Appendix F – Technical Basis for CSB Combustible Dust Testing Methods

Particle Size Testing

Didion specifications for each finished product gave a range of particle sizes in terms of weight percent for each particle size category, as reported by Didion. **Table F-1** below shows several Didion finished products' typical particle size ranges, as reported by Didion.

Table F-1: Typical particle size distributions for several Didion finished products as reported by Didion.[a] (Credit: Didion, adapted by CSB)

Product	Bran Product (wt %)	Yellow Corn Flour (wt %)	Fine Yellow Corn Bran (wt %)	Low Moisture Pregel Flour (wt %)[b]	Medium Viscosity Flour (wt %)	Yellow Corn Bran (wt %)
Didion Product Code	8480	4300	8010	7403	4407	8000
Larger than 850 microns	NA	NA	NA	NA	NA	1.0
Larger than 425 microns	NA	0.0	NA	0.0	Trace	34.0
Larger than 250 microns	Trace	0.1	0.0	0.0	1.0	50.0
Larger than 180 microns	0.5	NA	1.0	NA	NA	NA
Larger than 150 microns	4.3	NA	2.0	5.0	28.0	10.0
Smaller than 150 microns	95.2	99.9	97.0	95.0	71.0	5.0

After the incident, the CSB collected available samples at the incident scene to verify particle sizes of various product streams, including product material, in-process material, and material inside dust collectors. The CSB was able to obtain two finished product samples: a bran product and a yellow corn product. These same two products, coded 8480 and 4300, are also detailed in **Table F-1** above for comparison purposes. Two dust collectors were sampled: the Torit Filter, described in detail in **Section 2.2.3**, and the 4D filter,[c] which was used to collect dust from some Fractionation System and Bran System equipment. The 4D filter was sampled because it represented unburned material from a dust collector near

[a] Typical particle size data for the 8480 Bran product was derived from averages of lab results from a February 2017 production run of 8480.

[b] Didion defined Pregel material as "corn meal and corn flour that is cooked at high temperature under pressure then ground to a flour".

[c] Didion called this filter "4D" because it was located on the 4th floor of D Mill. It was a bag filter similar to, but smaller than, the Dry Grit Filter described in **Section 2.2.3**.

and similar to the Dry Grit Filter, described in detail in **Section 2.2.3**. The Dry Grit Filter could not be sampled due to severe burn damage, rendering any remaining material unsuitable for testing. In-process material was collected from the Coarse Grinder[a], which was part of the Pre-gelatinized Corn Meal (PCM) Process. For comparison to typical product properties, these samples were analyzed as received for particle size. The results of the analysis are shown in **Table F-2** below and indicate that particle sizes of as-found samples were as expected, similar to published Didion specifications, particularly that nearly all material was below 425-micron particle size.

Table F-2: Properties of as-received samples collected at incident scene. (Credit: ioKinetic)

	Bran Product	Flour Product	Torit Filter	4D Filter	Coarse Grinder[b]
Didion Product Code	8480	4300	NA	NA	NA
Particle Size[c] (vol % < 500 µm)	100	100	100	100	NA
Particle Size (vol % < 425 µm)	99.1	98.4	97.7	100	NA
Particle Size (vol % < 250 µm)	94.0	89.9	90.3	99.8	NA
Particle Size (vol % < 150 µm)	80.4	72.6	82.9	97.0	NA
Particle Size (vol % < 75 µm)	52.9	48.2	71.0	85.9	NA[d]

Combustible Dust Testing

In addition to the requested data for dust characteristics from Didion, the CSB collected samples of materials found in the process equipment following the incident and finished products for dust combustibility testing as previously described.

These samples were assessed using dust explosibility test standards[e] established through ASTM International[f] (ASTM). These analyses included standardization of sample moisture content and particle size to less than 5% moisture by weight and 75 microns, respectively. The samples were dried, milled, or

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[a] The Coarse Grinder (VFD-13045) was a hammermill with a dust collector directly connected to it and vented into the room in 1B.

[b] Sample particles were too large for laser particle size analysis equipment that was used on the other samples in this table.

[c] Didion measured particle sizes as a *weight* percentage of samples below a set screen size. A different particle size measurement, reported by *volume* percentage of samples below a set size, was used in the testing commissioned by CSB. For similar materials with constant density throughout the size distribution, as in this case, the two measurements are comparable.

[d] Sample particles were too large for laser particle analysis.

[e] These test standards use the term 'explosibility' to describe the properties they test for. For the purposes of consistency in this report, explosibility and combustibility will be considered synonymous.

[f] Formerly the American Society for Testing and Materials and started in 1898, ASTM International is "one of the world's largest international standards developing organizations" and is a "globally recognized leader in the development and delivery of voluntary consensus standards." From https://www.astm.org/about/overview/fact-sheet.html

sieved as required prior to testing for dust combustibility. An excerpt of the test results, inclusive of P_{max}, K_{St}, and MEC, are included in **Table F-3**.

Table F-3: Dust Characteristics of Didion Materials Collected by CSB (Credit: ioKinetic)

	Bran Product	Flour Product	Torit Filter	4D Filter	Coarse Grinder
P_{max} [bar(g)]	8.2	8.1	8.1	8.8	8.3
K_{St} (bar*m/s)	137	148	158	159	123
MEC (g/m^3)	60 – 75	70 – 80	70 – 80	70 – 80	70 – 80

Given the definition of agricultural combustible dust in NFPA 61 (2017 edition) described in **Section 1.2** [6, p. 8], all Didion materials sampled met the particle size requirement (as received, before any sample conditioning occurred) to be considered combustible dust. An older definition in the 2008 edition of NFPA 61 added a limit of "420 microns or smaller [47, p. 5]." All samples' particle size distributions indicated that 100% of each sample was less than 500 microns (**Table F-2**). Further, the sample with the largest weight fraction over 425 microns was still only 2.3%. This means that nearly all materials tested were less than 425 microns, qualifying virtually all of each sample measured as combustible dust even using the older NFPA definition of under 420 microns.

In 2022, Didion objected to the combustibility tests the CSB had contracted in 2018 because the material was not tested as-received, stating that "the explosibility of the "as-collected" samples is unknown and these samples are not representative of the material that existed in the Didion mill before the explosion". The CSB testing protocol followed ASTM testing methods, which recommend:

> [D]ue to the possible accumulation of fines at some location in a processing system, it is recommended that the test sample be at least 95% minus 200 mesh (75 microns). […] When a material is tested in the as-received state, it should be recognized that the test results may not represent the most severe dust deflagration possible. Any process change resulting in a higher fraction of fines than normal or drier product than normal may increase the explosion severity. […] To achieve this particle fineness […] the sample may be ground or pulverized or it may be sieved. […] The moisture content of the test sample should not exceed 5% in order to avoid test results of a given dust being noticeably influenced.

NFPA 68 *Standard on Explosion Protection by Deflagration Venting* (2007 edition) further states:

> It is necessary for a given dust to be tested in a form that bears a direct relation to the form of that dust in any enclosure to be protected […] Only standardized dusts and samples taken from such enclosures are normally tested in the as-received state. The following factors affect the K_{St} :
>
> (1) Size distribution
> (2) Particle shape
> (3) Contaminants (gas or solid)

> Although dusts can be produced in a coarse state, attrition can generate fines. Fines can accumulate in cyclones and baghouses, on surfaces, and in the void space when large enclosures are filled. For routine testing, it is assumed that such fines can be represented by a sample screened to sub-200 mesh (75 μm). [...] If a sufficient sample cannot be obtained as sub-200 mesh (75 μm), it might be necessary to grind the coarse material [48, p. 59].

Accordingly, the ASTM standard recommendations above were followed when the Didion samples were tested, and the samples were ground and sieved as needed to achieve the requisite particle size and dried to reach the target moisture content as stated in ASTM E-1226 and E-1515. In addition to following ASTM protocols, the CSB chose this recommended method because (1) dry, fine material is more representative of dust collectors, their associated ductwork, and fugitive dust; and (2) the samples available after the incident were limited. Much of the material "representative of the material that existed in the Didion mill before the explosion" had been burned, such as in the Dry Grit Filter.

Material that escapes the process equipment and settles on overhead surfaces is necessarily some of the smallest particle size. Material that sits in dust collectors or their supply ductwork, with air passing over it continuously, will dry out over time. Thus, low moisture and small particle-size material are realistic circumstances inside a dry corn mill.

The locations of most interest did not contain testable material. Burned material cannot be tested as combustible dust. The remaining unburned material had been exposed to fire hoses, demolition activities, and the elements for several months in some cases; the adopted sample preparation protocols were necessary in this case. Finally, bran material such as that exiting the South BM in the normal process is some of the smallest particle-size material in the mill facility during normal operation. Since this material was not directly available due to fire damage, other samples were the only in-process material available.

As shown in **Table F-2**, the as-received samples contained a majority of particles smaller than 75 microns in any case. To simulate dust collector content such as in dust collector ductwork or the Dry Grit Filter itself, higher fines content is realistic and recommended by ASTM and NFPA. Supporting this, the 4D filter sample was already 86% under 75 microns as received from the incident scene.

The test results indicated that Didion material was combustible dust. The results were consistent with other available published data and the properties published in Didion's SDSs.-Some of these results are detailed in **Table F-4** for comparison. While particle size and moisture content, among other material properties, affect the combustibility results, the results in **Table F-4** show all corn dust samples were combustible.

Table F-4: Comparison of Combustible Dust Properties (Credit: CSB)

Data Source	P_{max} [bar(g)]	K_{St} (bar m/s)	MEC (g/m^3)
CSB Testing – Bran Product 8480, <5% moisture, <75 microns	8.2	137	60-75
CSB Testing – Torit Filter, <5% moisture, <75 microns	8.1	158	70-80
Didion SDSs	7.9	180	120-140, also 55
Didion Dust Calculations	NR[a]	NR	55
NFPA 68 (2007), Corn	9.4	75	60
NFPA 68 (2007), Starch, Corn	10.3	202	NR
NFPA 61 (2008), Corn Meal 8.2% moisture, 403 microns	6.2	47	NR
NFPA 61 (2008), Cornstarch, 11.2% moisture	7.8	163	NR

The CSB could not locate any literature source that considered corn dust, in any form under 425-micron particle size, as non-combustible. In fact, corn and cornstarch are frequently used as test material in combustible dust research.

In conclusion, while preparing the Didion samples according to NFPA and ASTM recommendations might have given slightly higher P_{max}, K_{St} or MEC values, all results, regardless of source, indicated that material at Didion was combustible dust. The differences in P_{max}, K_{St} or MEC would only be significant if using them for designing engineering controls, as described in **Section 4.3**. Since neither the CSB nor Didion used such values for such purposes in any case, and the as-received particle size of materials was well below the NFPA definition for combustible dust, the sample preparation used by the CSB was valid.

[a] Not Reported