	1.123	N/A	3.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.4
GA-1-14% BP 2/24 9.5 ton	1801	3.504	2.846	464.7	396.0	315.082	396.1	0.967	0.782	3.04	4.89	94.00	4.86	93.39	14.78	46.64	18.78	12.4
	1802	3.503	2.847	488.8	414.5	329.930	415.2	1.010	0.838	3.06	4.86	93.48	4.74	91.15	15.20	45.19	18.73	12.4
	1803	3.503	2.847	488.4	414.0	329.431	414.9	1.006	0.820	3.07	4.84	93.15	4.84	93.04	15.23	46.15	18.73	12.4
	1804	3.503	2.854	489.6	415.2	329.724	415.6	1.018	0.837	3.04	4.83	92.98	4.73	90.97	15.20	45.41	18.53	12.4
	1805	3.503	2.860	487.0	412.6	327.884	413.6	1.007	0.825	3.06	4.81	92.57	4.75	91.33	15.28	45.38	18.36	12.4
	1806	3.503	2.850	457.3	387.4	307.915	388.9	0.946	0.780	3.06	4.78	91.99	4.75	91.34	15.29	45.41	18.64	12.4
GA-2-0%, CP	1519	3.255	2.601	497.8	473.5	377.297	473.5	1.400	1.113	2.61	4.92	94.65	4.88	93.93	4.88	49.23	20.09	0.5
GA-2-0%, CP	1776	3.256	2.547	475.7	448.9	359.522	449.6	1.375	1.077	2.54	4.98	95.84	4.99	95.97	5.63	52.06	21.78	0.4
GA-2-0% BP 4/20, 13.5 ton	2266	3.507	2.767	475.4	449.6	360.321	449.9	1.153	0.916	2.60	5.02	96.52	4.98	95.76	5.43	50.54	21.10	0.4
18.9 ton	2267	3.507	2.785	470.2	444.7	356.448	445.0	1.117	0.899	2.66	5.02	96.58	4.95	95.26	5.42	49.23	20.59	0.4
GA-2-4%, CP	1506	3.257	2.592	450.9	421.0	335.436	421.2	1.268	0.997	2.60	4.91	94.40	4.88	93.88	6.63	50.19	20.42	3.4
GA-2-4% BP 2/24 9.5 ton	1807	3.505	2.792	422.2	379.9	301.170	380.6	0.980	0.814	2.72	4.78	91.98	4.65	89.43	10.02	47.29	20.34	3.4
	1808	3.505	2.765	436.4	401.7	321.095	402.4	1.055	0.830	2.62	4.94	95.01	4.92	94.56	7.95	51.03	21.11	3.4
	1809	3.505	2.782	472.4	435.5	347.649	435.8	1.130	0.894	2.64	4.94	95.01	4.89	94.02	7.81	50.15	20.63	3.4
	1810	3.505	2.775	495.5	457.0	365.330	457.2	1.185	0.936	2.64	4.97	95.66	4.92	94.71	7.77	50.48	20.83	3.4
	1811	3.505	2.758	425.9	392.8	313.577	392.9	1.035	0.815	2.60	4.95	95.23	4.92	94.64	7.77	51.23	21.31	3.4
	1812	3.505	2.783	353.3	320.9	259.844	326.4	0.844	0.677	2.65	4.82	92.72	4.75	91.42	9.17	49.42	20.60	3.4
GA-2-6%, CP	1503	3.256	2.616	457.2	415.3	330.196	415.4	1.215	0.977	2.76	4.87	93.73	4.82	92.78	9.16	48.08	19.66	6.3
GA-2-6% BP 2/24 9.5 ton	1813	3.505	2.804	403.9	365.6	291.100	365.8	0.930	0.747	2.75	4.89	94.12	4.84	92.98	9.48	48.58	20.00	6.3
	1814	3.505	2.793	459.3	413.0	329.328	413.0	1.050	0.843	2.77	4.94	94.92	4.88	93.81	10.08	49.01	20.31	6.3
	1815	3.505	2.793	481.0	432.0	344.929	432.1	1.105	0.864	2.75	4.96	95.30	4.98	95.74	10.19	50.34	20.31	6.3
	1816	3.505	2.773	375.1	335.7	267.695	336.5	0.880	0.725	2.70	4.88	93.83	4.68	89.95	10.50	48.42	20.88	6.3
	1817	3.505	2.800	479.3	430.4	342.942	430.5	1.093	0.881	2.77	4.92	94.53	4.84	93.08	10.20	48.55	20.11	6.3
	1818	3.505	2.796	451.9	405.7	323.451	405.9	1.035	0.824	2.76	4.92	94.63	4.89	94.08	10.22	49.33	20.23	6.3
GA-2-8%, CP	1504	3.256	2.598	455.6	410.7	327.024	410.7	1.222	0.970	2.73	4.91	94.39	4.87	93.70	9.86	49.45	20.21	7.3

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-2-8% BP 2/24 14 ton	1819	3.505	2.830	452.3	403.0	321.973	403.0	0.975	0.791	2.93	4.97	95.65	4.94	95.02	10.90	47.10	19.26	7.3
	1820	3.505	2.833	472.7	419.7	335.600	419.9	1.034	0.828	2.89	4.98	95.74	4.91	94.34	11.21	47.68	19.17	7.3
	1821	3.505	2.824	507.3	450.4	360.304	450.5	1.195	0.887	2.68	4.99	96.03	4.95	95.11	11.22	51.81	19.43	7.3
	1822	3.505	2.826	455.1	404.0	323.084	404.0	0.984	0.784	2.92	4.99	96.02	5.01	96.38	11.23	48.20	19.37	7.3
	1823	3.505	2.834	436.6	387.7	309.410	387.7	0.942	0.762	2.93	4.95	95.23	4.92	94.63	11.20	47.11	19.14	7.3
	1824	3.505	2.824	399.6	355.0	283.151	355.0	0.865	0.705	2.92	4.94	95.02	4.90	94.32	11.16	47.08	19.43	7.3
GA-2-12%, CP	1498	3.256	2.612	454.8	394.6	313.696	394.7	1.165	0.926	2.86	4.87	93.68	4.85	93.30	13.24	48.84	19.78	11.6
GA-2-12% BP 3/10 10 ton	1850	3.502	2.805	364.9	311.4	248.224	311.5	0.784	0.639	2.95	4.92	94.64	4.81	92.52	14.66	47.70	19.90	11.6
	1851	3.501	2.812	407.3	347.7	276.756	347.7	0.875	0.698	2.95	4.90	94.25	4.89	94.10	14.63	48.53	19.68	11.6
	1852	3.502	2.814	470.2	401.4	319.461	401.5	1.005	0.804	2.96	4.89	94.09	4.90	94.18	14.63	48.34	19.65	11.6
	1853	3.502	2.808	394.2	336.4	268.017	336.7	0.843	0.690	2.96	4.90	94.19	4.80	92.36	14.66	47.37	19.82	11.6
	1854	3.502	2.806	451.7	385.3	307.276	385.6	0.966	0.780	2.96	4.92	94.60	4.87	93.71	14.70	48.15	19.87	11.6
	1855	3.502	2.804	388.2	331.2	263.643	331.4	0.843	0.664	2.92	4.89	94.00	4.93	94.76	14.68	49.49	19.93	11.6
GA-3-6%, CP	1515	3.254	2.606	498.7	461.3	366.210	462.1	1.364	1.099	2.68	4.81	92.51	4.80	92.32	7.50	48.31	19.91	4.8
GA-3-6% BP 3/10 10 ton	1857	3.504	2.803	443.5	403.8	321.215	403.9	1.030	0.828	2.72	4.88	93.92	4.82	92.72	8.95	48.55	20.01	4.8
	1858	3.504	2.809	466.6	429.0	340.975	429.3	1.094	0.878	2.70	4.86	93.41	4.81	92.50	8.06	48.41	19.83	4.8
	1859	3.505	2.804	469.5	431.9	343.700	432.1	1.097	0.885	2.71	4.89	93.96	4.82	92.72	8.01	48.36	20.00	4.8
	1860	3.504	2.799	486.3	447.4	355.995	447.6	1.136	0.906	2.71	4.88	93.92	4.90	94.15	8.00	49.10	20.12	4.8
10-13 ton	1861	3.505	2.837	456.1	419.6	334.336	420.2	1.019	0.839	2.83	4.89	93.98	4.83	92.82	8.00	46.05	19.06	4.8
	1862	3.504	2.776	317.6	292.4	232.640	293.0	0.763	0.599	2.63	4.84	93.16	4.92	94.62	7.93	50.72	20.78	4.8
GA-3-10%	1510	3.255	2.617	519.5	462.7	367.212	462.7	1.362	1.093	2.80	4.85	93.19	4.80	92.33	10.93	48.12	19.60	7.5
GA-3-12%, CP	1514	3.254	2.645	458.8	400.0	317.624	400.5	1.153	0.930	2.92	4.83	92.82	4.78	91.83	12.82	46.70	18.72	10.0
GA-3-12% BP 3/10 10 ton	1866	3.507	2.883	453.0	392.8	312.775	393.0	0.935	0.776	3.06	4.90	94.16	4.73	90.97	13.29	43.90	17.79	10.0
	1868	3.505	2.849	410.7	356.6	283.757	356.7	0.885	0.707	2.93	4.89	94.01	4.83	92.82	13.17	47.21	18.72	10.0
GA-3-14%, CP	1516	3.253	2.620	499.4	429.6	341.865	430.0	1.245	0.996	2.94	4.87	93.74	4.88	93.86	13.98	48.10	19.46	10.5
GA-3-14% BP 3/15 10 ton	1869	3.505	2.811	494.6	439.0	349.093	439.1	1.105	0.900	2.83	4.88	93.80	4.79	92.21	11.24	47.60	19.80	7.5
	1870	3.505	2.817	495.3	438.6	348.676	438.8	1.128	0.898	2.78	4.87	93.59	4.78	91.94	11.45	48.57	19.63	7.5
	1871	3.505	2.821	492.8	436.6	346.626	436.8	1.102	0.892	2.83	4.84	93.11	4.78	91.87	11.40	47.56	19.51	7.5
	1872	3.505	2.819	489.0	433.7	344.085	434.1	1.108	0.881	2.79	4.82	92.66	4.81	92.53	11.31	48.56	19.57	7.5
	1873	3.504	2.809	491.5	435.6	346.336	435.8	1.108	0.890	2.81	4.87	93.63	4.82	92.65	11.37	48.37	19.83	7.5
	1874	3.505	2.788	460.1	415.3	330.270	415.4	1.071	0.854	2.72	4.88	93.82	4.86	93.45	9.74	49.54	20.46	7.5
GA-4-6%, CP	1518	3.254	2.585	495.1	454.9	361.410	455.2	1.366	1.090	2.66	4.85	93.27	4.85	93.29	8.12	49.63	20.56	4.9
GA-4-6% BP 3/15 10 ton	1875	3.505	2.794	436.3	399.8	317.881	399.8	1.040	0.828	2.65	4.88	93.85	4.80	92.39	8.37	49.40	20.29	4.9
	1876	3.505	2.787	448.2	410.6	326.827	410.7	1.073	0.853	2.64	4.90	94.14	4.81	92.57	8.39	49.73	20.49	4.9
	1877	3.505	2.812	325.0	297.4	237.205	297.4	0.731	0.620	2.81	4.94	95.01	4.71	90.61	8.49	45.40	19.77	4.9
	1878	3.505	2.792	459.5	420.3	334.286	420.3	1.089	0.875	2.67	4.89	93.97	4.79	92.04	8.53	49.01	20.34	4.9
	1879	3.505	2.796	462.0	423.0	335.791	423.0	1.100	0.881	2.66	4.85	93.28	4.77	91.74	8.44	49.02	20.23	4.9
	1880	3.505	2.786	477.8	436.9	347.498	437.0	1.147	0.909	2.63	4.88	93.87	4.81	92.50	8.56	49.92	20.51	4.9
GA-4-8%, CP	1511	3.255	N/A	498.7	453.6	N/A	N/A	1.355	N/A	2.70	N/A	N/A	N/A	N/A	9.04	N/A	N/A	5.3

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-4-8% BP 3/15 10 ton	1881	3.506	2.774	485.6	442.8	352.992	443.0	1.166	0.918	2.63	4.92	94.61	4.87	93.63	8.81	50.70	20.88	7.5
	1882	3.505	2.775	490.1	446.8	355.964	447.0	1.166	0.920	2.66	4.91	94.38	4.90	94.20	8.83	50.53	20.83	7.5
	1883	3.506	2.773	491.7	447.7	357.260	448.3	1.174	0.931	2.65	4.92	94.57	4.86	93.41	8.95	50.38	20.91	7.5
	1884	3.506	2.780	488.5	445.7	355.206	446.3	1.164	0.924	2.65	4.89	94.09	4.85	93.23	8.76	50.08	20.71	7.5
GA-4-10%, CP	1512	3.254	2.600	487.1	433.5	343.394	433.8	1.291	1.039	2.77	4.80	92.21	4.79	92.19	11.00	48.61	20.10	7.4
GA-4-10%, CP	1533	3.258	2.568	498.8	448.3	356.543	448.7	1.387	1.100	2.63	4.86	93.55	4.80	92.31	10.12	50.72	21.18	6.2
GA-4-10% BP 3/15 10 ton	1885	3.505	2.792	472.5	425.1	338.856	425.3	1.100	0.881	2.72	4.92	94.57	4.81	92.46	10.03	49.17	20.34	6.9
	1886	3.505	2.808	444.5	393.3	312.043	393.6	1.010	0.809	2.78	4.82	92.74	4.79	92.10	11.52	48.58	19.89	6.9
	1887	3.504	2.811	466.3	411.5	326.482	411.6	1.055	0.848	2.80	4.83	92.97	4.77	91.73	11.75	48.26	19.78	6.9
	1888	3.505	2.792	475.6	420.7	334.860	420.7	1.083	0.864	2.78	4.90	94.25	4.85	93.30	11.54	49.37	20.34	6.9
	1889	3.506	2.806	481.1	426.1	338.349	426.3	1.095	0.878	2.78	4.84	93.17	4.79	92.07	11.43	48.63	19.97	6.9
	1890	3.506	2.794	482.6	427.5	339.982	427.5	1.101	0.881	2.77	4.88	93.94	4.83	92.85	11.42	49.17	20.31	6.9
	1891	3.505	2.767	487.3	434.6	346.002	434.6	1.143	0.915	2.70	4.91	94.33	4.82	92.67	10.81	50.10	21.06	6.9
	1892	3.506	2.766	491.2	439.7	349.147	439.9	1.174	0.924	2.64	4.85	93.17	4.83	92.91	10.48	51.00	21.11	6.9
	1893	3.506	2.750	487.9	437.6	348.395	437.7	1.179	0.932	2.62	4.90	94.23	4.82	92.74	10.31	51.36	21.56	6.9
	1894	3.506	2.766	486.0	436.1	345.883	436.7	1.170	0.929	2.63	4.80	92.35	4.77	91.65	10.27	50.57	21.11	6.9
	1895	3.506	2.755	485.5	435.4	346.620	435.7	1.169	0.917	2.62	4.89	94.00	4.86	93.44	10.32	51.55	21.42	6.9
	1897	3.505	2.776	483.8	434.5	344.838	435.7	1.175	0.933	2.60	4.78	91.96	4.69	90.27	10.19	50.18	20.80	6.9
	1898	3.506	2.774	485.9	436.3	346.215	437.0	1.180	0.938	2.60	4.81	92.42	4.70	90.29	10.21	50.23	20.88	6.9
	1900	3.506	2.798	490.2	439.3	350.042	439.5	1.131	0.905	2.74	4.91	94.44	4.82	92.62	10.38	49.03	20.19	6.9
GA-4-12%, CP	1517	3.254	N/A	500.5	444.0	N/A	N/A	1.310	N/A	2.80	N/A	N/A	N/A	N/A	11.29	N/A	N/A	7.1
GA-4-12% BP 3/15 10 ton	1903	3.507	2.782	441.7	394.9	314.778	395.4	1.042	0.833	2.68	4.90	94.20	4.76	91.50	10.60	49.68	20.67	7.1
	1904	3.506	2.804	438.3	389.5	310.184	391.7	1.020	0.832	2.72	4.78	91.89	4.62	88.94	11.13	47.82	20.02	7.1
	1905	3.506	2.801	472.8	420.2	334.770	421.2	1.083	0.874	2.76	4.86	93.49	4.76	91.54	11.13	48.48	20.11	7.1
	1906	3.506	2.784	502.2	445.8	355.579	446.2	1.158	0.920	2.74	4.92	94.60	4.86	93.39	11.23	49.90	20.59	7.1
	1907	3.506	2.790	505.4	448.6	357.662	448.9	1.159	0.932	2.76	4.92	94.55	4.80	92.36	11.24	49.07	20.42	7.1
	1908	3.507	2.802	518.8	461.3	367.720	462.2	1.192	0.948	2.75	4.88	93.89	4.81	92.58	11.08	49.22	20.10	7.1
GA-4-12%, CP G3021-1	2089	3.254	2.546	498.5	447.5	356.694	448.0	1.392	1.102	2.63	4.90	94.25	4.87	93.58	10.23	51.53	21.76	5.4
GA-4-14%, CP	1513	3.255	2.612	499.4	436.8	347.775	437.5	1.278	1.034	2.87	4.87	93.62	4.81	92.49	12.54	47.89	19.75	9.3
GA-4-14% BP 3/15 10 ton	1909	3.504	2.805	494.3	433.6	345.374	434.4	1.112	0.890	2.81	4.87	93.66	4.81	92.49	12.28	48.70	19.95	9.3
	1910	3.504	2.797	474.2	412.6	328.745	413.2	1.069	0.863	2.81	4.89	93.95	4.75	91.29	12.99	48.55	20.18	9.3
	1911	3.504	2.799	479.4	416.8	332.120	418.7	1.065	0.856	2.85	4.81	92.58	4.83	92.84	13.06	48.70	20.12	9.3
	1912	3.505	2.811	481.2	418.6	333.697	419.8	1.067	0.871	2.85	4.86	93.49	4.72	90.85	13.01	47.49	19.80	9.3
	1913	3.504	2.812	501.4	437.2	348.541	438.9	1.117	0.898	2.84	4.84	93.05	4.78	91.97	12.80	48.21	19.75	9.3
GA-5-6%	1532	3.254	2.532	499.5	458.7	364.157	458.9	1.476	1.154	2.48	4.84	93.11	4.82	92.61	8.17	52.65	22.19	4.4
GA-5-10%	1536	3.253	2.559	495.2	447.3	354.342	447.8	1.421	1.129	2.56	4.79	92.04	4.70	90.37	9.67	50.82	21.33	5.5

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-5-12%, G0518-0 Full, BP 7/10, 4.9 tons	2804	3.508	2.730	493.9	422.6	336.916	422.7	1.145	0.900	2.72	4.93	94.74	4.89	94.11	14.44	52.39	22.18	9.4
5.8 tons	2805	3.510	2.704	496.2	421.6	336.312	421.7	1.151	0.903	2.72	4.94	94.95	4.96	95.38	15.03	53.43	22.96	9.4
4.4 tons	2806	3.507	2.643	459.7	383.3	304.906	383.4	1.144	0.868	2.54	4.88	93.91	4.91	94.43	16.62	56.90	24.64	9.4
6.4 tons	2807	3.508	2.688	478.6	398.5	317.089	398.6	1.149	0.882	2.63	4.89	94.02	4.86	93.41	16.74	54.92	23.38	9.4
7.4 tons	2808	3.507	2.700	494.6	409.4	326.473	409.5	1.154	0.892	2.71	4.93	94.83	4.89	94.04	17.23	54.18	23.01	9.4
7 tons	2809	3.509	2.691	486.9	406.2	323.576	406.3	1.158	0.892	2.65	4.91	94.43	4.88	93.93	16.57	54.69	23.31	9.4
GA-7/4-10%	1528	3.254	2.545	500.1	435.2	343.330	440.8	1.500	1.200	2.45	4.46	85.86	4.35	83.64	12.98	51.05	21.79	7.9
GA-8/4-10%	1527	3.258	2.502	468.6	405.3	320.000	406.7	1.438	1.096	2.39	4.67	89.90	4.59	88.24	13.51	55.04	23.20	7.5
GA-8/4-12%	1624	3.253	2.577	499.8	420.1	333.074	420.9	1.296	1.032	2.83	4.78	91.99	4.76	91.56	15.95	50.02	20.78	9.3
GA-9-8%	1508	3.259	2.538	439.3	392.8	311.565	395.1	1.311	1.025	2.45	4.70	90.43	4.62	88.87	10.59	52.57	22.12	6.5
GA-11-6%	1502	3.255	2.598	502.1	437.4	349.658	437.7	1.300	1.034	2.83	4.97	95.54	4.87	93.62	12.89	49.32	20.18	6.2
GA-11-8%	1501	3.255	2.600	512.6	437.7	349.324	437.8	1.291	1.042	2.91	4.95	95.14	4.83	92.82	14.61	48.49	20.12	8.1
GA-11-10%, CP	1531	3.254	2.620	500.1	419.7	334.073	420.5	1.227	0.989	2.99	4.86	93.39	4.80	92.34	16.08	47.74	19.48	9.7
GA-11-10% BP 2/24, 9.5 ton	1789	3.503	2.815	409.9	343.6	273.904	344.9	0.860	0.708	3.02	4.84	93.07	4.76	91.48	16.17	46.83	19.64	9.7
	1790	3.503	2.805	479.0	401.1	319.241	401.9	1.013	0.815	2.99	4.85	93.32	4.86	93.43	16.26	48.40	19.93	9.7
8.5 ton	1791	3.501	2.812	476.6	398.8	317.675	399.9	1.009	0.824	2.99	4.85	93.27	4.75	91.43	16.32	47.31	19.68	9.7
9.5 ton	1792	3.502	2.816	457.8	383.1	305.216	384.4	0.973	0.793	2.98	4.84	93.04	4.73	91.00	16.32	47.29	19.59	9.7
	1793	3.502	2.807	451.1	377.7	301.222	377.9	0.953	0.770	3.00	4.93	94.73	4.84	92.99	16.27	48.08	19.85	9.7
	1794	3.503	2.800	286.3	240.1	191.338	240.1	0.613	0.489	2.96	4.92	94.69	4.86	93.55	16.14	49.02	20.07	9.7
GA-13-6%	1538	3.255	2.576	555.4	504.3	401.934	504.6	1.514	1.205	2.69	4.91	94.46	4.90	94.21	9.20	50.14	20.86	2.8
GA-13-10%	1539	3.254	N/A	527.8	N/A	N/A	N/A	1.329	N/A	2.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.8
GA-13-12%, CP	1623	3.252	2.621	499.4	418.6	333.725	420.1	1.223	1.000	3.00	4.85	93.20	4.73	91.02	16.18	46.88	19.40	10.8
GA-13-12% BP 3/16 10 ton	1916	3.507	2.829	456.5	382.8	305.380	384.0	0.961	0.778	3.00	4.87	93.63	4.78	91.83	16.14	47.31	19.33	10.9
	1917	3.504	2.826	466.0	389.6	310.952	391.0	0.979	0.784	3.01	4.87	93.60	4.83	92.95	16.39	47.90	19.35	10.9
	1918	3.496	2.819	460.4	384.9	306.698	386.0	0.972	0.785	3.01	4.85	93.34	4.79	92.16	16.40	47.48	19.36	10.9
	1919	3.498	2.818	461.7	385.7	307.714	387.0	0.974	0.778	3.01	4.86	93.55	4.85	93.25	16.46	48.15	19.44	10.9
	1920	3.504	2.817	475.1	397.2	316.332	398.0	1.005	0.805	2.99	4.86	93.53	4.83	92.88	16.40	48.22	19.61	10.9
	1921	3.503	2.836	411.6	343.8	274.069	345.9	0.880	0.715	2.96	4.79	92.04	4.64	89.30	16.47	46.74	19.04	10.9
GA-13-14%	1540	3.254	2.624	498.3	416.8	331.498	418.1	1.207	0.990	3.03	4.81	92.55	4.75	91.33	16.36	46.65	19.36	11.3
GA-14-10% Full Batch	1530	3.254	2.585	499.3	448.6	355.194	448.6	1.387	1.100	2.64	4.80	92.36	4.74	91.16	10.15	49.94	20.56	6.7
GA-14-14%	1535	3.253	2.582	499.2	431.7	342.687	431.9	1.309	1.045	2.80	4.84	93.06	4.81	92.56	13.52	49.70	20.63	9.2
GA-15-10%, CP	1534	3.253	2.581	499.3	442.7	350.536	442.7	1.366	1.090	2.68	4.80	92.37	4.74	91.07	11.34	49.76	20.66	5.8
GA-15-10% BP 3/16 10 ton	1922	3.507	2.821	524.1	464.0	369.226	464.3	1.171	0.945	2.83	4.88	93.85	4.79	92.16	11.47	47.77	19.56	5.8
	1923	3.508	2.778	498.8	442.8	351.649	443.1	1.162	0.926	2.71	4.84	93.11	4.81	92.56	11.23	50.02	20.81	5.8
	1924	3.507	2.795	501.3	445.1	353.046	446.1	1.189	0.941	2.66	4.78	91.99	4.70	90.44	11.21	49.72	20.30	5.8
	1925	3.506	2.777	499.9	443.9	352.863	444.7	1.164	0.927	2.71	4.83	92.95	4.82	92.75	11.20	50.03	20.79	5.8
	1926	3.507	2.778	499.9	443.9	352.611	444.8	1.169	0.927	2.70	4.82	92.60	4.82	92.69	11.20	50.23	20.79	5.8

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-15-14%, CP	1529	3.255	2.600	498.5	427.1	339.221	427.5	1.283	1.032	2.85	4.84	93.04	4.76	91.45	14.32	48.67	20.12	9.5
GA-15-14% BP 3/16 10 ton	1927	3.505	2.804	484.7	421.1	334.412	422.3	1.100	0.875	2.79	4.79	92.14	4.75	91.43	13.12	49.08	20.00	8.3
	1928	3.509	N/A	477.7	N/A	N/A	N/A	1.044	N/A	2.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.3
	1929	3.510	2.798	503.7	428.1	340.400	429.3	1.100	0.927	2.89	4.82	92.61	4.58	88.11	15.01	46.44	20.28	8.3
	1930	3.508	2.864	509.8	437.0	347.731	438.6	1.043	0.890	3.09	4.81	92.48	4.65	89.42	14.28	43.11	18.36	8.3
	1931	3.508	2.849	516.9	443.5	353.406	444.6	1.068	0.873	3.06	4.86	93.52	4.86	93.49	14.20	46.08	18.79	8.3
	1932	3.511	N/A	458.5	N/A	N/A	N/A	1.080	N/A	2.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.3
GA-15-15%	1537	3.254	2.594	499.6	420.5	333.222	421.0	1.277	1.019	2.87	4.79	92.12	4.76	91.61	15.83	49.28	20.28	10.2
GA-16-8%	1618	3.252	2.520	454.6	413.2	328.988	413.7	1.354	1.052	2.47	4.88	93.80	4.80	92.39	9.11	53.34	22.51	3.9
GA-16-14%	1615	3.255	2.521	498.0	437.3	349.067	437.5	1.408	1.092	2.59	4.94	95.10	4.89	94.12	12.19	53.47	22.55	5.8
GA-17-10%	1544	3.254	2.572	497.8	449.1	355.411	451.6	1.475	1.158	2.48	4.67	89.79	4.55	87.57	9.78	50.94	20.96	3.7
GA-18-10%	1619	3.254	2.590	612.8	547.1	434.089	547.8	1.700	1.351	2.64	4.81	92.53	4.69	90.17	10.72	49.64	20.41	6.9
GA-18-12%	1620	3.254	2.577	500.7	440.5	349.500	441.3	1.376	1.095	2.67	4.80	92.28	4.71	90.48	12.02	50.08	20.81	8.1
GA-18-14%	1616	3.254	2.570	498.8	430.4	342.345	430.6	1.328	1.060	2.76	4.88	93.78	4.78	91.83	13.71	50.20	21.02	9.1
GA-19-4%	1543	3.254	2.589	498.9	460.8	366.733	460.9	1.392	1.099	2.63	4.89	94.10	4.86	93.44	7.64	50.01	20.44	3.8
GA-19-8%	1621	3.254	2.590	501.0	447.5	357.186	447.8	1.335	1.053	2.75	4.94	94.97	4.92	94.63	10.68	50.02	20.41	7.4
GA-19-10%, CP	1625	3.255	N/A	497.2	N/A	N/A	N/A	1.267	N/A	2.88	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.9
GA-19-10% BP 3/21 10 ton	1945	3.505	2.813	477.9	420.1	334.539	420.6	1.063	0.858	2.84	4.88	93.87	4.81	92.43	12.09	48.00	19.74	8.9
	1946	3.504	2.815	480.3	420.9	335.032	421.3	1.056	0.852	2.88	4.88	93.83	4.84	93.12	12.37	47.92	19.66	8.9
	1947	3.505	2.817	481.0	421.4	335.105	421.4	1.055	0.853	2.88	4.88	93.91	4.84	92.99	12.39	47.76	19.63	8.9
GA-19-10% (Repeat)	1662	3.255	2.609	497.8	438.1	348.870	438.1	1.288	1.026	2.83	4.91	94.42	4.87	93.70	11.99	48.81	19.85	9.4
GA-19-12%, CP	1541	3.254	2.595	499.7	429.5	341.595	429.9	1.284	1.026	2.86	4.86	93.54	4.83	92.86	14.05	49.17	20.25	10.7
GA-19-12% BP 3/21 10 ton	1950	3.505	2.785	477.4	412.5	328.602	412.8	1.063	0.855	2.84	4.90	94.21	4.83	92.91	13.59	49.21	20.54	10.7
	1951	3.504	2.782	483.8	415.2	330.598	415.4	1.086	0.865	2.82	4.90	94.16	4.82	92.64	14.18	49.78	20.61	10.7
	1952	3.505	2.783	489.5	419.4	334.008	419.7	1.088	0.872	2.85	4.89	94.12	4.82	92.76	14.32	49.46	20.60	10.7
	1955	3.503	2.787	486.1	414.1	330.017	414.4	1.073	0.860	2.87	4.91	94.37	4.82	92.60	14.81	49.26	20.44	10.7
GA-19-14%, CP	1622	3.253	2.596	501.1	422.6	337.329	423.1	1.259	1.009	2.92	4.93	94.75	4.83	92.83	15.67	48.95	20.20	11.8
GA-19-14% BP 3/21 10 ton	1956	3.502	2.804	461.7	388.6	310.956	389.3	0.977	0.807	2.99	4.96	95.39	4.76	91.48	15.83	47.04	19.93	11.8
	1957	3.501	2.810	479.0	403.1	322.142	404.0	1.003	0.815	3.03	4.92	94.70	4.87	93.57	15.85	47.64	19.74	11.8
	1958	3.501	2.805	480.9	404.6	323.266	405.6	1.014	0.825	3.01	4.91	94.50	4.84	93.11	15.87	47.76	19.88	11.8
	1959	3.502	2.790	488.5	411.1	327.899	412.0	1.058	0.854	2.92	4.89	94.00	4.80	92.37	15.84	48.76	20.33	11.8
	1960	3.501	2.808	486.7	409.8	327.192	410.7	1.023	0.832	3.02	4.91	94.37	4.85	93.31	15.80	47.67	19.79	11.8
GA-20-0%, CP	1642	3.256	2.556	449.0	418.6	336.651	418.6	1.320	1.028	2.49	5.11	98.23	4.84	93.10	6.77	52.00	21.50	0.5
GA-20-0% BP 4/20, 9.3 ton	2256	3.505	2.736	439.6	407.2	326.180	407.3	1.070	0.851	2.60	5.02	96.53	4.97	95.48	7.37	51.53	21.94	0.4
9.8 ton	2257	3.505	2.734	461.0	427.4	342.543	427.8	1.142	0.902	2.55	5.01	96.41	4.92	94.69	7.29	51.93	22.00	0.4
7 ton	2258	3.504	2.719	452.5	420.8	337.307	421.0	1.450	0.890	1.97	5.03	96.69	4.97	95.53	7.01	63.03	22.40	0.4
6 ton	2259	3.504	2.722	430.9	394.5	315.897	394.8	1.070	0.842	2.55	5.00	96.15	4.91	94.46	8.45	52.50	22.32	0.4
6 ton, 0.2 pre-press	2260	3.506	2.710	380.5	350.4	280.378	350.5	0.971	0.755	2.48	5.00	96.10	4.91	94.40	7.91	53.54	22.70	0.4

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-20-8%, CP	1626	3.254	2.580	499.2	435.1	345.666	435.1	1.320	1.050	2.77	4.87	93.56	4.84	92.99	12.84	49.99	20.71	7.5
GA-20-8% BP 3/21 10 ton	1962	3.508	2.792	463.4	403.1	322.825	403.2	1.013	0.808	2.89	5.02	96.45	4.97	95.60	13.01	49.46	20.41	7.2
	1964	3.506	2.795	479.4	416.3	333.395	416.5	1.049	0.836	2.89	5.01	96.33	4.95	95.22	13.16	49.34	20.28	7.2
	1965	3.506	2.796	478.4	415.4	332.426	415.5	1.049	0.838	2.88	5.00	96.16	4.93	94.72	13.17	49.18	20.25	7.2
GA-20-10%, CP	1771	3.255	2.569	500.4	423.9	336.765	424.1	1.317	1.034	2.79	4.85	93.34	4.82	92.79	15.29	51.09	21.08	9.8
GA-20-10% BP 3/21 10 ton	1967	3.506	2.784	437.7	373.2	298.529	373.4	0.961	0.770	2.88	4.98	95.86	4.86	93.41	14.74	49.47	20.59	8.6
	1969	3.506	2.786	438.8	372.5	297.611	372.5	0.953	0.760	2.91	4.97	95.65	4.90	94.32	15.11	49.63	20.54	8.6
	1970	3.507	2.784	438.8	372.5	297.373	372.5	0.950	0.765	2.92	4.96	95.35	4.88	93.84	15.11	49.24	20.62	8.6
	1971	3.504	2.744	428.7	363.8	288.715	363.8	0.996	0.783	2.72	4.85	93.18	4.79	92.17	15.14	51.78	21.69	8.6
	1972	3.506	2.740	470.5	401.1	319.035	401.2	1.085	0.860	2.74	4.88	93.88	4.83	92.80	14.75	51.58	21.85	8.6
GA-20-12%	1627	3.252	2.575	499.2	422.3	336.023	422.5	1.285	1.016	2.85	4.88	93.91	4.87	93.64	15.40	50.42	20.82	10.6
GA-22-10%, CP	1628	3.254	2.530	500.2	428.1	339.627	429.3	1.428	1.093	2.57	4.77	91.81	4.75	91.40	14.41	53.72	22.25	8.5
GA-22-10% BP 3/21 10 ton	1973	3.507	2.724	478.1	407.5	325.704	407.5	1.127	0.868	2.68	4.98	95.81	4.91	94.51	14.77	53.53	22.33	7.8
	1974	3.506	2.725	490.4	417.5	333.564	417.9	1.150	0.888	2.70	4.95	95.20	4.92	94.58	14.87	53.34	22.28	7.8
	1975	3.507	2.725	490.5	417.8	333.740	418.0	1.156	0.900	2.68	4.96	95.36	4.86	93.38	14.82	52.99	22.30	7.8
	1976	3.506	2.728	480.9	409.8	327.012	409.8	1.128	0.877	2.69	4.95	95.19	4.88	93.79	14.78	52.92	22.19	7.8
GA-22-12%, CP	1629	3.253	N/A	499.0	N/A	N/A	N/A	1.355	N/A	2.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.4
GA-22-12% BP 3/21 10 ton	1984	3.506	2.741	467.4	389.1	310.465	389.1	1.065	0.821	2.77	4.95	95.16	4.90	94.23	16.75	52.87	21.82	10.4
	1985	3.506	2.731	469.7	391.3	312.655	391.7	1.060	0.828	2.80	4.95	95.20	4.92	94.65	16.69	52.60	22.10	10.4
on side	1986	3.506	2.740	493.6	411.3	328.294	411.5	1.120	0.868	2.79	4.94	93.44	4.90	94.28	16.67	52.66	21.85	10.4
7 ton	1987	3.504	2.672	488.9	408.0	324.129	408.1	1.213	0.931	2.55	4.86	94.13	4.77	91.69	16.55	55.36	23.74	10.4
8 ton	1990	3.508	2.723	470.0	396.8	311.670	392.0	1.093	0.857	2.71	4.94	94.99	4.85	93.28	15.57	52.75	22.38	10.4
10 ton	1993	3.508	2.715	461.2	383.0	305.980	383.7	1.064	0.815	2.74	4.93	94.77	4.95	95.23	16.96	54.11	22.61	10.4
7 ton	1995	3.507	2.648	458.4	380.9	302.151	380.9	1.175	0.879	2.46	4.84	93.02	4.80	92.31	16.91	57.34	24.49	10.4
on side, 7.5 ton	1997	3.509	2.708	451.8	375.2	299.164	375.2	1.053	0.810	2.71	4.93	94.89	4.91	94.35	16.95	54.18	22.83	10.4
7.25 ton	2000	3.507	2.657	456.2	379.1	300.211	379.2	1.164	0.880	2.48	4.80	92.30	4.74	91.15	16.90	56.60	24.24	10.4
GA-22-12% Full	1834	3.256	2.499	499.5	418.6	332.024	418.6	1.425	1.087	2.57	4.84	92.98	4.79	92.11	16.20	55.06	23.25	10.4
GA-22-14%, CP	1630	3.253	2.526	499.6	414.4	329.067	414.5	1.360	1.049	2.70	4.85	93.28	4.81	92.48	17.05	53.48	22.35	10.4
GA-22-14% BP 3/21 10 ton	1978	3.506	2.707	463.8	382.4	304.288	382.4	1.081	0.840	2.71	4.90	94.14	4.83	92.80	17.55	53.67	22.79	11.9
	1979	3.505	2.711	484.6	398.5	316.861	398.5	1.126	0.875	2.72	4.88	93.87	4.81	92.56	17.77	53.50	22.65	11.9
	1980	3.505	2.715	497.3	407.8	323.807	407.8	1.155	0.906	2.72	4.86	93.37	4.74	91.21	18.00	52.93	22.54	11.9
	1981	3.506	2.718	501.9	412.5	327.328	412.5	1.175	0.907	2.70	4.84	93.14	4.78	91.96	17.81	53.60	22.48	11.9
	1982	3.504	2.760	488.2	401.3	319.516	401.5	1.081	0.860	2.86	4.89	94.13	4.76	91.50	17.80	50.63	21.23	11.9
	1983	3.504	2.727	390.3	320.4	255.716	321.4	0.868	0.692	2.85	4.88	93.81	4.84	93.00	17.91	51.70	22.17	11.9
GA-23-6%, CP	1832	3.255	2.590	569.8	523.8	416.727	528.3	1.640	1.304	2.55	4.69	90.28	4.65	89.45	8.07	49.65	20.43	3.6
GA-23-6% BP 3/22 10 ton	2004	3.504	2.746	481.5	440.7	350.672	441.3	1.190	0.938	2.56	4.86	93.51	4.84	93.07	8.47	51.58	21.63	4.0
	2005	3.506	2.752	486.7	446.0	354.980	447.0	1.206	0.948	2.55	4.85	93.21	4.83	92.79	8.36	51.56	21.51	4.0
8 ton	2006	3.506	2.762	485.3	445.2	354.153	447.8	1.208	0.959	2.54	4.75	91.42	4.73	90.90	8.26	50.72	21.22	4.0

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-23-8%, CP	1631	3.253	N/A	501.0	N/A	N/A	N/A	1.372	N/A	2.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.0
GA-23-8% BP 3/22 10 ton	2009	3.506	2.806	495.3	444.6	353.887	445.1	1.137	0.906	2.75	4.87	93.74	4.84	93.10	10.24	48.95	19.97	5.7
12 ton	2010	3.506	2.785	496.0	445.2	354.026	445.4	1.156	0.915	2.71	4.87	93.70	4.87	93.70	10.24	50.05	20.56	5.7
10 ton	2011	3.506	2.820	497.9	447.3	355.812	448.8	1.143	0.916	2.75	4.81	92.51	4.77	91.72	10.16	48.14	19.57	5.7
GA-23-10%, CP	1632	3.252	N/A	499.3	N/A	N/A	N/A	1.362	N/A	2.69	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.6
GA-23-10% BP 3/22 7 ton	2014	3.507	2.682	445.1	377.1	N/A	N/A	1.146	0.868	2.45	N/A	N/A	4.69	90.22	15.28	55.69	23.52	8.6
	2015	3.507	2.690	448.3	382.7	302.148	383.5	1.161	0.879	2.44	4.70	90.47	4.67	89.87	14.63	55.45	23.30	8.6
	2016	3.507	2.671	467.0	398.7	315.244	398.7	1.213	0.919	2.43	4.78	91.87	4.72	90.84	14.63	56.04	23.84	8.6
	2017	3.507	2.700	467.6	399.6	N/A	N/A	1.211	0.925	2.44	N/A	N/A	4.60	88.52	14.54	54.72	23.01	8.6
GA-23-12%, CP Full (G0229-2)	1835	3.255	2.539	499.6	421.5	334.280	425.6	1.423	1.106	2.57	4.62	88.76	4.59	88.31	15.63	52.70	22.00	9.2
GA-23-12% (G0229-2) BP 3/22 7 ton	2041	3.507	2.709	496.7	415.7	328.030	419.2	1.265	0.965	2.48	4.56	87.68	4.56	87.68	16.31	54.47	22.75	9.2
	2042	3.507	2.715	497.5	416.5	328.417	421.0	1.261	0.970	2.49	4.50	86.51	4.52	87.01	16.28	53.89	22.58	9.2
	2043	3.507	2.687	498.4	416.5	328.511	418.0	1.263	0.961	2.49	4.65	89.50	4.66	89.67	16.43	55.33	23.38	9.2
	2045	3.506	2.698	497.8	416.2	329.348	419.9	1.276	0.972	2.47	4.60	88.39	4.57	87.87	16.39	54.88	23.05	9.2
7.4 ton	2049	3.507	2.686	496.3	413.6	326.487	414.8	1.261	0.958	2.49	4.68	90.06	4.65	89.39	16.66	55.43	23.41	9.2
GA-23-12% CP (G0306-0)	1934	3.255	2.519	499.4	422.9	334.072	422.9	1.429	1.098	2.56	4.76	91.56	4.71	90.67	15.32	53.97	22.61	10.4
GA-23-12% CP (G0306-1)	1935	3.254	N/A	484.4	N/A	N/A	N/A	1.395	N/A	2.55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
GA-23-12% CP (G0306-2)	1936	3.255	N/A	499.9	N/A	N/A	N/A	1.398	N/A	2.62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.4
GA-23-12% (G0306-2 & G0126-1) BP 3/22 7.3 ton	2055	3.506	2.698	501.0	423.4	336.264	425.1	1.253	0.960	2.53	4.77	91.66	4.71	90.50	15.49	54.62	23.05	10.5
7.4 ton	2056	3.505	2.715	497.3	419.6	332.918	422.1	1.238	0.945	2.54	4.70	90.48	4.68	89.98	15.62	54.19	22.54	10.5
7 ton	2058	3.506	2.691	485.0	407.6	322.082	408.4	1.223	0.927	2.51	4.72	90.81	4.72	90.70	15.96	55.34	23.25	10.5
7.1 ton	2059	3.506	2.674	477.0	399.6	316.729	399.6	1.202	0.907	2.51	4.82	92.73	4.79	92.04	16.23	56.11	23.73	10.5
7.2 ton	2060	3.505	2.680	500.5	419.6	332.159	419.7	1.261	0.947	2.51	4.79	92.18	4.79	92.15	16.16	56.09	23.54	10.5
7 ton	2064	3.505	2.707	495.3	416.0	329.140	419.0	1.255	0.965	2.50	4.63	89.03	4.57	87.87	16.01	54.13	22.77	10.5
	2065	3.505	2.690	497.0	417.1	N/A	N/A	1.253	0.957	2.51	N/A	N/A	4.68	89.97	16.08	55.00	23.25	10.5
	2066	3.505	2.679	494.8	414.4	327.567	414.4	1.245	0.939	2.51	4.77	91.78	4.78	91.85	16.25	55.93	23.57	10.5
	2067	3.504	2.680	497.8	417.1	329.115	417.2	1.251	0.958	2.52	4.74	91.06	4.71	90.55	16.21	55.19	23.52	10.5
	2068	3.503	2.680	495.5	415.0	328.334	415.0	1.244	0.940	2.52	4.79	92.09	4.77	91.82	16.25	55.76	23.49	10.5
	2069	3.504	N/A	490.3	N/A	N/A	N/A	1.240	0.933	2.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.5
GA-23-12%, CP (G0316-0)	1941	3.256	2.540	457.8	386.3	305.537	386.3	1.253	0.969	2.68	4.78	91.98	4.80	92.30	15.62	52.93	21.99	
GA-23-12% CP (G0316-1)	1943	3.255	2.501	437.4	368.7	292.091	369.3	1.250	0.954	2.57	4.78	91.83	4.80	92.29	15.71	54.93	23.16	9.6
GA-24-8% CP	1826	3.256	2.535	463.3	407.9	321.561	407.9	1.360	1.052	2.50	4.72	90.85	4.69	90.13	11.96	53.10	22.14	6.1

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-24-8% BP 3/22 7 ton	2020	3.508	2.703	441.8	386.9	305.117	388.1	1.157	0.892	2.41	4.66	89.66	4.61	88.68	12.43	54.22	22.95	5.8
	2021	3.507	2.698	465.0	408.2	323.001	412.3	1.255	0.959	2.34	4.57	87.91	4.54	87.35	12.22	54.77	23.07	5.8
	2022	3.507	2.702	463.9	407.1	322.659	412.4	1.259	0.958	2.33	4.54	87.24	4.52	86.94	12.24	54.82	22.95	5.8
GA-24-10% CP	1836	3.255	2.541	498.3	428.0			1.444	1.119	2.53	N/A	N/A	4.60	88.49	14.11	52.77	21.94	8.3
GA-24-10% BP 3/22 7 ton	2025	3.505	2.677	472.1	399.1	N/A	N/A	1.220	0.933	2.45	N/A	N/A	4.64	89.16	15.46	55.38	23.62	8.3
	2026	3.506	2.668	491.2	415.0	328.209	415.7	1.269	0.953	2.45	4.74	91.22	4.75	91.38	15.51	56.50	23.90	8.3
	2027	3.506	2.683	488.2	413.3	327.634	415.9	1.260	0.963	2.45	4.68	90.05	4.63	89.06	15.34	55.23	23.47	8.3
GA-24-12% CP	1827	3.256	2.523	500.0	417.5	330.763	418.9	1.410	1.083	2.60	4.74	91.10	4.70	90.46	16.50	53.87	22.51	9.7
GA-24-12% BP 3/22, 7 ton, G0224-1	2031	3.506	2.673	476.3	395.7	N/A	N/A	1.207	0.912	2.49	N/A	N/A	4.72	90.71	16.92	56.07	23.76	9.5
	2032	3.506	2.667	498.6	413.6	327.431	414.4	1.268	0.962	2.49	4.76	91.46	4.69	90.29	17.05	56.09	23.93	9.5
	2033	3.506	2.699	497.1	412.0	327.432	417.0	1.257	0.975	2.50	4.60	88.46	4.51	86.65	17.12	54.02	23.02	9.5
GA-24-14% CP	1828	3.256	2.552	499.2	414.3	327.900	417.5	1.409	1.089	2.60	4.62	88.92	4.54	87.26	17.01	52.51	21.62	11.1
GA-24-14%, G0224-2, BP 3/22 7 ton	2035	3.505	2.697	472.8	388.8	308.077	393.0	1.192	0.909	2.51	4.58	88.04	4.57	87.84	17.77	54.84	23.05	10.7
	2036	3.506	2.690	488.0	400.9	317.521	403.9	1.228	0.927	2.51	4.64	89.25	4.64	89.27	17.85	55.55	23.27	10.7
	2037	3.506	2.707	488.4	401.8	317.549	405.8	1.226	0.940	2.52	4.55	87.56	4.53	87.13	17.73	54.28	22.79	10.7
	2039	3.508	2.683	483.0	399.1	N/A	N/A	1.220	0.924	2.50	N/A	N/A	4.66	89.63	17.37	55.69	23.52	10.7
GA-25-10%	1634	3.252	2.545	499.5	445.4	353.327	445.7	1.426	1.116	2.57	4.82	92.73	4.79	92.04	10.83	52.06	21.74	6.1
GA-25-14%	1635	3.253	2.593	499.2	435.1	345.317	436.1	1.315	1.060	2.79	4.79	92.17	4.74	91.19	12.84	48.77	20.29	8.4
GA-26-10%	1655	3.255	2.575	499.5	449.7	357.061	451.7	1.420	1.125	2.58	4.75	91.38	4.68	90.05	9.97	50.41	20.89	5.5
GA-26-14%	1653	3.253	2.609	499.9	414.6	328.320	414.8	1.256	1.000	2.92	4.79	92.20	4.73	90.98	17.06	48.78	19.80	11.4
GA-26-14% (repeat)	1654	3.254	2.615	499.2	438.7	348.247	440.1	1.310	1.054	2.80	4.78	91.85	4.73	90.92	12.12	48.03	19.64	8.4
GA-28-10% CP	1706	3.256	2.565	497.9	433.6	343.605	434.1	1.369	1.072	2.67	4.79	92.14	4.78	91.83	12.91	51.40	21.22	7.1
GA-28-10% BP 4/7 7.5 ton	2090	3.502	2.768	508.9	443.2	350.762	443.5	1.199	0.942	2.69	4.78	91.90	4.77	91.73	12.91	50.91	20.96	6.6
	2091	3.505	2.761	482.2	421.6	332.899	422.0	1.160	0.908	2.63	4.73	90.99	4.73	90.98	12.57	51.42	21.23	6.6
8 ton	2092	3.505	2.751	498.0	433.6	343.664	433.8	1.193	0.925	2.64	4.81	92.51	4.81	92.52	12.93	52.23	21.51	6.6
10 ton	2093	3.506	2.761	488.0	424.1	336.372	424.0	1.146	0.908	2.69	4.84	93.07	4.76	91.52	13.09	50.85	21.25	6.6
13.5 ton	2094	3.506	2.785	502.2	436.4	346.479	436.4	1.143	0.900	2.78	4.85	93.33	4.86	93.38	13.10	50.31	20.56	6.6
	2095	3.506	2.780	499.9	434.1	345.066	434.4	1.131	0.896	2.79	4.86	93.45	4.87	93.64	13.16	50.18	20.71	6.6
GA-28-12% CP G0210-2	1707	3.257	2.499	500.1	418.4	331.565	418.9	1.437	1.092	2.55	4.79	92.13	4.77	91.64	16.34	55.26	23.27	9.2
	1772	3.255	2.546	500.6	432.7	342.839	434.2	1.410	1.113	2.60	4.74	91.08	4.66	89.59	13.56	51.70	21.78	8.0
GA-28-12% G0210-2 BP 4/12, 7 ton	2098	3.507	2.727	455.5	396.1	313.971	396.3	1.110	0.868	2.59	4.81	92.52	4.77	91.66	13.04	52.71	22.24	9.2
8 ton	2099	3.507	2.668	437.8	369.3	293.950	370.0	1.093	0.831	2.53	4.86	93.38	4.85	93.26	15.65	55.99	23.92	9.2
7.5 ton	2100	3.507	2.671	475.5	397.1	315.747	397.3	1.175	0.897	2.56	4.87	93.64	4.82	92.69	16.49	55.71	23.84	9.2
7 ton	2101	3.507	2.680	495.6	414.3	328.980	414.6	1.232	0.941	2.54	4.84	93.05	4.76	91.56	16.40	55.39	23.58	9.2

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-28-12% Full G0214-0 CP	1749	3.255	2.526	500.3	430.5	341.639	430.5	1.415	1.095	2.59	4.84	93.17	4.79	92.04	13.95	53.39	22.40	8.0
GA-28-12%, G0214-0 Full, 10 ton BP 4/12	2119	3.507	2.713	494.3	424.3	336.868	424.7	1.218	0.943	2.56	4.83	92.90	4.75	91.31	14.16	53.66	22.64	8.0
7.5 ton	2120	3.507	2.707	493.9	424.0	337.422	424.3	1.210	0.941	2.58	4.88	93.85	4.78	91.85	14.15	53.66	22.81	8.0
8 ton	2121	3.507	2.710	495.3	425.7	337.897	426.0	1.212	0.934	2.58	4.83	92.92	4.82	92.70	14.05	53.98	22.73	8.0
10 ton	2122	3.507	2.717	486.6	418.3	332.963	418.6	1.171	0.908	2.62	4.88	93.93	4.85	93.22	14.04	53.45	22.53	8.0
	2123	3.507	2.732	492.2	423.1	335.755	423.7	1.188	0.922	2.62	4.81	92.52	4.78	91.84	14.04	52.89	22.10	8.0
8 ton	2126	3.505	2.729	484.6	417.2	329.906	417.7	1.190	0.931	2.58	4.75	91.39	4.67	89.88	13.91	52.56	22.14	8.0
GA-28-12%, BP 4/12, G0316-0 Full, 9 ton	2105	3.507	2.734	584.8	490.5	387.394	491.1	1.397	1.084	2.64	4.73	90.96	4.70	90.42	16.13	52.83	22.04	9.7
10 ton	2106	3.507	2.730	527.1	441.6	350.280	442.0	1.243	0.974	2.68	4.81	92.59	4.73	90.87	16.22	52.51	22.16	9.7
15 ton	2107	3.508	2.758	507.6	425.4	338.350	425.7	1.143	0.909	2.80	4.87	93.66	4.78	91.90	16.19	50.83	21.38	9.7
20 ton	2108	3.509	2.775	510.2	427.7	340.390	428.1	1.126	0.895	2.86	4.88	93.77	4.82	92.70	16.17	50.28	20.92	9.7
10 ton	2110	3.508	2.741	505.1	423.2	334.279	423.6	1.190	0.940	2.68	4.74	91.11	4.65	89.51	16.21	51.77	21.86	9.7
	2111	3.508	2.742	506.0	423.8	334.820	424.2	1.196	0.936	2.67	4.74	91.18	4.68	89.95	16.25	52.18	21.84	9.7
	2113	3.508	2.748	507.9	425.5	335.625	426.0	1.203	0.944	2.67	4.71	90.54	4.64	89.16	16.22	51.84	21.66	9.7
GA-28-14%, CP G0210-1	1705	3.255	2.544	499.0	416.0	331.050	416.6	1.330	1.038	2.75	4.86	93.51	4.81	92.50	16.63	52.32	21.84	9.8
GA-28-14%, BP 4/12, G0210-1, 10 ton	2128	3.505	2.845	505.3	430.2	N/A	N/A	1.194	0.933	2.68	N/A	N/A	4.42	85.09	14.86	48.51	18.83	9.8
	2129	3.505	2.729	551.8	460.9	367.327	461.4	1.262	0.983	2.77	4.90	94.22	4.89	94.04	16.47	52.77	22.14	9.8
	2130	3.505	2.736	527.1	438.8	349.340	439.4	1.196	0.947	2.79	4.87	93.70	4.81	92.46	16.75	51.74	21.94	9.8
	2131	3.505	2.731	503.2	418.0	333.570	415.6	1.143	0.890	2.78	5.10	97.99	4.89	94.06	16.93	52.72	22.08	9.8
	2133	3.507	2.729	472.0	391.4	312.708	392.8	1.073	0.849	2.78	4.89	93.98	4.81	92.47	17.08	52.08	22.18	9.8
GA-28-14% CP Full, G0214-1	1750	3.255	2.534	499.3	411.9	326.292	411.9	1.360	1.050	2.69	4.81	92.53	4.75	91.26	17.50	53.20	22.15	11.1
GA-28-14%, G0214-1 Full BP 4/12, 10 ton	2134	3.507	2.720	435.9	359.5	286.818	360.6	1.009	0.793	2.73	4.87	93.70	4.76	91.53	17.53	52.71	22.44	11.1
	2135	3.507	2.718	476.1	391.9	311.928	392.0	1.097	0.855	2.74	4.89	94.12	4.82	92.68	17.69	53.18	22.50	11.1
	2137	3.507	2.725	497.4	409.3	325.046	409.3	1.143	0.889	2.75	4.86	93.42	4.82	92.61	17.71	53.03	22.30	11.1
	2138	3.507	2.756	493.8	406.5	321.940	406.5	1.136	0.889	2.75	4.81	92.45	4.68	89.92	17.68	51.66	21.41	11.1
	2141	3.507	2.730	485.0	397.1	317.632	398.5	1.092	0.855	2.81	4.91	94.43	4.84	93.09	18.12	52.55	22.16	11.1
	2142	3.507	2.720	505.6	414.2	330.486	415.5	1.159	0.897	2.76	4.87	93.69	4.85	93.23	18.08	53.44	22.44	11.1
	2143	3.507	2.717	505.3	415.0	330.454	415.0	1.158	0.896	2.76	4.91	94.40	4.87	93.72	17.87	53.55	22.53	11.1
GA-28-14% Full CP (G0315-1)	1942	3.256	2.543	499.4	415.6	329.758	415.6	1.326	1.032	2.76	4.84	93.10	4.84	93.02	16.78	52.52	21.90	10.3

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-28-14% Full, BP 4/12, 10 ton, G0315-1	2148	3.507	2.737	520.4	430.6	343.328	431.0	1.186	0.920	2.77	4.91	94.45	4.85	93.33	17.26	52.74	21.96	10.3
7 ton	2154	3.506	2.713	498.6	412.8	327.951	413.0	1.170	0.915	2.69	4.85	93.34	4.76	91.56	17.21	53.16	22.62	10.3
	2155	3.506	2.705	489.2	404.9	322.550	405.1	1.158	0.894	2.67	4.90	94.33	4.81	92.46	17.23	54.04	22.85	10.3
GA-28-14% CP Full (G0315-2)	1940	3.253	2.591	499.6	412.1	328.386	412.1	1.237	0.983	2.97	4.92	94.67	4.85	93.28	17.51	49.58	20.35	11.2
GA-28-14% Full, BP 4/12, 7 ton, G0315-2	2159	3.512	2.783	508.2	416.6	333.309	418.1	1.110	0.879	2.88	4.91	94.49	4.75	91.41	18.02	50.26	20.76	11.2
5 ton	2162	3.506	2.770	523.4	429.0	342.537	430.4	1.146	0.909	2.89	4.88	93.90	4.78	91.88	18.04	50.48	20.99	11.2
4 ton	2163	3.504	2.778	523.1	429.9	341.649	431.9	1.161	0.914	2.85	4.76	91.60	4.73	91.04	17.82	50.51	20.72	11.2
	2164	3.503	2.759	484.8	396.6	316.049	398.4	1.089	0.853	2.82	4.82	92.61	4.74	91.24	18.19	51.40	21.24	11.2
	2166	3.503	2.761	480.0	393.3	312.606	394.4	1.075	0.849	2.83	4.81	92.47	4.72	90.77	18.06	50.93	21.18	11.2
	2167	3.504	2.774	492.0	403.3	320.502	404.9	1.093	0.868	2.85	4.78	91.90	4.69	90.19	18.03	50.22	20.83	11.2
GA-28-14%, G0331-0, BP 7/7, 10.6 tons	2776	3.507	2.780	519.6	450.5	359.924	450.8	1.162	0.923	2.82	4.96	95.33	4.91	94.34	13.30	50.08	20.73	8.7
5.75 tons	2777	3.505	2.740	492.2	425.8	339.958	425.9	1.140	0.899	2.73	4.95	95.28	4.90	94.24	13.49	51.80	21.83	8.7
5.8 tons	2778	3.505	2.755	493.3	426.0	339.972	426.2	1.155	0.910	2.70	4.94	95.01	4.79	92.13	13.64	51.31	21.40	8.7
	2779	3.506	2.739	492.0	425.0	338.808	425.4	1.143	0.908	2.72	4.91	94.39	4.85	93.19	13.62	51.51	21.88	8.7
	2780	3.506	2.741	495.3	427.5	341.770	427.6	1.147	0.900	2.73	4.98	95.78	4.91	94.44	13.69	52.03	21.82	8.7
6 tons	2781	3.505	2.747	500.0	431.8	345.003	432.0	1.150	0.912	2.75	4.96	95.45	4.87	93.72	13.64	51.28	21.63	8.7
GA-28-14%, G0331-1, BP 7/7, 6.2 tons	2782	3.505	2.748	501.0	431.5	344.948	431.7	1.146	0.904	2.76	4.97	95.65	4.91	94.42	13.87	51.50	21.60	9.9
3.8 tons	2783	3.505	2.711	478.7	408.8	325.960	408.9	1.139	0.893	2.66	4.93	94.79	4.84	93.04	14.60	53.09	22.65	9.9
6.4 tons	2784	3.505	2.750	506.2	433.8	346.663	434.0	1.155	0.916	2.77	4.97	95.52	4.86	93.54	14.30	51.17	21.54	9.9
	2785	3.505	2.748	506.4	433.2	346.553	433.4	1.153	0.912	2.78	4.99	95.92	4.89	93.96	14.45	51.37	21.60	9.9
6.5 tons	2786	3.506	2.749	508.3	435.7	348.342	436.0	1.150	0.915	2.79	4.97	95.59	4.89	94.12	14.28	51.08	21.59	9.9
? Tons	2787	3.505	2.751	509.2	434.0	347.153	434.3	1.150	0.914	2.80	4.98	95.77	4.87	93.72	14.77	51.03	21.51	9.9
1.8 tons	2788	3.505	2.660	438.4	375.7	298.338	376.4	1.135	0.871	2.44	4.81	92.55	4.74	91.06	14.30	55.79	24.11	9.9
GA-29-8%	1636	3.255	2.599	498.6	440.1	350.645	440.4	1.304	1.030	2.80	4.90	94.30	4.91	94.49	11.73	49.63	20.15	7.7
GA-29-10%	1637	3.252	2.622	499.2	431.5	343.564	431.6	1.253	1.007	2.93	4.90	94.26	4.84	93.10	13.56	47.75	19.37	9.0
GA-29-10% Repeat	1647	3.253	2.644	499.4	432.1	342.338	432.4	1.242	1.006	2.95	4.80	92.27	4.77	91.78	13.48	46.48	18.72	9.2
GA-29-10%, BP 4/12, 10 ton	2170	3.513	2.798	540.5	447.9	358.037	448.4	1.152	0.911	2.95	4.96	95.32	4.88	93.81	17.13	49.83	20.35	9.2
	2172	3.503	2.813	533.5	459.7	365.955	460.0	1.161	0.925	2.91	4.89	94.00	4.88	93.81	13.83	48.61	19.70	9.2
7 ton	2173	3.504	2.789	509.8	439.1	348.583	439.4	1.143	0.905	2.82	4.83	92.98	4.84	93.17	13.87	49.83	20.41	9.2
	2174	3.503	2.789	507.6	436.7	346.820	436.8	1.130	0.908	2.84	4.85	93.33	4.80	92.36	13.97	49.05	20.38	9.2
	2177	3.506	2.811	496.9	430.2	339.107	430.2	1.115	0.891	2.82	4.72	90.82	4.75	91.27	13.42	48.62	19.82	9.2
	2178	3.503	2.811	493.1	426.0	336.423	426.0	1.100	0.883	2.84	4.76	91.46	4.74	91.20	13.61	48.30	19.75	9.2
	2179	3.504	2.811	492.2	424.3	335.550	424.3	1.097	0.880	2.84	4.78	91.94	4.74	91.15	13.80	48.36	19.78	9.2
GA-30-8% CP	1646	3.255	2.592	499.5	441.8	351.409	442.3	1.312	1.055	2.79	4.86	93.48	4.84	93.11	11.55	49.00	20.37	6.9

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-30-8%,BP 6/19, 23 tons	2611	3.511	2.851	578.2	512.0	410.390	512.8	1.200	0.991	3.04	5.00	96.14	4.94	94.95	11.45	45.54	18.80	6.9
13.1 tons	2612	3.507	2.801	529.2	466.1	372.585	466.0	1.163	0.929	2.87	4.99	95.95	4.97	95.52	11.92	49.04	20.13	6.9
6.3 tons	2613	3.505	2.749	479.0	421.6	334.649	421.6	1.145	0.903	2.65	4.85	93.24	4.80	92.29	11.98	51.48	21.57	6.9
8.1 tons	2614	3.506	2.782	508.9	444.4	354.058	444.5	1.153	0.915	2.79	4.91	94.49	4.87	93.74	12.67	50.02	20.65	6.9
6.4 tons	2615	3.505	2.768	511.9	443.7	352.315	443.7	1.174	0.930	2.76	4.86	93.37	4.84	93.01	13.32	50.59	21.03	6.9
GA-30-10% CP	1643	3.253	2.614	499.2	432.8	343.475	432.8	1.262	1.021	2.90	4.85	93.18	4.82	92.67	13.30	47.75	19.64	8.3
	2070	3.253	2.567	499.5	437.0	348.668	437.1	1.313	1.047	2.79	4.94	95.03	4.92	94.61	12.51	50.34	21.09	8.0
GA-30-10% BP 4/3, 7 ton, G0202-2 & G0223-2	2071	3.498		475.0				1.189										
	2072	3.502	2.762	499.4	435.5	344.268	435.5	1.195	0.942	2.65	4.77	91.80	4.71	90.52	12.80	50.96	21.13	8.0
	2073	3.501	2.757	507.9	441.1	349.894	441.2	1.200	0.950	2.68	4.83	92.90	4.74	91.25	13.15	50.90	21.25	8.0
	2074	3.503	2.746	497.3	431.4	343.103	431.4	1.162	0.912	2.71	4.89	93.96	4.87	93.70	13.25	51.76	21.61	8.0
	2075	3.502	2.772	502.8	436.9	345.408	437.1	1.182	0.943	2.69	4.76	91.63	4.68	90.06	13.11	50.00	20.85	8.0
	2076	3.501	2.752	501.7	435.3	345.888	435.3	1.181	0.912	2.69	4.87	93.62	4.90	94.14	13.24	52.28	21.39	8.0
	2077	3.502	2.756	500.9	434.4	344.584	434.5	1.178	0.929	2.69	4.83	92.91	4.78	91.96	13.28	51.15	21.30	8.0
	2078	3.503	2.768	498.6	433.1	342.578	433.2	1.162	0.929	2.72	4.78	91.91	4.73	90.89	13.14	50.07	20.98	8.0
	2079	3.500	2.733	448.6	388.8	309.848	389.0	1.060	0.830	2.68	4.91	94.46	4.87	93.68	13.33	52.25	21.91	8.0
GA-30-10% Full G0223-2	1788	3.257	2.590	500.5	438.2	347.802	438.3	1.319	1.052	2.78	4.84	93.12	4.82	92.75	12.45	49.56	20.48	8.0
GA-30-12% CP	1644	3.253	2.621	501.3	430.7	342.086	431.6	1.249	1.018	2.95	4.81	92.53	4.78	92.00	14.08	47.08	19.43	9.5
GA-30-12%, BP 6/19, 6.7 tons	2616	3.506	2.773	512.2	442.0	350.873	442.2	1.169	0.929	2.77	4.84	93.07	4.81	92.42	13.71	50.28	20.91	9.5
6.3 tons	2617	3.507	2.750	514.1	441.8	352.418	442.1	1.168	0.921	2.78	4.93	94.74	4.93	94.75	14.06	51.51	21.59	9.5
6.1 tons	2618	3.505	2.754	517.4	443.7	353.402	443.1	1.169	0.924	2.80	4.95	95.13	4.92	94.57	14.24	51.19	21.43	9.5
	2619	3.505	2.755	518.1	442.8	352.788	443.0	1.168	0.925	2.81	4.91	94.39	4.90	94.21	14.53	51.06	21.40	9.5
6.4 tons	2620	3.505	2.759	519.9	444.6	353.949	444.6	1.171	0.928	2.81	4.90	94.32	4.89	94.01	14.48	50.89	21.28	9.5
GA-31-8% CP	1648	3.253	2.596	499.8	443.2	352.467	443.3	1.320	1.053	2.78	4.88	93.83	4.85	93.29	11.32	49.19	20.20	6.8
GA-31-8%, BP 6/19, 4.5 tons	2621	3.504	2.713	477.2	417.4	331.462	417.4	1.162	0.909	2.60	4.86	93.40	4.85	93.19	12.53	53.10	22.57	6.8
5.9 tons	2622	3.505	2.714	487.9	429.9	343.407	429.9	1.167	0.911	2.64	4.97	95.58	4.98	95.70	11.89	53.19	22.57	6.8
7.2 tons	2623	3.506	2.743	508.5	448.0	358.295	448.1	1.178	0.928	2.73	4.99	95.93	4.98	95.84	11.90	51.77	21.76	6.8
6.2 tons	2624	3.508	2.744	507.5	447.2	357.171	447.2	1.174	0.928	2.73	4.97	95.52	4.97	95.60	11.88	51.63	21.78	6.8
6 tons	2625	3.505	2.724	501.4	441.9	352.663	441.7	1.172	0.923	2.71	4.96	95.44	5.01	96.38	11.87	52.42	22.28	6.8
GA-31-10% CP	1767	3.253	2.578	499.9	433.1	345.784	433.2	1.303	1.036	2.82	4.95	95.28	4.89	93.96	13.36	50.05	20.75	9.2
GA-31-10%, BP 6/19, 5.9 tons	2626	3.505	2.724	502.3	437.1	348.909	437.1	1.170	0.922	2.71	4.96	95.31	4.96	95.43	12.98	52.39	22.28	9.2
	2627	3.505	2.722	505.0	436.0	348.134	435.5	1.172	0.913	2.72	4.99	95.97	5.01	96.27	13.66	53.01	22.34	9.2
5.2 tons	2628	3.505	2.715	499.7	430.8	343.974	430.6	1.169	0.914	2.70	4.97	95.64	4.97	95.51	13.79	53.08	22.54	9.2
5 tons	2629	3.505	2.710	497.3	428.4	342.380	428.5	1.168	0.911	2.69	4.97	95.66	4.97	95.65	13.85	53.36	22.68	9.2
4.8 tons	2630	3.505	2.707	495.6	426.8	341.131	427.1	1.173	0.912	2.67	4.96	95.47	4.96	95.39	13.88	53.62	22.77	9.2
GA-31-12% CP	1645	3.252	2.621	501.0	425.7	339.074	426.0	1.234	0.991	2.98	4.90	94.18	4.86	93.40	15.03	47.82	19.40	10.2

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-31-12%, BP 6/19, 6.1 tons	2631	3.504	2.756	515.3	443.1	353.780	443.2	1.174	0.922	2.78	4.96	95.29	4.91	94.51	14.01	51.41	21.35	10.2
6.5 tons	2632	3.505	2.779	541.9	461.9	368.177	461.8	1.182	0.942	2.90	4.93	94.88	4.93	94.84	14.76	49.89	20.71	10.2
6.3 tons	2633	3.506	2.776	541.9	460.3	367.214	460.5	1.175	0.938	2.91	4.93	94.89	4.95	95.12	15.06	49.94	20.82	10.2
4.2 tons	2634	3.503	2.792	510.4	434.5	344.227	436.9	1.173	0.931	2.75	4.69	90.16	4.65	89.43	14.87	49.57	20.30	10.2
4 tons	2635	3.504	2.755	510.8	433.5	343.617	433.8	1.168	0.925	2.77	4.81	92.44	4.80	92.23	15.13	51.03	21.38	10.2
1 tons	2636	3.505	2.694	367.5	312.9	247.295	321.5	1.060	0.811	2.19	4.22	81.09	4.13	79.41	14.86	54.79	23.14	10.2
GA-31-14%	1704	3.257	2.594	500.1	420.3	N/A	N/A	1.233	N/A	2.97	N/A	N/A	N/A	N/A	15.96	N/A	20.36	11.5
GA-32-4% CP	1656	3.255	2.575	499.6	460.5	366.170	461.0	1.399	1.110	2.62	4.86	93.39	4.86	93.46	7.83	50.34	20.89	3.2
GA-32-4%, BP 6/14, G0207-2, 4.9 ton	2586	3.508	2.726	473.7	422.0	336.816	422.1	1.145	0.900	2.61	4.95	95.16	4.90	94.25	10.91	52.53	22.29	3.2
5.4 ton	2587	3.505	2.728	459.9	422.9	337.397	423.0	1.148	0.900	2.53	4.94	95.00	4.90	94.31	8.05	52.50	22.17	3.2
5.2 ton	2588	3.505	2.722	457.9	421.2	336.258	421.2	1.148	0.893	2.52	4.96	95.36	4.94	95.09	8.01	53.08	22.34	3.2
10 ton	2589	3.510	2.770	494.7	455.2	363.870	455.3	1.174	0.931	2.66	4.98	95.74	4.95	95.18	7.98	50.60	21.08	3.2
10.4 ton	2590	3.510	2.766	494.7	455.3	364.147	455.3	1.174	0.932	2.66	4.99	96.06	4.96	95.38	7.96	50.69	21.20	3.2
GA-32-8% CP	1657	3.254	2.625	500.0	439.4	348.421	440.0	1.310	1.052	2.80	4.80	92.27	4.71	90.54	12.12	47.73	19.33	7.1
GA-32-8%, BP 7/10, 10.3 tons	2789	3.507	2.783	516.2	455.0	363.484	455.1	1.165	0.921	2.80	4.97	95.51	4.95	95.28	11.86	50.21	20.64	7.1
17.5 tons	2790	3.510	2.834	554.0	486.4	389.204	486.7	1.180	0.955	2.96	4.99	95.94	4.93	94.72	12.20	47.23	19.26	7.1
9.5 tons	2791	3.506	2.785	513.4	451.3	359.916	451.6	1.152	0.921	2.82	4.92	94.66	4.91	94.37	12.10	49.54	20.56	7.1
5.1 tons	2792	3.506	2.740	482.9	424.2	338.122	424.4	1.140	0.898	2.68	4.92	94.55	4.89	93.99	12.16	51.88	21.85	7.1
4.1 tons	2793	3.506	2.726	465.8	409.3	325.046	409.4	1.138	0.886	2.59	4.85	93.31	4.83	92.86	12.13	52.92	22.25	7.1
GA-32-10% Full CP G0223-3	1825	3.254	2.587	501.8	431.8	344.436	431.9	1.273	1.013	2.89	4.94	94.94	4.95	95.14	13.95	49.69	20.50	8.9
GA-32-10%, G0223-3, BP 7/10, 6.63 tons	2794	3.508	2.762	512.8	440.6	351.333	440.7	1.148	0.914	2.82	4.93	94.81	4.91	94.39	14.08	50.64	21.27	8.9
6.9 tons	2795	3.507	2.764	523.5	447.7	351.825	447.7	1.157	0.920	2.86	4.67	89.80	4.95	95.15	14.48	50.60	21.19	8.9
6.1 tons	2796	3.504	2.750	513.1	438.7	350.473	438.7	1.145	0.909	2.84	4.97	95.62	4.96	95.33	14.50	51.09	21.52	8.9
	2797	3.506	2.746	507.8	434.6	347.008	434.6	1.151	0.906	2.79	4.96	95.42	4.94	95.02	14.42	51.70	21.68	8.9
6.3 tons	2798	3.507	2.752	513.3	439.0	350.466	439.1	1.149	0.911	2.82	4.95	95.25	4.94	95.04	14.47	51.17	21.53	8.9
6.5 tons	2799	3.505	2.758	517.4	442.6	353.436	442.7	1.156	0.915	2.83	4.96	95.35	4.94	94.99	14.46	50.98	21.31	8.9
? Tons	2800	3.504	2.734	501.6	428.7	342.300	428.9	1.142	0.901	2.78	4.95	95.20	4.94	95.08	14.53	51.96	21.97	8.9
4.9 tons	2801	3.506	2.727	497.0	425.3	339.489	425.4	1.146	0.899	2.74	4.95	95.20	4.94	95.02	14.43	52.53	22.22	8.9
4 tons	2802	3.503	2.718	484.8	414.2	330.074	414.4	1.138	0.897	2.70	4.91	94.46	4.86	93.37	14.56	52.54	22.41	8.9
? Tons	2803	3.504	2.633	401.0	342.3	270.622	344.8	1.139	0.849	2.23	4.61	88.74	4.52	86.87	14.64	57.90	24.86	8.9
GA-32-12% CP	1658	3.254	2.630	499.9	430.0	341.299	431.4	1.264	1.025	2.90	4.77	91.78	4.71	90.60	13.98	47.02	19.18	8.7

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-32-12%, BP 6 ton	2580	3.507	2.800	551.7	461.9	368.080	462.3	1.165	0.936	2.99	4.90	94.28	4.89	94.02	16.28	48.78	20.16	8.9
5.3 ton	2581	3.505	2.760	517.2	441.0	351.326	441.3	1.160	0.923	2.82	4.90	94.26	4.87	93.69	14.73	50.65	21.26	8.9
4.3 ton	2582	3.504	2.737	491.0	422.2	334.908	422.3	1.160	0.912	2.68	4.83	92.91	4.80	92.31	14.01	52.02	21.89	8.9
3.8 ton	2583	3.505	2.730	493.8	423.8	337.541	424.1	1.155	0.911	2.70	4.90	94.16	4.85	93.24	14.18	52.14	22.11	8.9
4.5 ton	2584	3.507	2.743	495.8	425.0	337.993	425.3	1.148	0.906	2.73	4.87	93.61	4.84	93.13	14.28	51.71	21.79	8.9
4 ton	2585	3.505	2.737	492.6	422.4	336.143	422.5	1.147	0.905	2.72	4.89	94.06	4.84	93.07	14.25	51.88	21.91	8.9
GA-32-14% CP G0207-1	1661	3.254	2.636	500.0	418.5	332.878	418.5	1.192	0.965	3.08	4.89	94.00	4.85	93.23	16.30	46.86	18.99	11.5
GA-32-14%, BP 6/14, G0407, 2	2571	N/A								N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.3
2.7 ton	2572	3.506	2.711	478.0	401.3	318.465	402.3	1.155	0.905	2.62	4.79	92.05	4.69	90.12	16.05	53.14	22.68	10.3
3.1 ton	2573	3.506	2.712	491.1	410.7	326.251	411.7	1.150	0.903	1.05	4.81	92.43	4.80	92.37	16.37	53.01	22.65	10.3
6 ton	2574	3.509	2.799	503.2	421.1	336.132	421.3	1.073	0.856	2.96	4.94	95.08	4.88	93.79	16.32	49.23	20.23	10.3
22.6 ton	2575	3.511	2.837	550.7	466.7	373.613	467.2	1.128	0.917	3.08	4.99	95.90	4.91	94.45	15.25	46.91	19.20	10.3
GA-32-16%	2088	3.253	2.608	501.2	414.2	329.945	415.3	1.229	0.991	2.99	4.85	93.32	4.77	91.79	17.36	48.16	19.83	12.0
GA-33-8%	1659	3.255	2.605	499.8	431.6	344.154	432.0	1.265	1.014	2.90	4.91	94.48	4.87	93.69	13.65	48.65	19.97	8.7
GA-33-8% Repeat	1708	3.254	2.616	499.0	432.1	344.430	432.7	1.252	1.007	2.92	4.90	94.14	4.87	93.66	13.41	48.01	19.61	7.5
GA-33-10%	1709	3.254	2.625	499.1	425.7	339.566	426.4	1.221	0.981	3.00	4.90	94.28	4.89	94.07	14.71	47.71	19.33	9.5
GA-33-12%	1660	3.251	2.607	500.0	415.6	330.565	416.9	1.249	1.003	2.94	4.81	92.57	4.74	91.07	16.88	48.35	19.81	12.2
GA-34-8%	1751	3.254	2.592	498.5	440.7	350.203	440.7	1.325	1.050	2.76	4.87	93.65	4.85	93.32	11.59	49.71	20.34	6.9
GA-34-8%	1781	3.254	2.586	500.1	442.2	352.580	442.7	1.331	1.056	2.76	4.91	94.36	4.86	93.53	11.58	49.88	20.53	6.9
GA-34-12%	1752	3.254	2.596	498.9	427.4	340.428	427.4	1.271	1.010	2.88	4.91	94.50	4.88	93.79	14.33	49.41	20.22	8.7
GA-34-12%	1780	3.254	2.591	497.5	427.9	341.064	428.1	1.274	1.018	2.87	4.92	94.55	4.86	93.53	13.99	49.33	20.37	8.7
GA-35-8%	1753	3.254	2.621	499.9	436.3	346.604	436.3	1.268	1.021	2.89	4.86	93.54	4.83	92.92	12.72	47.75	19.45	6.9
GA-35-8%	1778	3.255	2.616	500.3	436.6	347.211	437.2	1.271	1.031	2.89	4.85	93.30	4.81	92.43	12.73	47.60	19.63	6.9
GA-35-12%	1754	3.253	2.635	499.3	425.6	337.950	425.6	1.228	0.990	2.99	4.86	93.38	4.81	92.49	14.76	47.09	19.00	8.1
GA-35-12%	1777	3.254	2.620	501.4	428.3	340.608	428.4	1.244	1.000	2.96	4.88	93.82	4.85	93.20	14.58	47.88	19.48	8.1
GA-36-8% CP	1774	3.255	2.604	500.1	439.2	349.847	439.6	1.298	1.041	2.83	4.89	94.10	4.83	92.94	12.18	48.66	20.00	6.6
GA-36-8%, BP 6/28, 4 tons	2637	3.506	2.720	463.4	407.8	322.801	408.9	1.160	0.909	2.52	4.74	91.08	4.71	90.58	12.00	52.83	22.42	8.0
6.1 tons	2638	3.505	2.745	490.0	430.5	341.763	431.4	1.169	0.929	2.65	4.80	92.36	4.78	91.86	12.14	51.25	21.68	8.0
5.8 tons	2639	3.505	2.765	498.6	437.5	347.482	438.5	1.174	0.925	2.69	4.81	92.44	4.81	92.41	12.25	50.96	21.11	8.0
5.7 tons	2640	3.506	2.755	497.7	436.6	347.760	437.6	1.175	0.928	2.68	4.86	93.46	4.81	92.59	12.28	51.22	21.42	8.0
5.5 tons	2641	3.506	2.750	493.7	433.5	344.501	434.3	1.169	0.912	2.67	4.83	92.84	4.88	93.89	12.19	51.99	21.56	8.0
GA-36-12% CP	1779	3.255	2.610	499.9	425.8	339.112	425.7	1.235	0.990	2.97	4.92	94.57	4.90	94.31	14.82	48.45	19.82	9.3
GA-36-12%, BP 6/29, 4.5 tons	2657	3.506	2.762	527.1	440.5	351.030	440.7	1.163	0.920	2.86	4.91	94.47	4.88	93.75	16.43	50.90	21.22	9.3
10.1 tons	2658	3.508	2.826	569.2	481.1	384.082	481.4	1.185	0.955	3.03	4.94	95.07	4.90	94.22	15.48	47.69	19.44	9.3
6.2 tons	2659	3.508	2.811	558.2	473.3	376.986	473.5	1.180	0.955	2.99	4.90	94.31	4.87	93.69	15.21	48.02	19.87	9.3
6.25 tons	2660	3.506	2.795	539.2	457.5	363.790	457.6	1.172	0.940	2.91	4.88	93.79	4.84	93.06	15.15	49.02	20.28	9.3
5 tons	2661	3.505	2.780	515.8	438.0	346.869	439.1	1.166	0.933	2.80	4.75	91.33	4.72	90.73	15.08	49.65	20.68	9.3
GA-37-6%	1830	3.256	2.627	498.6	446.0	353.851	450.1	1.332	1.091	2.74	4.63	89.11	4.60	88.48	10.55	46.67	19.32	4.8
GA-37-8%	1768	3.252	2.601	499.8	426.0	337.454	426.5	1.280	1.030	2.87	4.78	92.00	4.75	91.32	14.77	48.51	20.02	7.6

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-37-10%	1831	3.254	2.662	498.8	424.5	336.781	428.7	1.225	1.010	2.99	4.62	88.81	4.61	88.60	14.90	44.81	18.19	9.2
GA-37-12%	1769	3.253	2.628	498.9	416.1	329.906	418.3	1.243	1.008	2.95	4.71	90.53	4.64	89.28	16.60	47.06	19.21	9.6
GA-38-8%	1770	3.255	2.539	500.9	434.9	346.649	434.9	1.372	1.074	2.68	4.93	94.77	4.88	93.83	13.18	52.36	22.00	7.7
GA-38-12%	1773	3.254	2.555	500.2	419.1	334.422	419.4	1.305	1.024	2.81	4.93	94.84	4.87	93.65	16.21	51.61	21.48	10.9
GA-39-10% CP	1833	3.254	2.586	498.3	429.5	342.495	429.6	1.278	1.018	2.86	4.93	94.82	4.90	94.24	13.81	49.68	20.53	8.3
GA-39-10%, BP 6/28, 3.5 tons	2642	3.506	2.737	475.6	413.4	327.697	414.6	1.160	0.919	2.59	4.76	91.48	4.66	89.70	13.08	51.71	21.93	10.0
2.8 tons	2643	3.506	2.691	471.8	404.0	322.161	404.9	1.168	0.898	2.55	4.88	93.90	4.83	92.80	14.37	54.70	23.25	10.0
4.7 tons	2644	3.505	2.734	504.1	431.0	344.915	432.0	1.168	0.917	2.73	4.95	95.18	4.88	93.93	14.50	52.22	22.00	10.0
4.6 tons	2645	3.505	2.727	501.4	429.6	343.310	430.3	1.169	0.912	2.71	4.94	94.97	4.92	94.62	14.32	52.77	22.20	10.0
4.4 tons	2646	3.506	2.720	497.4	424.2	338.688	424.9	1.165	0.914	2.70	4.92	94.62	4.87	93.70	14.72	52.77	22.42	10.0
GA-39-12% CP	1838	3.254	2.612	499.3	419.1	334.465	419.8	1.232	0.985	2.97	4.91	94.45	4.84	93.16	16.06	48.48	19.73	10.4
GA-39-12%, BP 6/28, 6.3 tons	2652	3.506	2.743	512.6	444.1	355.695	445.2	1.181	0.933	2.74	4.96	95.42	4.91	94.50	13.36	51.63	21.76	12.0
3.8 tons	2653	3.506	2.731	507.7	427.1	340.979	428.1	1.166	0.916	2.75	4.90	94.28	4.86	93.38	15.88	52.32	22.10	12.0
3 tons	2654	3.505	2.729	507.9	424.4	338.588	425.4	1.175	0.915	2.73	4.89	94.01	4.84	93.03	16.44	52.78	22.14	12.0
3 tons	2655	3.505	2.734	507.4	423.7	336.415	423.8	1.172	0.916	2.74	4.85	93.24	4.81	92.44	16.50	52.44	22.00	12.0
2.7 tons	2656	3.505	2.725	512.6	427.6	340.078	428.6	1.188	0.931	2.73	4.83	92.89	4.80	92.39	16.58	52.62	22.25	12.0
GA-39-14% CP	1839	3.253	2.604	498.4	415.1	331.097	415.9	1.228	0.977	2.98	4.89	94.13	4.87	93.59	16.71	49.01	19.95	11.4
GA-39-14%, BP 6/29, 2.3 tons	2667	3.505	2.760	506.0	421.6	334.056	422.8	1.153	0.910	2.78	4.75	91.36	4.72	90.85	16.68	51.05	21.26	11.4
2.2 tons	2668	3.504	2.736	497.1	411.5	326.753	411.8	1.137	0.889	2.77	4.84	93.05	4.80	92.36	17.22	52.32	21.92	11.4
2.3 tons	2669	3.504	2.740	499.2	412.8	327.812	412.9	1.135	0.888	2.78	4.85	93.30	4.81	92.49	17.31	52.15	21.80	11.4
5 tons	2670	3.508	2.779	536.0	443.6	354.588	443.9	1.147	0.907	2.95	4.97	95.52	4.92	94.60	17.24	50.37	20.78	11.4
3.6 ton	2671	3.505	2.756	521.6	430.1	343.257	430.1	1.149	0.898	2.87	4.95	95.24	4.90	94.19	17.54	51.67	21.37	11.4
2.5 ton	2672	3.505	2.742	505.3	417.1	331.848	417.3	1.134	0.889	2.82	4.88	93.87	4.85	93.21	17.45	52.01	21.77	11.4
GA-40-10% CP	1840	3.255	2.575	500.1	437.5	349.517	437.8	1.319	1.045	2.78	4.96	95.30	4.90	94.31	12.52	50.41	20.89	7.4
GA-40-10%, BP 6/28, 4.5 tons	2647	3.507	2.724	496.4	426.8	341.145	427.9	1.167	0.904	2.69	4.92	94.61	4.94	95.04	14.02	53.26	22.33	10.0
6 tons	2648	3.505	2.727	503.6	437.1	350.212	438.2	1.177	0.920	2.71	4.97	95.53	4.96	95.43	13.20	52.68	22.20	10.0
	2649	3.505	2.725	501.5	436.4	349.723	437.5	1.173	0.923	2.70	4.97	95.61	4.95	95.11	12.98	52.43	22.25	10.0
	2650	3.506	2.726	500.2	435.9	349.163	436.3	1.171	0.925	2.70	5.00	96.20	4.93	94.73	12.85	52.24	22.25	10.0
5.6 tons	2651	3.506	2.725	496.8	432.6	346.368	434.0	1.181	0.908	2.66	4.94	94.93	4.98	95.84	12.92	53.55	22.28	10.0
GA-40-12% CP	1841	3.253	2.628	500.0	419.3	333.911	420.1	1.210	0.979	3.03	4.86	93.56	4.82	92.63	16.14	47.18	19.21	10.0
GA-40-12%, BP 6/29, 3.7 tons	2662	3.506	2.775	501.3	424.3	335.840	427.2	1.163	0.930	2.72	4.64	89.31	4.60	88.50	15.36	49.89	20.85	10.0
1.3 tons	2663	3.502	2.729	440.5	368.7	291.418	374.9	1.125	0.886	2.48	4.42	84.93	4.34	83.46	16.30	52.17	22.07	10.0
1.6 tons	2664	3.504	2.742	458.7	383.2	302.872	388.9	1.140	0.900	2.55	4.45	85.66	4.40	84.59	16.46	51.65	21.75	10.0
2.3 tons	2665	3.504	2.765	508.1	423.7	335.460	424.7	1.159	0.917	2.77	4.75	91.31	4.69	90.28	16.61	50.72	21.09	10.0
2.6 tons	2666	3.505	2.763	510.6	425.4	337.297	425.8	1.146	0.910	2.82	4.81	92.43	4.76	91.47	16.69	50.65	21.17	10.0
GA-41-10%	1937	3.254		500.2	N/A	N/A	N/A	1.285	N/A	2.86	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7.9
GA-41-14% G0309-1	1938	3.255	2.558	500.3	431.9	344.058	431.9	1.328	1.046	2.76	4.92	94.55	4.90	94.26	13.67	51.35	21.41	8.6
GA-41-14%, G0310-0	2774	3.255	2.570	499.6	421.2	336.529	422.1	1.277	1.023	2.87	4.92	94.66	4.84	93.11	15.69	50.05	21.04	8.6

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GA-41-14%, Full G0310-1	2775	3.246	2.530	500.5	405.6	322.485	407.6	1.347	1.146	2.74	4.77	91.64	4.29	82.59	18.96	48.31	22.06	11.3
GA-42-14%	1842	3.253	2.599	499.6	415.3	331.329	416.3	1.237	0.987	2.97	4.89	93.99	4.84	93.05	16.87	49.06	20.10	11.3
GA-44-12%	1837	3.254	2.589	499.6	427.7	341.382	427.7	1.269	1.008	2.89	4.95	95.29	4.92	94.56	14.39	49.71	20.44	10.1
GA-45-12%, G0425-2, BP 7/13, 4.4 tons	2811	3.507	2.670	486.3	405.7	320.840	405.9	1.231	0.929	2.50	4.77	91.72	4.76	91.50	16.57	56.25	23.87	8.2
5 tons	2812	3.506	2.671	499.2	417.1	N/A	N/A	1.262	0.960	2.50	N/A	N/A	4.73	90.97	16.45	55.84	23.82	8.2
	2813	3.508	2.700	505.6	425.8	336.063	425.8	1.258	0.958	2.54	4.74	91.25	4.74	91.07	15.78	54.88	23.03	8.2
5.2 tons	2814	3.507	2.690	499.6	420.7	333.163	420.9	1.240	0.947	2.54	4.80	92.21	4.77	91.70	15.79	55.06	23.30	8.2
5.4 tons	2815	3.507	2.696	508.7	428.5	338.868	428.9	1.261	0.967	2.55	4.76	91.53	4.74	91.07	15.77	54.67	23.13	8.2
5.3 tons	2816	3.507	2.705	505.9	426.6	336.650	426.8	1.254	0.960	2.55	4.73	91.00	4.72	90.72	15.68	54.45	22.87	8.2
6 tons	2817	3.507	2.693	496.0	418.2	332.469	418.5	1.208	0.926	2.59	4.86	93.48	4.84	93.02	15.69	54.79	23.21	8.2
5.9 tons	2818	3.508	2.700	500.2	421.6	334.605	421.9	1.220	0.937	2.59	4.83	92.88	4.79	92.19	15.71	54.49	23.03	8.2
5.2 tons	2819	3.512	2.716	500.6	421.7	335.212	421.9	1.198	0.922	2.63	4.86	93.55	4.82	92.62	15.76	53.96	22.67	8.2
6.2 tons	2820	3.507	2.690	501.3	422.2	335.575	422.1	1.219	0.933	2.60	4.88	93.84	4.86	93.41	15.78	54.96	23.30	9.4
	2821	3.508	2.700	502.7	423.1	N/A	N/A	1.221	0.940	2.60	N/A	N/A	4.80	92.23	15.83	54.39	23.03	9.4
6 tons	2822	3.508	2.687	496.3	417.6	332.157	417.4	1.206	0.921	2.60	4.90	94.21	4.88	93.81	15.86	55.19	23.40	9.4
6.1 tons	2823	3.507	2.690	495.5	417.2	331.320	416.8	1.205	0.922	2.60	4.88	93.86	4.86	93.41	15.80	54.97	23.30	9.4
5.4 tons	2824	3.507	2.714	448.4	377.6	301.211	377.9	1.045	0.815	2.71	4.92	94.69	4.89	93.96	15.79	53.28	22.61	9.4
10.6 tons	2825	3.507	2.740	427.0	352.1	281.052	352.7	0.980	0.754	2.75	4.91	94.51	4.83	92.91	17.54	53.03	21.87	9.4
GA-45-12%, G0426, BP 7/19, 12.8 tons	2826	3.508	2.754	511.8	431.9	344.251	432.4	1.164	0.913	2.78	4.90	94.22	4.84	93.17	15.61	51.65	21.49	9.4
8.2 tons	2827	3.503	2.798	525.3	446.0	355.192	446.5	1.152	0.915	2.89	4.88	93.93	4.84	93.00	15.10	49.32	20.13	9.4
12 tons	2828	3.505	2.828	557.6	475.0	379.288	475.4	1.165	0.942	3.03	4.94	95.04	4.90	94.18	14.81	47.35	19.32	9.4
10 tons	2829	3.505	2.812	544.0	463.1	369.625	463.4	1.155	0.930	2.98	4.94	94.97	4.89	94.07	14.87	48.16	19.77	9.4
5.3 tons	2830	3.503	2.795	516.5	439.8	N/A	N/A	1.145	0.917	2.86	N/A	N/A	4.77	91.71	14.85	49.01	20.21	9.4
	2831	3.504	2.795	521.3	443.6	352.653	444.4	1.147	0.917	2.88	4.84	92.98	4.81	92.50	14.91	49.12	20.23	9.4
GB-1-12% Hf/Ce/U	U300	3.500	2.748	509.7	457.3	370.880	458.2	1.141	0.895	2.83	5.24	91.71	5.26	92.04	10.28	51.64	21.49	5.4
	U301	3.500	2.739	499.9	449.5	364.940	450.6	1.120	0.878	2.83	5.25	91.89	5.30	92.82	10.09	51.98	21.74	5.4
	U302	3.500	2.742	499.8	447.2	363.290	447.3	1.112	0.880	2.85	5.32	93.23	5.25	91.94	10.52	51.42	21.66	5.4
Sched 3	U264	3.500	2.741	572.5	514.8	417.300	515.0	1.285	1.019	2.83	5.27	92.24	5.22	91.47	10.08	51.36	21.69	5.3
	U265	3.500	2.747	574.9	517.3	419.100	517.5	1.291	1.021	2.82	5.25	92.03	5.22	91.34	10.02	51.27	21.51	5.3
15000 lbs	U266	3.500	2.722	553.5	498.1	403.450	498.4	1.279	1.001	2.74	5.25	91.92	5.22	91.36	10.01	52.65	22.23	5.3
15000 lbs	U267	3.500		396.8				0.918	0.717	2.74	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.3
GB-1-14% Hf/Ce/U	U237	3.500	2.745	500.1	433.3	351.520	433.4	1.076	0.845	2.95	5.29	92.66	5.29	92.57	13.36	51.69	21.57	8.4
	U238	3.500	2.733	498.6	432.2	350.530	432.3	1.085	0.848	2.91	5.29	92.56	5.30	92.83	13.31	52.34	21.91	8.4
	U239	3.500	2.725	500.1	433.3	351.380	433.3	1.092	0.852	2.90	5.29	92.65	5.32	93.16	13.36	52.70	22.14	8.4
	U262	3.500	2.757	565.5	492.7	397.830	493.1	1.234	0.978	2.91	5.17	90.56	5.15	90.16	12.87	50.81	21.23	7.9
	U263	3.500	2.737	583.1	509.1	413.090	509.1	1.279	0.997	2.89	5.30	92.86	5.29	92.73	12.69	52.32	21.80	7.9

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
GB-2-12% Hf/Ce/U	U222	3.501	2.744	499.7	445.1	361.150	445.1	1.111	0.880	2.85	5.30	92.83	5.22	91.38	10.92	51.33	21.62	6.0
	U223	3.501	2.748	500.6	446.5	362.060	446.5	1.120	0.890	2.83	5.29	92.63	5.16	90.36	10.82	51.03	21.51	6.0
	U224	3.501	2.745	498.8	445.3	360.800	445.3	1.122	0.893	2.82	5.27	92.26	5.14	90.01	10.74	51.06	21.59	6.0
Sched 3	U231	3.500	2.738	559.6	499.3	405.010	499.6	1.246	0.989	2.85	5.28	92.44	5.23	91.61	10.78	51.42	21.77	6.0
	U232	3.500	2.738	558.4	499.2	404.720	499.5	1.250	0.984	2.83	5.27	92.22	5.26	92.06	10.60	51.82	21.77	6.0
	U233	3.500	2.740	557.5	498.3	404.000	498.6	1.246	0.971	2.84	5.27	92.29	5.31	92.98	10.62	52.23	21.71	6.0
GB-3-10% Hf/Ce/U	U225	3.500	2.800	499.7	430.5	349.750	430.5	1.003	0.798	3.16	5.33	93.41	5.34	93.59	13.86	49.07	20.00	10.2
	U226	3.500	2.800	501.5	431.7	350.810	431.7	1.008	0.814	3.16	5.34	93.47	5.25	92.02	13.92	48.31	20.00	10.2
	U227	3.500	2.789	500.7	432.3	351.280	432.3	1.015	0.810	3.13	5.33	93.43	5.33	93.34	13.66	49.32	20.31	10.2
	U248	3.501	2.800	581.0	502.4	408.120	502.7	1.182	0.952	3.12	5.31	93.07	5.23	91.57	13.53	48.47	20.02	10.2
	U249	3.502	2.795	583.0	503.5	409.170	503.5	1.183	0.948	3.12	5.34	93.48	5.28	92.48	13.64	48.95	20.19	10.2
	U250	3.501	2.792	669.5	579.1	470.600	579.3	1.366	1.089	3.11	5.33	93.28	5.30	92.80	13.50	49.29	20.25	10.2
GB-4-10% Hf/Ce/U	U228	3.500	2.779	499.3	439.6	356.870	439.6	1.051	0.835	3.01	5.32	93.09	5.29	92.73	11.96	49.90	20.60	7.5
	U229	3.500	2.780	498.8	439.6	356.850	439.7	1.051	0.825	3.01	5.31	92.98	5.36	93.79	11.87	50.47	20.57	7.5
	U230	3.500	2.783	499.5	440.2	357.340	440.2	1.052	0.838	3.01	5.31	93.06	5.27	92.26	11.88	49.63	20.49	7.5
Sched 3, 1.5 ksi	U268	3.500	2.747	573.5	505.5	409.270	505.7	1.267	0.994	2.87	5.24	91.81	5.23	91.68	11.86	51.66	21.51	7.5
GB-4-10% Repeat, GU0705	U290	3.500	2.782	501.3	431.3	350.320	431.4	1.028	0.808	3.09	5.32	93.16	5.36	93.82	13.96	50.33	20.51	9.1
	U291	3.500	2.783	502.4	431.7	350.690	432.0	1.025	0.811	3.11	5.31	92.98	5.34	93.49	14.07	49.97	20.49	9.1
	U292	3.500	2.795	508.5	436.8	354.900	436.9	1.030	0.820	3.13	5.33	93.29	5.30	92.76	14.10	49.22	20.14	9.1
GB-4-12% Hf/Ce/U	U269	3.494	2.782	503.4	421.9	342.120	422.9	1.012	0.809	3.17	5.23	91.53	5.23	91.67	16.18	49.31	20.38	11.1
	U270	3.495	2.785	498.1	417.7	338.820	418.5	1.002	0.800	3.16	5.25	91.87	5.23	91.57	16.14	49.29	20.31	11.1
	U271	3.495	2.786	500.0	419.1	339.710	420.4	1.005	0.809	3.16	5.19	90.94	5.18	90.80	16.18	48.84	20.29	11.1
3.5 ksi	U272	3.495	2.799	495.0	415.1	336.670	415.9	0.993	0.798	3.17	5.24	91.70	5.16	90.31	16.15	48.45	19.91	11.1
GB-5-12% Hf/Ce/U	U234	3.500	2.705	499.7	448.0	366.770	452.1	1.167	0.900	2.72	5.25	92.00	5.28	92.54	10.35	53.93	22.71	5.7
	U235	3.500	2.710	499.2	447.8	362.910	447.8	1.161	0.894	2.73	5.27	92.35	5.30	92.78	10.30	53.83	22.57	5.7
	U236	3.500	2.710	500.4	449.0	363.760	449.0	1.163	0.902	2.73	5.27	92.22	5.26	92.20	10.27	53.49	22.57	5.7
	U246	3.501	2.712	549.5	494.0	400.440	494.1	1.284	1.005	2.71	5.27	92.33	5.19	90.91	10.10	53.02	22.54	5.7
	U247	3.500	2.719	551.4	495.6	401.730	495.8	1.281	1.007	2.73	5.27	92.27	5.17	90.56	10.12	52.55	22.31	5.7
GB-6-10% Hf/Ce/U	U240	3.500	N/A	500.3	N/A	N/A	N/A	1.015	N/A	3.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.2
	U241	3.500	2.780	499.8	419.2	339.530	420.0	1.030	0.815	3.08	5.21	91.24	5.17	90.54	16.12	50.07	20.57	9.2
	U242	3.501	2.783	499.5	418.9	339.230	419.6	1.024	0.818	3.09	5.21	91.28	5.14	89.94	16.14	49.51	20.51	9.2
GB-8-0% Hf/Ce/U	U252	3.503	2.710	506.3	475.8	387.240	475.9	1.222	0.950	2.62	5.37	93.96	5.30	92.77	6.02	53.46	22.64	0.3
	U253	3.504	2.712	514.1	482.9	393.100	483.0	1.236	0.959	2.63	5.37	94.06	5.32	93.14	6.06	53.51	22.60	0.3
GB-8-10% Hf/Ce/U	U254	3.501	2.739	499.5	434.2	353.060	434.4	1.083	0.850	2.92	5.34	93.52	5.29	92.62	13.07	51.95	21.77	8.0
	U255	3.501	2.742	499.5	433.7	352.260	433.2	1.082	0.848	2.93	5.36	93.79	5.28	92.53	13.17	51.92	21.68	8.0
	U256	3.502	2.738	587.4	509.1	414.070	509.2	1.271	0.995	2.93	5.35	93.71	5.30	92.85	13.33	52.14	21.82	8.0

Appendix F - Puck Data for Granulation Matrix Testing

Batch ID	Puck ID	Green Puck Diam. (in.)	Sintered Puck Diameter (in.)	Green Weight (g)	Sintered Puck Weight (g)	Puck Suspended Weight (g)	Wet Weight (g)	Green Puck Thick. (in.)	Sintered Puck Thick. (in.)	Green Density (g/cc)	Archi-medes Density (g/cc)	Archi-medes Density (%TD)	Geom. Density (g/cc)	Geom. (%TD)	Mass % Shrink-age	Volume % Shinkage	Diam. % Shrink-age	Powder % Moist
Sched. 3	U260	3.501	2.732	558.0	485.4	394.580	485.7	1.221	0.949	2.90	5.33	93.26	5.32	93.22	13.01	52.66	21.97	7.4
	U261	3.500	2.751	549.7	477.8	387.870	478.1	1.204	0.942	2.90	5.30	92.79	5.21	91.17	13.08	51.66	21.40	7.4
GB-9-12% Hf/Ce/U	U274	3.499	2.752	500.8	422.3	342.630	423.0	1.053	0.824	3.02	5.25	91.97	5.26	92.05	15.68	51.58	21.35	9.4
	U275	3.500	2.755	500.4	421.8	342.230	423.0	1.063	0.832	2.99	5.23	91.51	5.19	90.87	15.70	51.50	21.29	9.4
	U276	3.499	2.756	499.2	421.4	341.700	422.2	1.055	0.829	3.00	5.23	91.67	5.20	91.03	15.59	51.24	21.23	9.4
1.5 ksi	U277	3.500	2.733	498.3	420.8	341.160	421.3	1.067	0.832	2.96	5.25	91.94	5.26	92.11	15.55	52.45	21.91	9.4
GE-1	1939	3.253	2.634	500.5	419.7	334.503	419.7	1.202	0.967	3.06	4.93	94.74	4.86	93.44	16.14	47.24	19.03	9.6
GD-10	2836	3.255	2.558	447.1	386.1	N/A	N/A	1.180	0.927	2.78	N/A	N/A	4.94	95.08	13.64	51.47	21.41	7.8
GD-14	2837	3.254	2.553	485.8	417.9	334.754	418.0	1.298	1.017	2.75	5.02	96.54	4.90	94.17	13.98	51.76	21.54	8.6
GD-16	2834	3.255	2.577	444.7	383.2	N/A	N/A	1.164	0.920	2.80	N/A	N/A	4.87	93.69	13.83	50.45	20.83	7.6
GD-18 Batch 6/12/00 8.5ton	2532	3.506	2.729	500.7	428.2	341.949	428.2	1.160	0.907	2.73	4.96	95.47	4.92	94.69	14.48	52.62	22.16	8.5
6.5ton	2533	3.506	2.725	499.5	425.3	339.419	425.4	1.164	0.906	2.71	4.95	95.12	4.91	94.43	14.85	52.97	22.28	8.5
7ton	2534	3.506	2.735	516.5	434.7	347.313	434.9	1.168	0.911	2.79	4.96	95.44	4.95	95.29	15.84	52.53	21.99	8.5
7ton	2535	3.505	2.724	517.1	432.5	345.942	432.7	1.162	0.905	2.81	4.99	95.87	5.00	96.20	16.36	52.95	22.28	8.5
6.5ton	2536	3.505	2.715	510.1	426.2	340.673	426.3	1.158	0.903	2.79	4.98	95.72	4.97	95.64	16.45	53.20	22.54	8.5
	2537	3.505	2.730	511.1	432.5	345.664	432.7	1.160	0.912	2.79	4.97	95.56	4.94	95.05	15.38	52.29	22.11	8.5
7 ton	2538	3.508	2.726	518.7	434.1	347.268	434.3	1.166	0.909	2.81	4.99	95.92	4.99	95.99	16.31	52.92	22.29	8.5

Figure 1a of Appendix F - Carver Press Archimedes Density Data

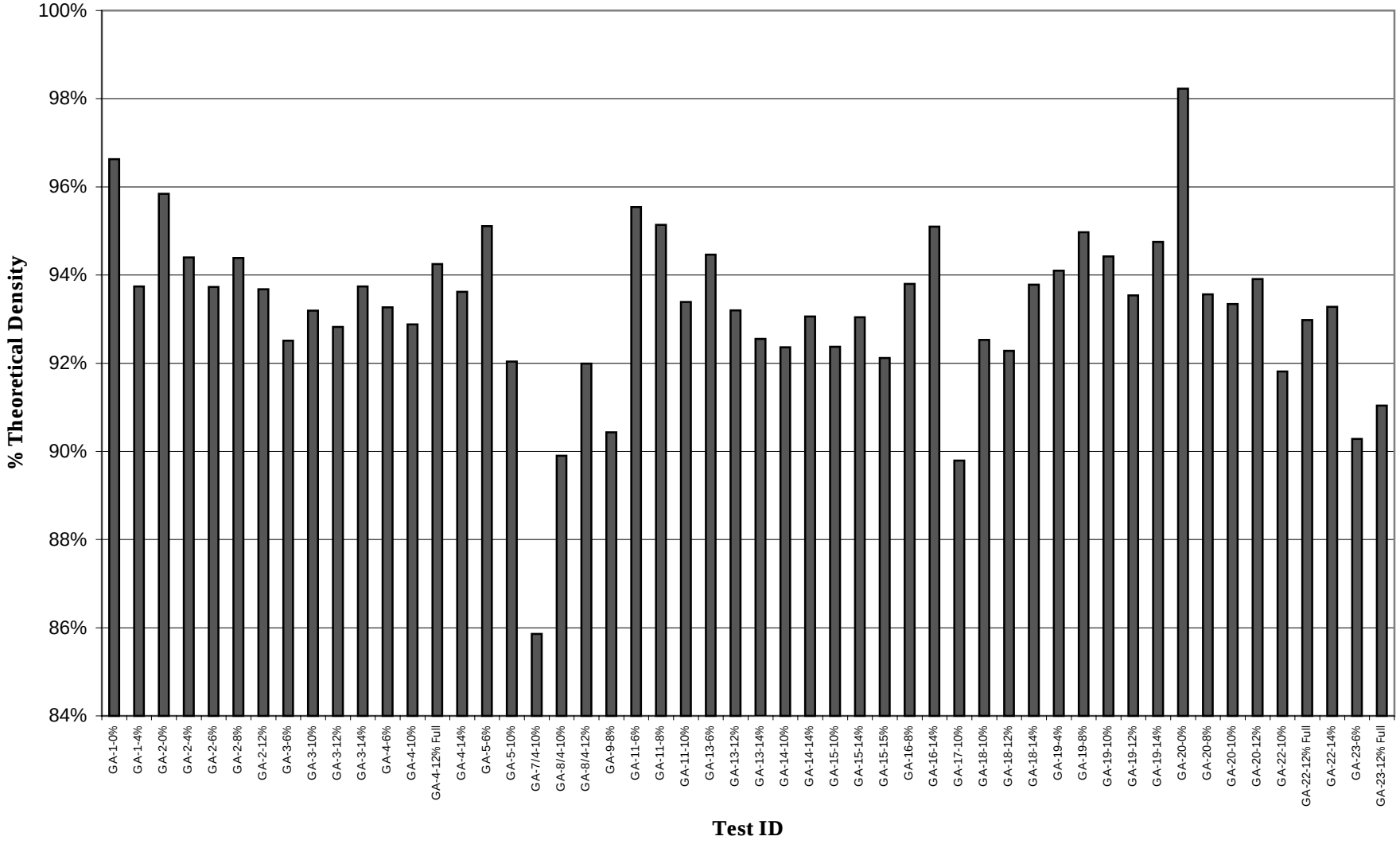


Figure 1b of Appendix F - Carver Press Archimedes Density Data

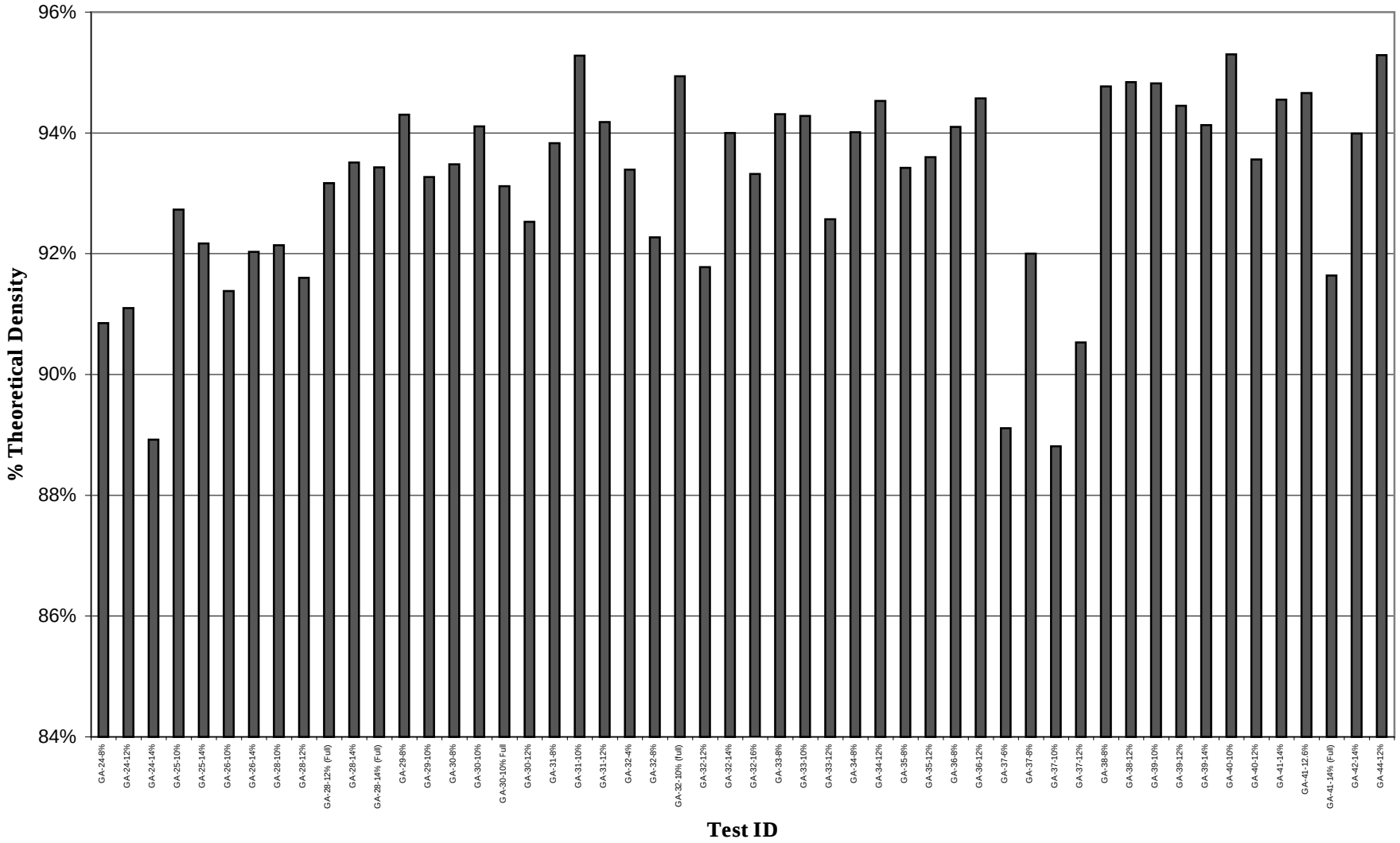
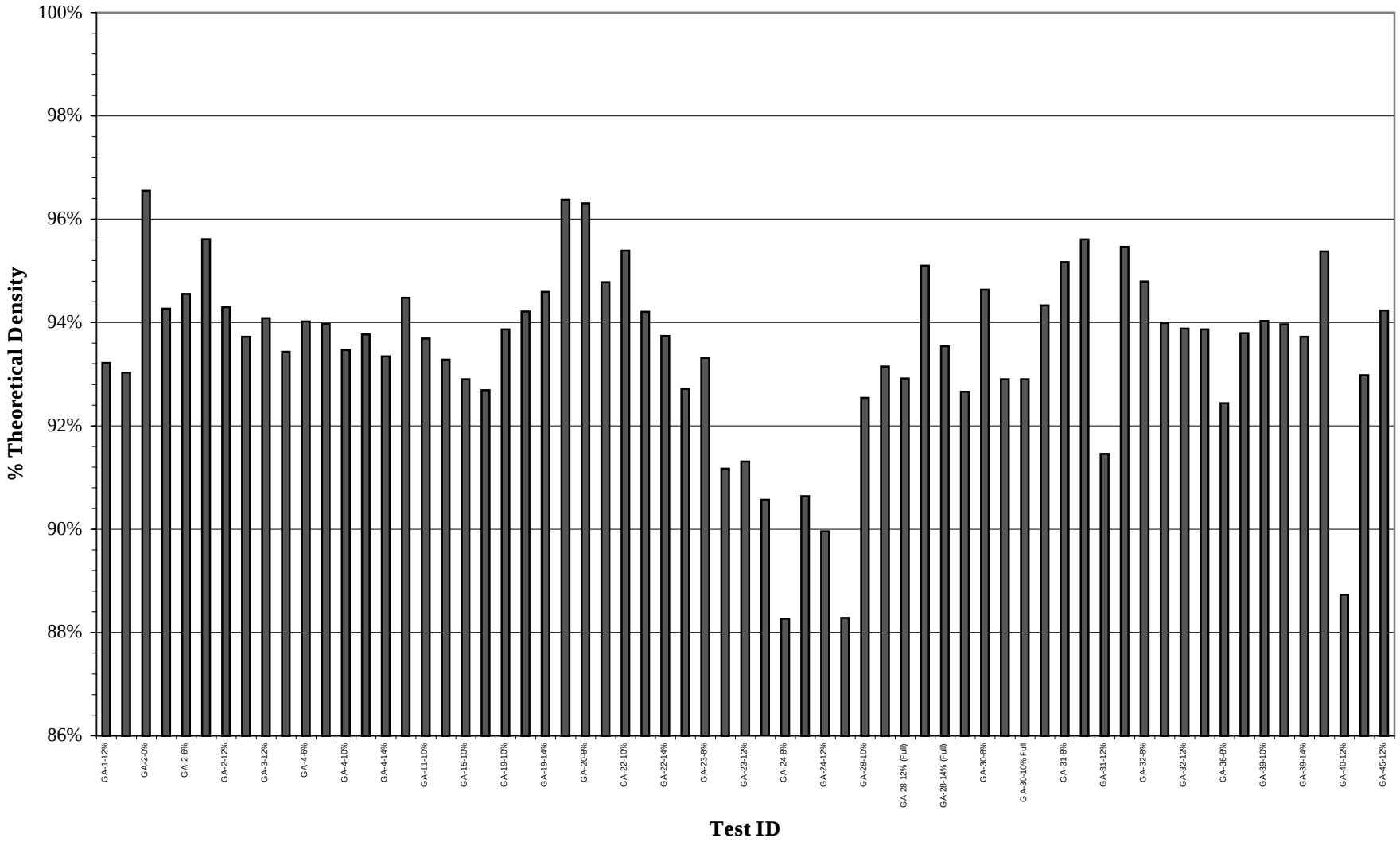


Figure 2 of Appendix F - Best Press Archimedes Density Data



Appendix G - Powder Test Center Data for Granulation Matrix Testing

Test ID	Powder Bulk Density (g/cc)	Powder Tap Density (g/cc)	Hausner Ratio	Measured Angle of Repose	Compact Pressure (psi)	Compact Slide Coefficient	Compactability Coefficient	Ejection Pressure (psi)	Axial Strength (psi)	Cohesiveness
GA-1-4%	1.456	1.627	1.117	74	2000	0.357	0.1544	101	283	0.54
					5000	0.435	0.1565	253	1430	1.30
GA-1-8%	1.475	1.654	1.121	74	2000	0.331	0.1638	77	510	0.92
					5000	0.420	0.1661	203	1506	1.32
GA-1-12%	1.555	1.702	1.095	70	2000	0.324	0.1646	68	180	0.31
					5000	0.400	0.1727	199	1827	1.48
GA-2-4%	1.275	1.482	1.162	71	2000	0.361	0.1628	103	241	0.47
					5000	0.444	0.1630	259	2528	2.47
GA-2-6%	1.359	1.555	1.144	86	2000	0.332	0.1688	81	412	0.79
					5000	0.424	0.1709	209	2935	2.73
GA-2-8%	1.341	1.526	1.138	75	2000	0.338	0.1713	80	430	0.79
					5000	0.414	0.1744	187	1314	1.18
GA-2-12%	1.449	1.577	1.088	73	2000	0.330	0.1776	96	1585	3.00
					5000	0.439	0.1842	280	3420	3.16
GA-3-6%	1.476	1.636	1.108	58	2000	0.519	0.1421	41	620	1.93
					5000	0.568	0.1443	117	1162	1.58
GA-3-10%	1.653	1.769	1.070	59	2000	0.295	0.1417	161	635	1.02
					5000	0.367	0.1486	321	1875	1.50
GA-3-12%	1.650	1.769	1.072	42	2000	0.440	0.0858	115	42	0.10
					5000	0.376	0.1561	295	2187	1.68
GA-3-14%	1.656	1.779	1.074	40	2000	0.302	0.1617	94	622	1.02
					5000	0.400	0.1319	279	1292	1.13
GA-4-6%	1.404	1.514	1.078	69	2000	0.364	0.1511	128	687	1.35
					5000	0.448	0.1541	251	1284	1.27
GA-4-8%	1.517	1.656	1.092	52	2000	0.413	0.1402	28	406	0.93
					5000	0.468	0.1481	209	1495	1.50
GA-4-10%	1.401	1.503	1.073	49	2000	0.296	0.1737	123	1254	2.04
					5000	0.386	0.1775	243	2322	1.93
GA-4-10% (Full)	1.498	1.616	1.079	56	2000	0.368	0.1355	100	1011	2.03
					5000	0.434	0.1419	270	1504	1.43
GA-4-12%	1.535	1.666	1.085	46	2000	0.347	0.1549	86	584	1.12
					5000	0.424	0.1606	223	1864	1.63
GA-4-14%	1.544	1.692	1.096	44	2000	0.325	0.1643	114	1193	2.08
					5000	0.412	0.1715	202	1911	1.58
GA-5-6%	1.317	1.444	1.096	64	2000	0.452	0.1362	75	407	1.03
					5000	0.540	0.1396	171	1024	1.32
GA-5-10%	1.405	1.516	1.079	61	2000	0.383	0.1381	93	368	0.75
					5000	0.474	0.1442	209	1429	1.53
GA-7/4-10%	1.129	1.256	1.112	64	2000	0.379	0.1559	83	276	0.56
					5000	0.452	0.1605	180	1287	1.30
GA-8/4-10%	1.055	1.177	1.116	76	2000	0.403	0.1633	71	187	0.41
					5000	0.470	0.1657	154	1013	1.07
GA-8/4-12%	1.430	1.552	1.085	65	2000	0.273	0.1698	164	1164	1.78
					5000	0.374	0.1793	247	3521	2.82
GA-11-6%	1.600	1.721	1.076	74	2000	0.440	0.1535	73	172	0.43
					5000	0.512	0.1633	170	2889	3.21
GA-11-6%	1.600	1.721	1.076	74	5000	0.529	0.1588	194	855	1.07
GA-11-10%	1.498	1.594	1.064	70	2000	0.329	0.1980	64	972	1.77
					5000	0.518	0.1913	149	1705	1.72
GA-13-6%	1.210	1.427	1.179	72	2000	0.495	0.1812	1	122	0.33
					5000	0.556	0.1773	127	1597	2.05

Appendix G - Powder Test Center Data for Granulation Matrix Testing

Test ID	Powder Bulk Density (g/cc)	Powder Tap Density (g/cc)	Hausner Ratio	Measured Angle of Repose	Compact Pressure (psi)	Compact Slide Coefficient	Compactability Coefficient	Ejection Pressure (psi)	Axial Strength (psi)	Cohesiveness
GA-13-12%	1.367	1.464	1.071	63	2000	0.294	0.2232	103	894	1.45
					5000	0.495	0.2050	174	1850	1.79
GA-13-14%	1.565	1.668	1.066	56	2000	0.302	0.1897	124	1411	2.29
					5000	0.493	0.1864	206	2636	2.62
GA-15-10%	1.567	1.668	1.064	67	2000	0.336	0.1376	169	814	1.56
					5000	0.361	0.1430	358	1228	0.96
GA-15-14%	1.478	1.594	1.078	58	2000	0.299	0.1768	28	1213	2.02
					5000	0.358	0.1795	334	1891	1.35
GA-15-15%	1.525	1.663	1.090	50	2000	0.279	0.1723	153	696	1.07
					5000	0.370	0.1735	309	3269	2.41
GA-19-4%	1.389	1.557	1.121	65	2000	0.489	0.1312	25	242	0.67
					5000	0.543	0.1329	129	1007	1.32
GA-19-8%	1.505	1.674	1.112	65	2000	0.315	0.1471	102	346	0.60
					5000	0.381	0.1502	265	1245	1.02
GA-19-10%	1.724	1.872	1.086	64	2000	0.308	0.1409	63	1140	1.96
					5000	0.362	0.1499	287	1633	1.26
GA-19-10% Repeat	1.487	1.629	1.095	60	2000	0.390	0.1717	119	3622	2.86
					5000	0.290	0.1687	154	1227	1.91
GA-19-12%	1.587	1.705	1.074	41	2000	0.274	0.1534	167	601	0.93
GA-19-14%	1.560	1.673	1.072	40	2000	0.271	0.1772	208	1249	1.90
					5000	0.366	0.1767	323	2729	1.94
GA-20-8%	1.412	1.556	1.102	58	2000	0.293	0.1604	163	784	1.26
					5000	0.348	0.1656	330	1985	1.47
GA-20-10%	1.204	1.260	1.047	62	2000	0.280	0.1893	166	1251	1.95
					5000	0.339	0.1940	322	3688	2.73
GA-20-12%	1.421	1.493	1.051	69	2000	0.299	0.1708	156	589	0.96
					5000	0.340	0.1775	351	3494	2.51
GA-22-10%	1.313	1.451	1.105	54	2000	0.315	0.1501	155	610	1.05
					5000	0.387	0.1466	278	2265	1.90
GA-22-12%	1.407	1.539	1.094	52	2000	0.287	0.1453	119	705	1.09
					5000	0.361	0.1441	258	1235	0.92
GA-22-14%	1.475	1.565	1.061	50	2000	0.314	0.1550	107	1060	1.85
					5000	0.384	0.1594	359	1675	1.37
GA-23-6%	1.324	1.514	1.144	71	2000	0.461	0.1441	154	493	1.28
					5000	0.581	0.1495	265	1297	1.92
GA-23-8%	1.410	1.561	1.107	65	2000	0.461	0.1441	117	706	1.82
					5000	0.557	0.1512	218	1515	2.07
GA-23-10%	1.243	1.373	1.105	73	2000	0.332	0.1540	148	239	0.00
					5000	0.409	0.1519	375	2275	1.96
GA-23-12%	1.453	1.534	1.056	53	2000	0.315	0.1444	128	874	1.59
					5000	0.409	0.1478	355	2984	2.54
GA-24-8%	1.082	1.236	1.142	74	2000	0.325	0.1707	217	471	0.83
					5000	0.410	0.1682	363	2035	1.79
GA-24-12%	1.315	1.440	1.095	52	2000	0.297	0.1531	96	348	0.70
					5000	0.386	0.1435	407	1977	1.66
GA-24-14%	1.391	1.474	1.060	57	2000	0.333	0.1479	108	752	1.35
					5000	0.396	0.1577	317	2637	2.25
GA-26-14%	1.629	1.733	1.064	55	2000	0.336	0.1718	79	458	0.83
					5000	0.472	0.1751	208	1356	1.36
GA-26-14% Repeat	1.518	1.662	1.095	51	2000	0.317	0.1580	148	419	0.74
					5000	0.425	0.1667	312	1474	1.32

Appendix G - Powder Test Center Data for Granulation Matrix Testing

Test ID	Powder Bulk Density (g/cc)	Powder Tap Density (g/cc)	Hausner Ratio	Measured Angle of Repose	Compact Pressure (psi)	Compact Slide Coefficient	Compactability Coefficient	Ejection Pressure (psi)	Axial Strength (psi)	Cohesiveness
GA-28-10%	1.227	1.389	1.132	76	2000	0.337	0.1825	110	677	1.28
					5000	0.426	0.1824	269	2474	2.22
GA-28-12%	1.190	1.320	1.109	70	2000	0.384	0.1725	133	571	1.32
					5000	0.480	0.1739	273	1001	1.09
GA-28-12% Full	1.239	1.363	1.100	71	2000	0.341	0.1683	118	698	1.36
					5000	0.410	0.1693	373	1044	0.94
GA-28-14%	1.472	1.577	1.071	59	2000	0.326	0.1648	100	853	1.52
					5000	0.424	0.1673	259	1135	1.00
GA-28-14% Full	1.381	1.440	1.043	70	2000	0.305	0.1717	161	327	0.56
					5000	0.400	0.1750	348	1175	1.02

Figure 1 of Appendix G - Measured Powder Densities

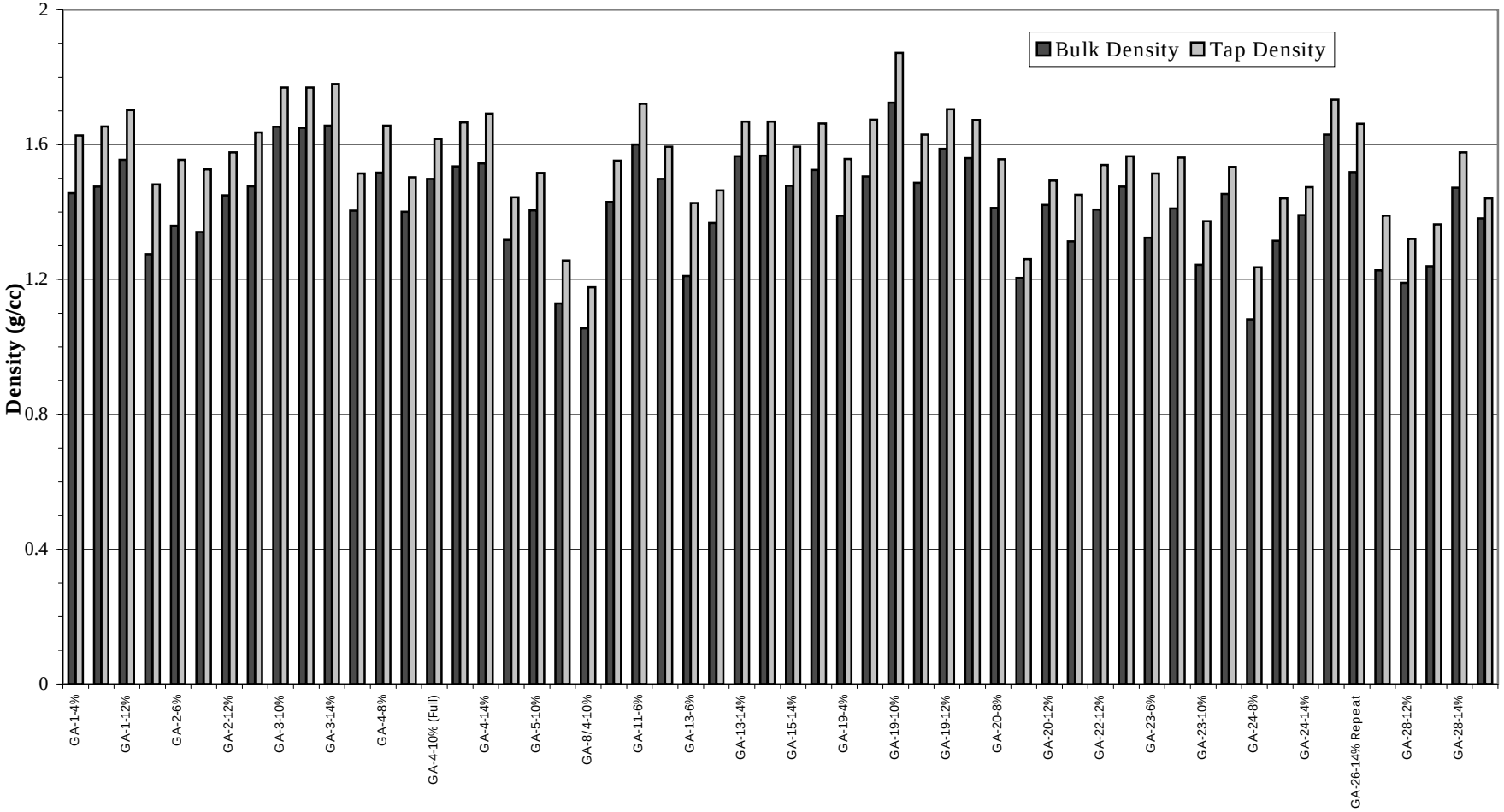


Figure 2 of Appendix G - Hausner Ratio

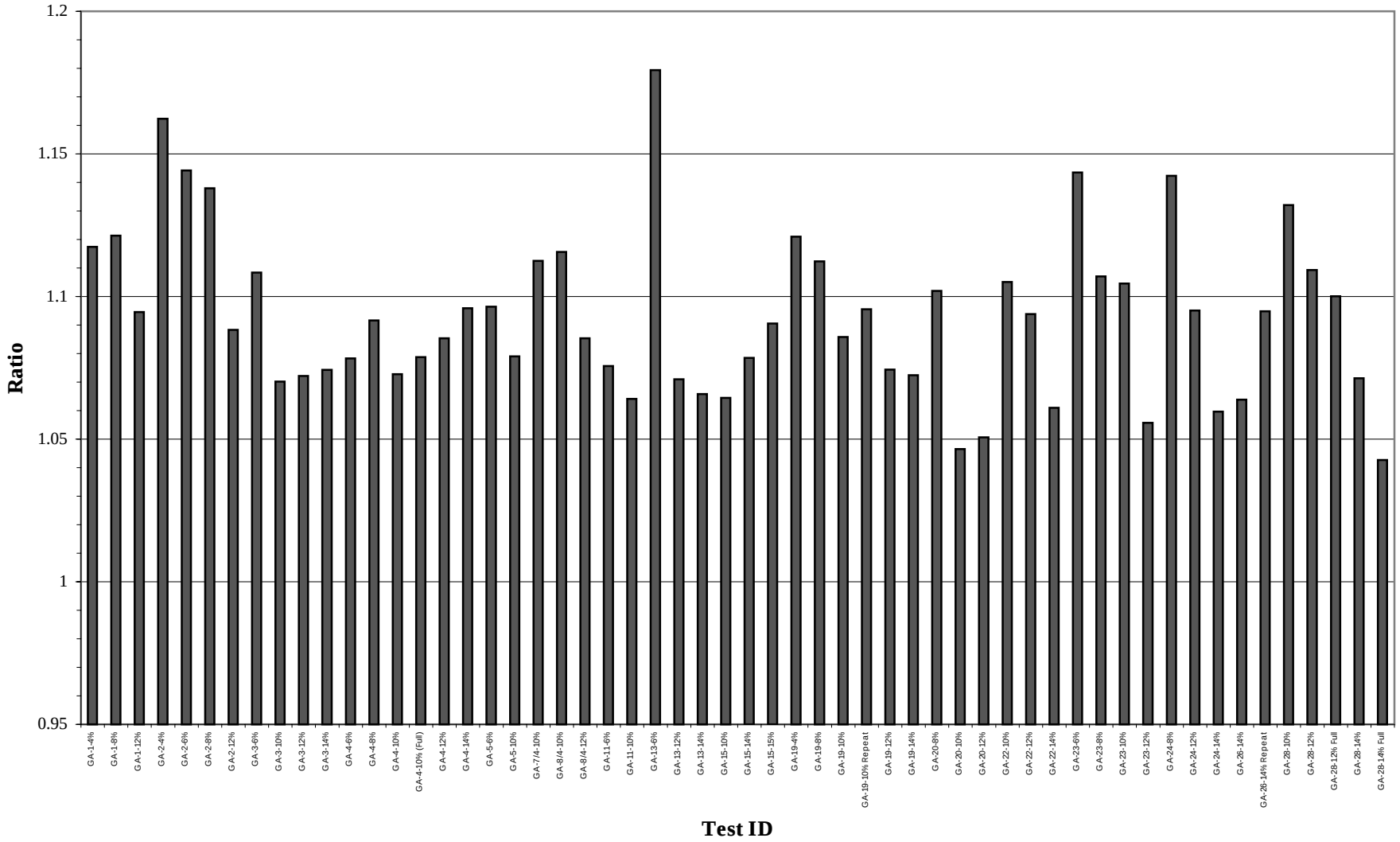


Figure 3 of Appendix G - Angle of Repose as Measured by the PTC

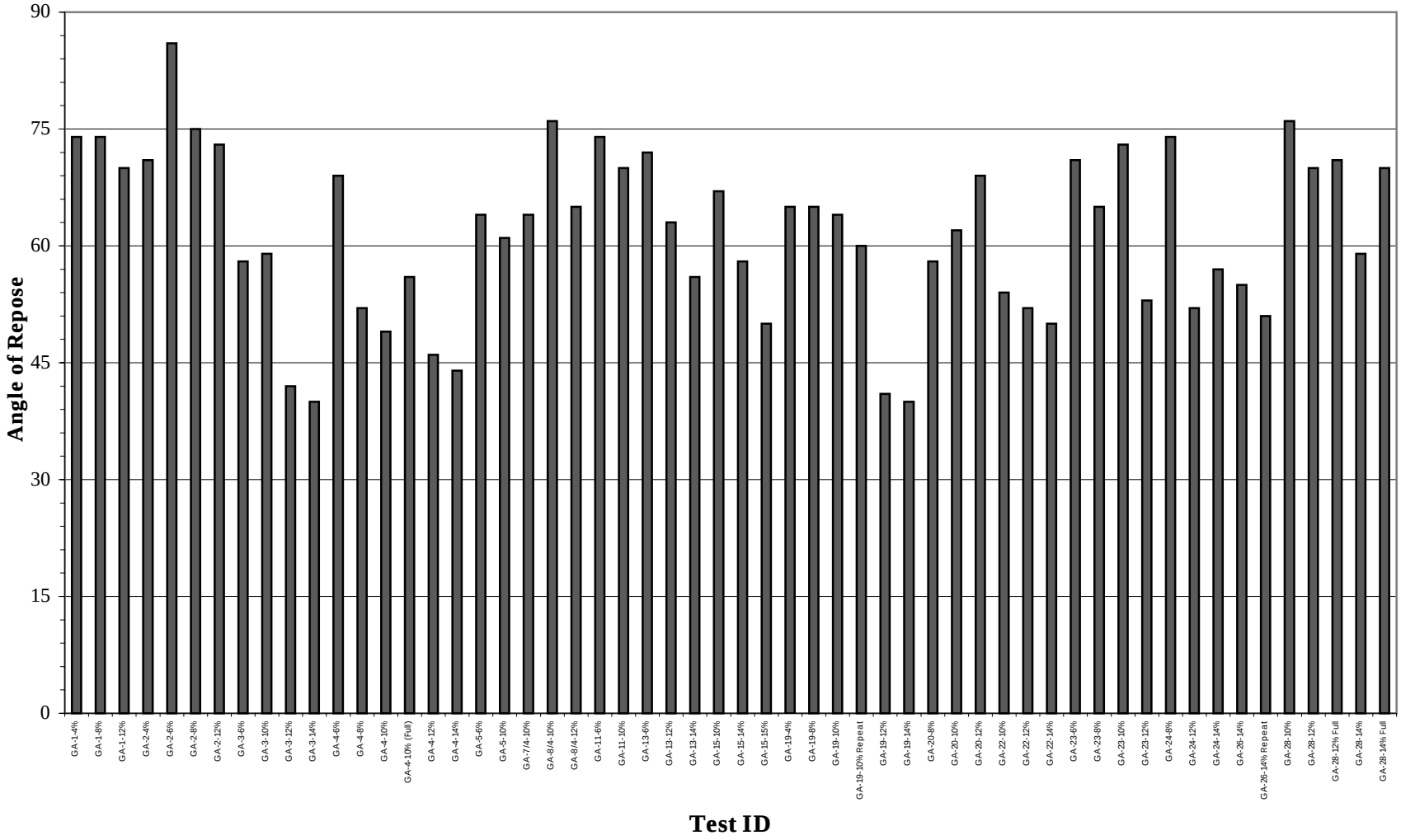


Figure 4 of Appendix G - Slide Coefficients as Measured by the PTC

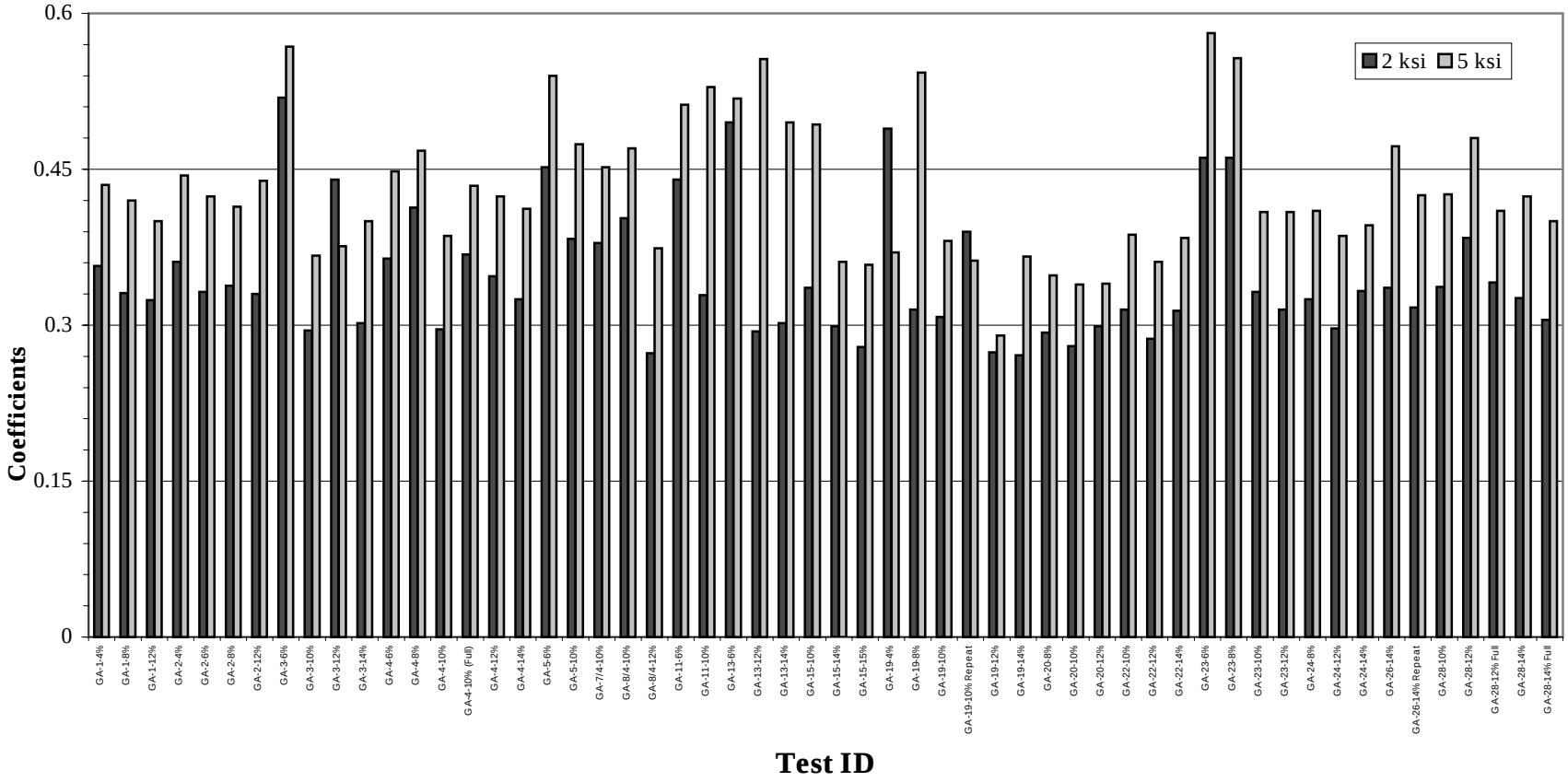


Figure 5 of Appendix G - Compactability Coefficients as Measured by the PTC

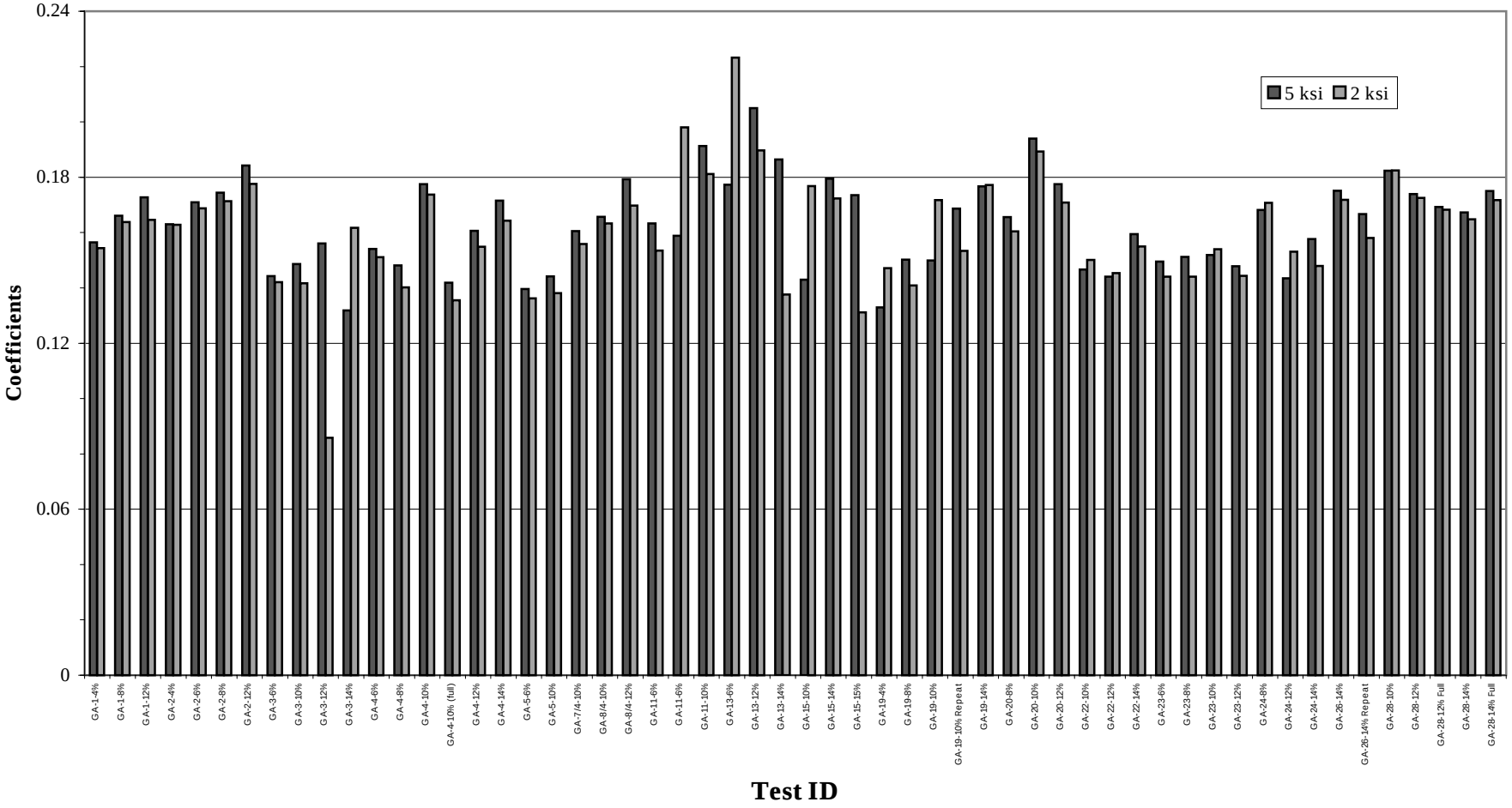


Figure 6 of Appendix G - Ejection Pressure as Measured by the PTC

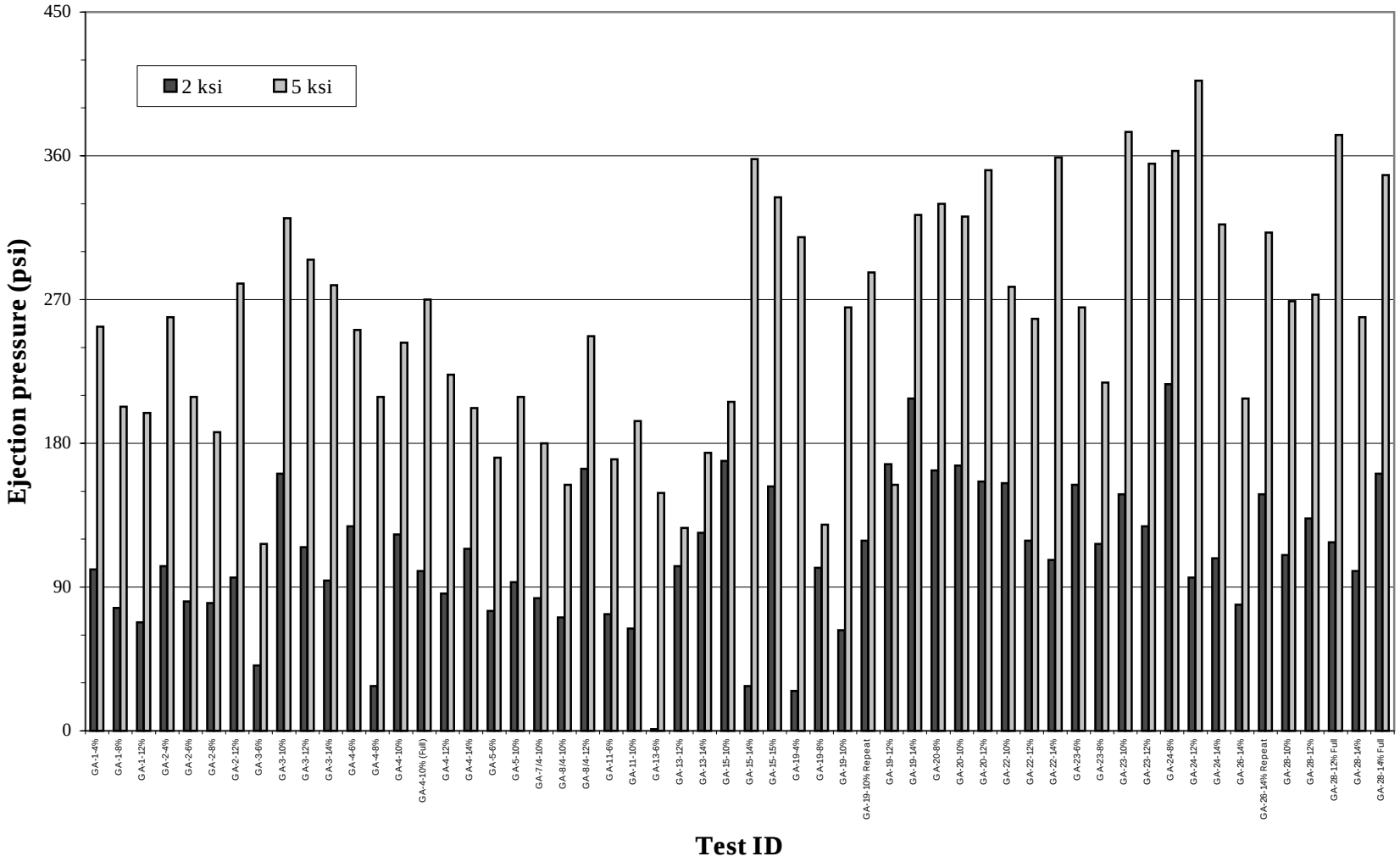


Figure 7 of Appendix G - Axial Strength as Measured by the PTC

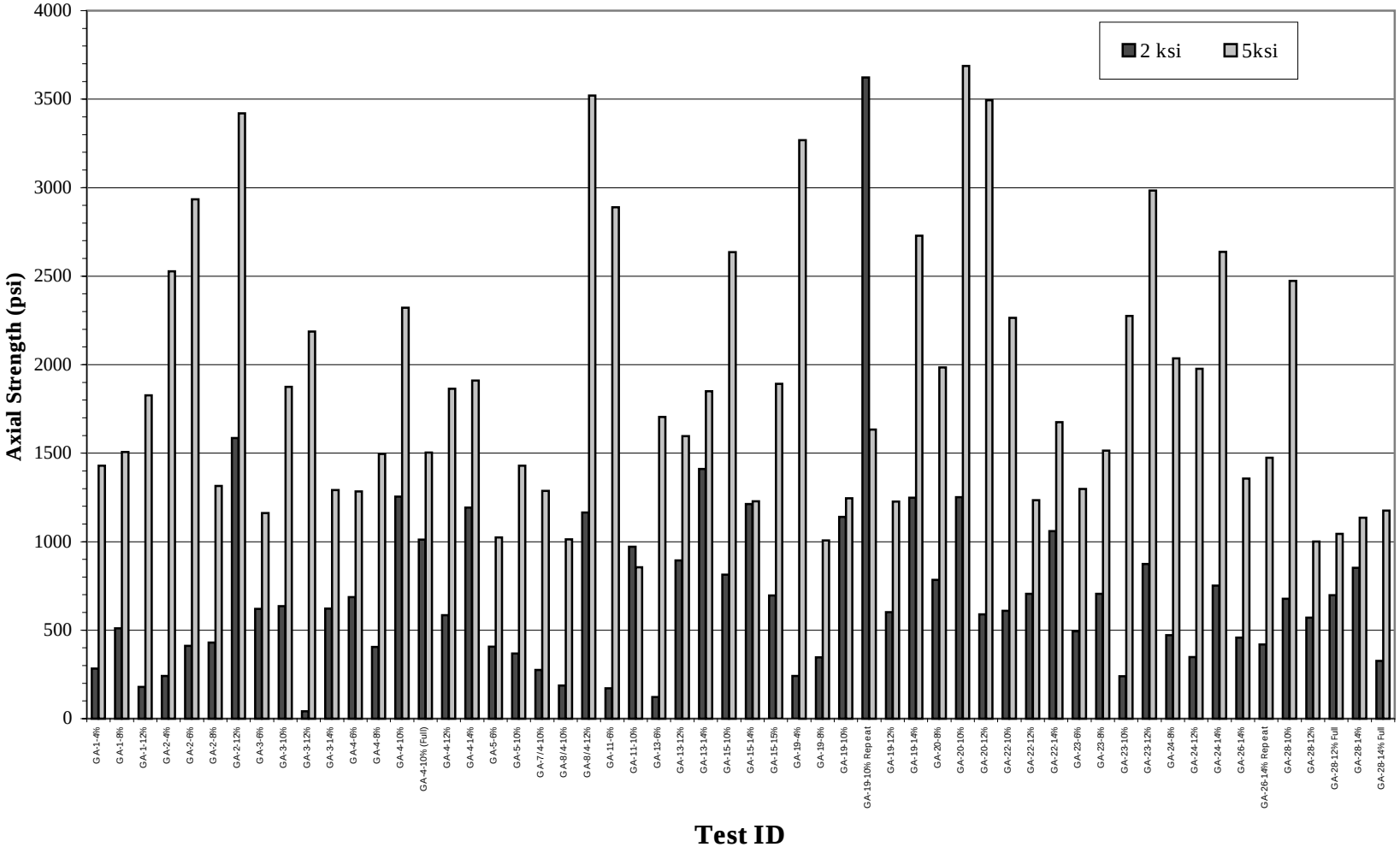


Figure 8 of Appendix G - Cohesiveness as Measured by the PTC