ANNUAL SUMMARY REPORT ON MOLTEN METAL INCIDENTS FOR 2021

September 2022

For the year 2021, 140 molten metal incident reports occurring world-wide were received as compared to 147 reports received for 2020 and 166 reports for 2019. The attached figures summarize the reports for 2021 as well as the data for the years 1980 thru 2021.

SUMMARY POINTS:

- For 2021, there were 140 explosion incidents reported, which continued the downward trend in reported incidents over the previous 4 years. The 2021 total incidents are lower than the historically high number of incidents (170 – 195) reported between 2016 and 2018.

- There were 116 Force 1 explosions, 23 Force 2 explosions and one Force 3 explosion reported in 2021. Compared to 2020, Force 2 explosions increased from 12 to 23, while the Force 1 explosions decreased from 134 to 116. One Force 3 incident has been reported each of the last three years.

- There has been a notable increase in Force 2 explosions over the past 6 years starting in 2016 with an average of 21/yr., which reversed a downward trend that was observed starting around 2008 and continued through 2014.

- Of note, there were no reported fatalities in 2021, as well as 2019 and 2020 and 2015 through 2017. There have been 99 reported fatalities for the entire length of the program, starting in 1981.

- Over the past 10 years there were only two years with Fatalities: 2014 with one and 2018 with 8, which involved two major Casting incidents. The 0.9/yr. average fatality rate for the past 10 years is significantly lower than the 2.4 annual rate for the entire length of the program.

- Reported injuries increased slightly to 10 (9 Minor & one Serious) from the 2020 record low of only 7 Minor injuries.

- Also of note, 7 of the 10 injuries, including the one Serious injury, were related to 5 casting Termination explosions and wet / rusty drain pans. 4 of the 5 explosions were Force 2 explosions with only one being a Force 1.

- Of high significance, the data shows a sharp decrease in injuries starting in 2016 compared to historical values. When comparing average amount of injuries/year for the years 2001-2015 vs. 2016-2021, the latter timeframe is significantly lower (16.8 vs. 48.1 injuries/yr.) for all categories: Minor, Serious and Fatal. For these last 6 years, the
average Fatal / Yr. were 30% lower, average Serious / Yr. were 58% lower, average Minor / Yr. were 68% lower and average Total injuries / Yr. were 65% lower.

- Of 59 Casting incidents, 46 (42 Force 1 and 4 Force 2) were related to Start-up, 13 (7 Force 1 and 6 Force 2) occurred during Termination. 7 of the 13 Termination explosions involved wet / rusty drain pans. There were no Steady State explosions, which is highly unusual.

- There were no injuries reported from any of the 55 Melting explosions. There were 12 Force 2 Melting explosions and one Force 3. All but one of these 12 Force 2 & Force 3 explosions were related to wet / contaminated scrap, sow, RSI or alloy materials. One Force 2 involved furnace overflow onto a wet floor.

- There were two Minor injuries reported from 22 Transfer incidents. Wet hand and furnace tools or wet equipment were involved in 13 of the explosions and 6 involved wet / rusty drain or skim pans.

- Force 2 and 3 Transfer incident data from 2008 through 2011 indicate that wet / rusty drain pans cause almost 3 times the number of incidents compared to the next leading cause of wet refractory / equipment.

- For 2021, 13 of 77 (17%) Casting and Transfer explosions were related to wet / rusty drain pans.

- Injury rate per incident has been trending downward over the past 5-10 years for all three operations, Melting, Casting and Transfer, which was observed in new charts added to the 2020 report.

- As stated in the past, this lower injury frequency can be attributed at least partially to 1) the increased use of primary and secondary PPE; 2) improvements in PPE materials and design; 3) an increased focus on hands-free casting operations that remove personnel from high-risk casting operations; and 4) possibly increased training and hazard awareness.

- 2015 and 2018 are two years in the past 10 that stand out with a high numbers of injuries: 1) one 2015 Force 3 Melting explosions with 35 minor injuries; and 2) two 2018 Force 3 casting explosions with 25 injuries, including 8 fatalities.

- New analysis and charts were added displaying incidents per month for the three categories of Melting, Casting and Transfer. The Melting data indicated a higher incident rate in the northern hemisphere “winter months” of January, February and March, most likely related to the higher potential for charging materials to be contaminated with water, snow and ice.

EXPLANATION & DISCUSSION OF CHARTS AND DATA:

The Aluminum Association classifies molten metal explosions according to Force level, with Force 1 being the least severe and Force 3 being the most severe. Table 1 below provides information
on the criteria used for rating Force level. Figures 1 through 46, provided after the discussion below, display various charts and tables, including Table 1, below.

Table 1: Explosion Rating Force Criteria

<table>
<thead>
<tr>
<th>Guidelines</th>
<th>LOW</th>
<th>SEVERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property Damage</td>
<td>None</td>
<td>Considerable</td>
</tr>
<tr>
<td>Light</td>
<td>Minimal</td>
<td>Intense</td>
</tr>
<tr>
<td>Sound</td>
<td>Short cracking</td>
<td>Loud Report</td>
</tr>
<tr>
<td>Vibration</td>
<td>Short and sharp</td>
<td>Brief rolling</td>
</tr>
<tr>
<td>Metal Dispersion</td>
<td>&lt;15 feet</td>
<td>&gt;15 to 50 feet</td>
</tr>
</tbody>
</table>

**Figure 1** displays by year from 1981 thru 2021 the total number of reported incidents, **4339**. The **140** explosions reported in 2020 continue a downward trend over the past four years, but still in the same higher range of an increased reporting level starting in 2015. There has been an average of **166 incidents/year** reported over the past 7 years, compared to an average of **145 incidents/year** from 2000 through 2007 and **83 incidents/year** from 2008 through 2014.

**Figures 2 thru 6** provide **Force Level** data for the years 1981 thru 2021 in various formats, including the number of incidents and rates. **Figure 2** displays the reported incidents each year for all three Force Levels. In 2021 there were **116 Force 1, 23 Force 2** and **one Force 3** explosions. Compared to 2020, Force 2 explosions increased from 12 to 23, while the Force 1 explosions decreased from 134 to 116. The last three years all had one Force 3 explosion reported.

**Figure 3** shows the data for only **Force Levels 2 and 3** and **Figure 4** displays only **Force Level 3**. Both **Figure 3 and Figure 4** include the average number of explosions per year for this time frame. From 2008 through 2021 there has been either **zero** or **one Force 3** explosion reported annually with one exception in 2018 when **two Force 3** explosions were reported. The average number of **Force 3** explosions over the last 5 and 10 years (1.0/yr. and 0.8/yr. respectively) continues to show a much lower level compared to the **2.8/yr.** average for the entire reporting history from 1981 through to 2021. The notable downward trend of **Force 2** explosions observed in **Figure 2** starting around 2008 and continuing through 2014 was reversed beginning in 2016 and has continued through 2021 with an average of **21/yr.** over the past 6 years.
Comparing the number of **Force 2 Melting** vs. **Casting** explosions for the last 6 years, they both had equal amounts, **56**. This is atypical of historic data where **Force 2** explosions occurred in **Melting** by a wide margin. The balance of the Force 2 incident occurred almost equally in **Transfer** (7) and **Other** (6).

**Figures 5 and 6** display a comparison of all three **Force Levels** for the entire reporting history from 1981 through 2021 in two different formats: 1) bar graph and 2) pie-chart. **Force 1** incidents account for **76.3%** of all incidents, up slightly from 2019 and 2020 which were at **75.6%** and **76.1%** respectively. The **Force 2** and **Force 3** incident rate in 2021 both lowered slightly compared to 2020 from **21.0%** to **20.9%** and from **2.9%** to **2.8%** respectively.

**Figures 7 thru 12** provide in various formats of injury incident data (**Minor, Serious and Fatal**) for the years 1981 thru 2021. The **Figure 7** bar chart shows **Minor, Serious and Fatal** injuries for each year. In 2021 there was a total of 10 injuries, **Zero Fatalities**, one **Serious** and **9 Minor**. This was a slight increase from the 2020 record low of only **7 Minor** injuries.

There have been **99** reported **Fatalities** for the entire length of the program, starting in 1981. Over the past 10 years there were only two years with **Fatalities**: 2014 with **one** and 2018 with **8**, which involved two **Force 3 Casting** incidents. The **0.9/yr.** average **Fatality** rate for the past 10 years is significantly lower than the **2.4/yr.** annual rate for the entire length of the program.

Of high significance, in **Figure 7** a green arrow indicates a sharp decrease in total injuries starting in 2016 compared to historical values. A reduction in injuries for the past 6 years is displayed more clearly in **Figure 8**, which is a chart started two years go for the 2020 Summary report. When comparing average injuries/year for the years 2001-2015 vs. 2016-2021, the latter timeframe is significantly lower for all categories of injury: **Minor, Serious** and **Fatal**. For these last 6 years, the average **Fatal / Yr.** were 30% lower, average **Serious / Yr.** were 58% lower, average **Minor / Yr.** were 68% lower and average **Total injuries / Yr.** were 65% lower. And this data includes the two 2018 **Force 3** explosions with **12** injuries (**8 Fatalities, 2 Serious and 2 Minor**).

From 1981 through 2021, there is now a total of **1615 Minor, Serious and Fatal** reported injuries with **Figure 9** showing the total injuries in these three categories. The **Figure 10** pie chart breaks this down into percentages: **70.0% Minor, 23.9% Serious** and **6.1% Fatal**.

**Figure 11** presents the likelihood of no injury per 100 incidents vs. the likelihood of an injury in each injury category. This indicates that for each 100 incidents reported there is a **26.1%** rate for **Minor** injuries, an **8.9%** rate for **Serious** injuries and a **2.3%** rate of a **Fatality** vs. a **62.8%** rate of **No Injury**. All three of these injury rates decreased in 2021 vs. 2020 percentages. Since explosions are typically more likely to be reported when there is an injury of some degree, these numbers are certainly inflated compared to data if all explosions were reported, but this does provide an indication of the potential rate of an injury per incident.
Figure 12 displays data only related to Fatalities for the entire reporting program from 1981 through 2021. There have been 9 fatalities over the past 10 years, with 8 of the 10 reported in 2018, as previously noted, due to the two Force 3 casting explosions. The 0.9/yr. average fatality rate for the past 10 years is significantly lower than the 2.41 annual rate for the entire length of the program.

Figures 13 thru 46 provide more detailed information regarding the 140 reported explosions in 2021 along with similar charts comparing this yearly data with the entire database from 1980 thru 2021. Additionally, there are newer charts, first presented in the 2020 report, which provide additional insight into: 1) Recent trends in reported explosions and injury rates for Melting, Casting and Transfer operations (Figures 15-20); and 2) Summaries of the major causes of Casting and Transfer incidents over recent years (Figures 26, 27, 30 & 31).

Figure 13 shows the 2021 data by Force Level for each of the four major categories of operations: Melting, Casting, Transfer and Other. This can be compared to the same data for the years 1980 thru 2021 in Figure 14. In 2021, most explosions occurred in Casting (59), with Melting (55) slightly lower; Transfer (22) and Other (4) being the lowest as usual. All Other explosions occurred in the Reduction Process. The 23 Force 2 incidents in 2021 is an increase compared to the 12 in 2020, but in-line with recent years. Melting and Casting had similar numbers of Force 2 incidents, 12 and 10 respectively.

The lone Force 3 explosion reported in 2021 was during a Melting operation in a Recycling plant and was related to wet scrap. Approximately 1000kg (2200lbs.) of metal was ejected from the furnace. There were no injuries because of the explosion.

Most Force 2 and Force 3 explosions for the entire reporting period continues to be related to the Melting operation by a wide margin as shown in Figure 14.

As reported in previous years and shown and discussed above when reviewing Figures 7 and 8, there is a general decrease in the number of injuries, especially when comparing the last 6 years to the previous 15 years. Figures 15 through 20 provide Injury and Incident data for each Melting, Casting and Transfer operations in two different formats: 1) Injuries and Incidents; and 2) # Injuries per Incident or Injury Rate. Data is displayed by year from 1990 through 2021, excluding 2011. Unfortunately, the data is not available for program years prior to 1990 and 2011.

In general, the data shows an up-swing in incidents in the early 2000’s and a higher incident volume for the last 7 years. There is downward trend over the last 5 years after a peak in 2016, as is seen previously in Figures 1 and 2. In contrast, however, there appears to be a downward trend in Injuries per Incident or Injury Rate over the last 7 to 10 years. A downward trend can be observed especially for the Casting and Transfer operations (Figures 18 and 20). Melting injuries and Injury Rate have been very low for the last 10 years (< 0.05), except for 2015 (>0.7),
which had 35 Minor injuries resulting from one Force 3 explosion when a furnace bled-out into a casting pit.

For the Injury per Incident Rate charts (Figures 16, 18 and 20) a best fit line is provided along with $R^2$ values, which are very low due to the scatter in the data. It is an obviously a positive sign that the Injury Rate is trending in this direction over the past several years. There are probably numerous reasons for this trend including improvement with primary and secondary PPE materials, design and use, movement toward ‘hands-free’ casting removing personnel from the casting pit during cast starts, and increased training and hazard awareness.

Figure 21 provides 2021 data regarding the type of charge materials involved in 55 Melting incidents, the same number as reported in 2020. The leading cause of the explosions (43 of the 55) was wet scrap, sows and RSI. Wet alloy material (Mg and Si) accounted for 9 explosions, one being Force 2. There were 12 Force 2 Melting explosions and one Force 3. All but one of these 13 Force 2 and Force 3 explosions were related to wet / contaminated scrap, sow, RSI or alloy materials. One Force 2 involved furnace overflow onto a wet floor.

A compilation of the Melting explosion data over the years 1980 thru 2021 for the various types of charging materials involved is shown in Figure 22. Wet or contaminated scrap continues to be the reason for most of the Melting explosions. The second highest area is related to wet alloying materials. Most of the Force 2 and Force 3 Melting explosions have been related to Scrap charging. After Scrap, the next leading cause of Force 2 and Force 3 explosions occurred when charging various types of sows (primary and RSI) and T-bar.

Figure 23 provides a breakdown of the 59 Casting incidents in 2021 in two different ways: by stage in the process and by type of casting process. There were 10 Force 2 and 0 Force 3 explosions in 2021. As typically seen in the past, most of the explosions occurred during Start-up (46), with 4 being Force 2. At cast Termination there were 13 explosions, with 6 of the 13 being Force 2. Wet / rusty drain pans was the cause of 7 of the 13 explosions with 4 being Force 2 incidents. There were zero Steady-State incidents, which is very unusual.

DC Billet or Slab accounted for 29 of the Casting incidents, with 27 occurred when casting Sows or Molds. Most Force 2 explosions (7 of 10) occurred during DC Billet or Slab casting.

Figure 24 shows DC Casting incidents by drop segment for years 1980 - 2021. The historical data is similar to the 2021 data shown in Figure 23 in that most explosions occur during Start-up. For the first time, the End-of-Cast explosions now outnumber the total Steady-State explosions.

For 2021, Figure 25 provides the major causes of the 59 Casting incidents. They are listed by cast stage for DC casting and for mold or sow casting. For DC casting, the main start-up issues were related to wet starting blocks, wet equipment or launders, butt-curl and bleed-overs, equipment set-up and hang-up and release. The main DC casting termination issues were wet / rusty drain
pan, wet tool and trough overflow. The main sow and mold casting incidents were due to wet or cracked molds, and wet equipment or tools.

**Figures 26 and 27** were new charts started in 2021 that provide additional analysis of the primary causes of **Casting** explosions, looking at the last 7 years of data, **2015 through 2021. Figure 26** shows the major causes for all Force levels, while **Figure 27** is data for only **Force 2 and 3 Casting** explosions. By a large margin, the reason for most **Casting** explosions at all **Force** levels is wet, cracked or rusty sow molds. This is followed by excessive curl / hang-up / bleed-out explosions during DC cast starts, which is also the highest cause if segregating for **Force 2 and 3** incidents only, **14 in total for these 7 years. Due to the high number of Force 2 wet /rusty drain pan Termination explosions in 2021, there are now **12 Force 2** and **3** incidents for this reason. These are followed by wet, cracked or rusty sow molds (8).

There were **22 Transfer** explosions (**21 Force 1 and 1 Force 2**) in 2021, as shown in **Figure 13. Figure 28** shows that the majority of these incidents were the result of two issues. Wet hand and furnace tools or equipment accounted for **13 of the incidents. Wet or rusty drain pans or molds totaled 6.**

**Figure 29** provides a bar chart showing the equipment involved in **862 Transfer** explosions for the years 1980 thru 2021. The highest number of **Transfer** explosions are related to **Drain Pans**, followed by **Trough** and then **Other.**

Like **Figures 26 and 27** presented above for **Casting,** **Figures 30 and 31** were first presented in 2021, providing further detail regarding the major causes of **Transfer** explosions. **Figure 30** provides the data regarding the major causes of all **Transfer** explosions for the years **2008 through 2021** (excluding 2011), while **Figure 31** provides this information for only **Force 2 & 3** explosions. The highest cause of explosions is wet / rusty drain pan (**89 incidents**); however wet refractory or equipment (**86 incidents**) is very nearly the same. It should be noted in the **Force 2 & 3** data, that wet / rusty drain pans cause almost 3 times the number of incidents compared to the next leading cause of wet refractory / equipment.

When combining **Casting** and **Transfer** incident data for wet / rusty drain pan, this source of explosions accounts for **17% (13 of 77)** of the 2021 explosions in these two categories.

**Injuries by Operation (Melting, Casting, Transfer and Other)** resulting from the 140 explosions in 2021 is provided in **Figure 32. Casting** accounted for **8** of the **10 injuries,** with one being **Serious** and the balance **Minor.** The **two Transfer injuries** were both **Minor.**

**Figure 33** provides **Injury by Operation** data for 1980 thru 2021. The highest number of **Minor** and **Serious** injuries has occurred in the **Casting Operation.** The **Melting Operation** accounts for the highest number of **Fatalities,** also the highest number of **Force 3** explosions as seen in **Figure**
14. It should be noted that a significant number of injuries have occurred in rather straightforward Transfer Operations, including 81 Serious and 7 Fatalities.

As noted above, the highest number of Fatalities and Force 3 explosions occur during Melting Operations. Additional data analysis was performed investigating if there was a correlation between the “time of year” vs. the number of incidents. Chart 1 below (Figure 34) provides this Melting incident data for the last five years (2017 thru 2021). All causes of melting incidents were part of the analysis, which primarily included wet or contaminated charge materials and wet equipment and tools.

This chart is presented starting in September through August, rather than in the traditional January through December format. This is to better emphasize a higher incident rate in the northern hemisphere “winter months” of January through February when there is a higher potential for winter weather of snow, ice and rain to contaminate scrap and sows. With this explanation of higher incidents at this time of year it may be anticipated that November and December would also show an increase. November does show a slight increase compared to August and September; however, December is decidedly lower. This result may be explained in that during December there can be more maintenance and holiday shutdowns / slowdowns that can occur in this month.

This data may be worthwhile sharing with plant personnel to emphasize the need for increased emphasis and attention to storage, drying and charging procedures at this time of year, which may have relaxed during the summer months.

Chart 1

![Chart 1](image)

Incident frequency by month is also provided in Charts 2 & 3 below (Figures 35 & 36) for Casting and Transfer in the same format to evaluate if there is a similar correlation to time of year for explosions occurring in these process categories. Correlation to “winter months” or any other
time of the year is not evident with this data. And December does not show the same lower frequency as was observed in the Melting data.

It should be noted that the incident database used for these charts does not include month of the year for all reported incidents, since not all reports contain this information. “Month of the Incident” is a requested item on the Aluminum Association Incident Report form, but it is not necessarily provided, especially when the incident data is provided via spreadsheet format.

Figures 37 and 38 provide incident data vs. the type of Process Plant (Reduction, Extrusion, Rolling and Recycling) for 2021 and for 1980 thru 2021 respectively.
In 2021, the highest number of incidents occurred in Reduction Operations (50), compared to the next highest Recycling Operations (37). Recycling also reported the highest number of Force 2 incidents (8) and the one Force 3 incident. Extrusion was next highest with 7 Force 2 incidents, followed by Rolling (5) and Reduction (2). Figure 35 provides corresponding data for the entire reporting period, 1980 thru 2021. The highest number of incidents occurring in Reduction and the second highest reported from Rolling, which by far has reported highest number of Force 3 explosions.

The main causes of the 2021 Reduction facility explosions are presented in Figures 39 and 40. They are listed by Melting, Casting and Transfer / Reduction incidents. Melting incidents were related to wet charge materials. The primary reason in Casting was cracked, wet or rusty molds for sow casting. Transfer and Reduction incidents were primarily related to wet / rusty equipment, tools and drain pans.

Figure 41 is a bar chart providing Reduction plant injury information for the two Minor Injuries in 2021. There were no Serious Injuries. The two injuries were both Transfer related to wet / unpreheated hand tools.

Rolling plant Injury information is provided in Figure 42, with all 4 occurring in Casting, 3 Minor and one Serious. Three of the 4 injuries, including the one Serious, were the result of wet / rusty drain pans.

For Extrusion, Figure 43, there was only one Minor injury, due to a wet/ rusty drain pan.

There was one Recycling Force 2 incident, Figure 44, which resulted in both injuries in this category, and it was also due to a wet/ rusty drain pan.

Figure 45 summarizes the 2021 injury data by type of Process Plant and Figure 46 shows this same data for 1980 thru 2021.

The last page of the report after the Figures provides an Aluminum Association Molten Metal Incident Report Form or you can link to the form at:

https://www.aluminum.org/health-safety

R T Richter – September 20, 2022
Incidents by Year
1981 to 2021 Total 4339

FIGURE 1. INCIDENTS REPORTED FOR THE PERIOD 1981 – 2021  Sep. 2022
# Explosion Rating Force Criteria

## Table 1. Explosion Rating Force Criteria

<table>
<thead>
<tr>
<th>Guidelines</th>
<th>Force 1</th>
<th>Force 2</th>
<th>Force 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property Damage</td>
<td>None</td>
<td>Minor</td>
<td>Considerable</td>
</tr>
<tr>
<td>Light</td>
<td>Minimal</td>
<td>Flash</td>
<td>Intense</td>
</tr>
<tr>
<td>Sound</td>
<td>Short cracking</td>
<td>Loud Report</td>
<td>Painful</td>
</tr>
<tr>
<td>Vibration</td>
<td>Short and sharp</td>
<td>Brief rolling</td>
<td>Massive structural</td>
</tr>
<tr>
<td>Metal Dispersion</td>
<td>&lt;15 feet</td>
<td>&gt;15 to 50 feet</td>
<td>&gt;50 feet</td>
</tr>
</tbody>
</table>
Incidents by Force Level
1981 to 2021 – Total 4339

FIGURE 2. INCIDENTS BY FORCE LEVEL FOR 1981 – 2021
Sep. 2022
Incidents by Force Levels 2 & 3
1981 to 2021

FIGURE 3. INCIDENTS BY FORCE LEVELS 2 & 3 FOR 1981 – 2021  Sep. 2022
FIGURE 4. FORCE 3 INCIDENTS FOR 1981 – 2021

- Force 3 Incidents Only
- 1981 to 2021
- 5 Yr. Avg.: 1.0
- 10 Yr. Avg: 0.8
- 2.8

Sep. 2022
Incidents by Force Level
1981 to 2021 – Total 4339

<table>
<thead>
<tr>
<th>Force</th>
<th>Incidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force 1</td>
<td>3312</td>
</tr>
<tr>
<td>Force 2</td>
<td>906</td>
</tr>
<tr>
<td>Force 3</td>
<td>121</td>
</tr>
</tbody>
</table>

FIGURE 5. INCIDENTS BY FORCE LEVEL 1981 – 2021 Sep. 2022
FIGURE 6. ALL FORCE LEVELS BY PERCENTAGE 1981 – 2021

- Force 1: 76.3%
- Force 2: 20.9%
- Force 3: 2.8%
Injuries from Incidents 1981 to 2021 (Total 1615 Injuries)

FIGURE 7. INJURIES FROM INCIDENTS FOR 1981 – 2021

Sep. 2022
Average # of Injuries / Year from Explosions
2001-2015 & 2016-2021

FIGURE 8. AVG. # INJURIES / YR. FOR 2001-2015 & 2016-2021

Sep. 2022
Injuries by Severity – Total 1615
1981 to 2021

FIGURE 9. INJURIES BY SEVERITY FOR 1981 – 2021
FIGURE 10. INJURY LEVELS BY PERCENTAGE FOR 1981 – 2021

Injury Levels by Percentage
1981 - 2021

Minor
Serious
Fatal

23.9%
6.1%
70.0%
### Injury Risk per 100 Explosions

**1980 - 2021**

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>% Injuries / 100 Explosions</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Injury</td>
<td>62.8%</td>
</tr>
<tr>
<td>Minor</td>
<td>26.1%</td>
</tr>
<tr>
<td>Serious</td>
<td>8.9%</td>
</tr>
<tr>
<td>Fatal</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

**FIGURE 11. INJURY RISK PER 100 EXPLOSIONS FOR 1981 – 2021**

Sep. 2022
Fatalities from Explosions
1981 to 2021

FIGURE 12. FATALITIES FROM EXPLOSIONS FOR 1981 – 2021

Avg. # of Fatalities / Yr.- 2.41

Fatals

Sep. 2022
FIGURE 13. FORCE LEVEL INCIDENTS BY OPERATION FOR 2021

<table>
<thead>
<tr>
<th>Operation</th>
<th>Force 1</th>
<th>Force 2</th>
<th>Force 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting</td>
<td>42</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Casting</td>
<td>49</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Transfer</td>
<td>21</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Sep. 2022
Melting Injuries and Incidents
1990 to 2021 (Total 334 Injuries)

FIGURE 15. MELTING INJURIES AND INCIDENTS FOR 1990 – 2021  Sep. 2022
2007 Rate – 3.4 Due to Force 3 China Explosion w/ 84 Total Injuries, Including 16 Fatalities

$R^2 = 0.0167$
Casting Injuries and Incidents
1990 to 2021 (Total 356 Injuries)

FIGURE 17. CASTING INJURIES AND INCIDENTS FOR 1990 – 2021    Sep. 2022

Casting Injuries
Casting Incidents
Casting Injuries per Incidents
1990 to 2021

FIGURE 18. CASTING INJURIES PER INCIDENTS FOR 1990 – 2022

Sep. 2022

R² = 0.2572
Transfer Injuries and Incidents
1990 to 2021 (Total 342 Injuries)

FIGURE 19. CASTING INJURIES AND INCIDENTS FOR 1990 – 2021 Sep. 2022

Transfer Injuries
Transfer Incidents
FIGURE 20. TRANSFER INJURIES PER INCIDENTS FOR 1990–2021

$R^2 = 0.1604$
Major Causes
Wet & Oxidized: Scrap, Sows, RSI
Wet Alloy Additions: Mg, Si
Wet Charge Buckets

FIGURE 21. MELTING EXPLOSIONS BY CAUSE FOR 2021
Melting Explosions - Charge Material Involved
1980 - 2021

FIGURE 22. MELTING EXPLOSIONS BY CHARGE MATERIAL 1980 – 2021  Sep. 2022
FIGURE 23. CASTING EXPLOSIONS FOR 2021

59 Casting Explosions - 2021

Start-up  | Steady State | Termination | DC Slab & Billet | Rod | Sow or Mold
---|---|---|---|---|---
Force 1 | 42 | 0 | 7 | 22 | 0 | 26
Force 2 | 4 | 0 | 6 | 7 | 0 | 1
Force 3 | 0 | 0 | 0 | 0 | 0 | 0

1 Force 2 Explosion – Cont. Strip Casting
1 Force 2 Explosion – Pellet Casting
1 Force 1 Explosion – Not Recorded
DC/HDC/EMC Explosions by Cast Segment 1980 to 2021

### Figure 24
**Casting Explosions by Cast Segment 1981 – 2021**

- **Start-up**: 808
- **Steady State**: 122
- **End of Cast**: 129

Sep. 2022
1. Major Causes of 60 Casting Incidents – 2021

- **DC Start-up Issues**: Wet Starting Blocks, Wet Equipment / Launder, Butt Curl – Bleed-overs, Equipment Set-up, Ingot Hang-up & Release

- **DC Steady State Issues**: No Steady State Explosions!

- **DC Termination Issues**: Wet Rusty Drain Pan, Wet Tool, Trough Overflow

- **Sow / Mold Casting Issues**: Wet / Cracked Molds, Wet Equipment / Tools
FIGURE 26. CASTING EXPLOSIONS by MAJOR CAUSES 2015–2021  Sep. 2022
MAJOR CAUSES OF FORCE 2 & 3 CASTING EXPLOSIONS - 2015 thru 2021

FIGURE 27. CASTING EXPLOSIONS by MAJOR CAUSES 2015–2021  Sep. 2022

- Ingot Head Under Water: 3 incidents
- Equipment Failure / Maint. Issue: 4 incidents
- DC Cast Start - Wet / Rusty Bottom Block: 6 incidents
- Sow Casting - Wet / Cracked / Rusty Molds: 8 incidents
- End of DC Cast & Aborts - Wet / Rusty Drain Pan: 12 incidents
- DC Cast Start - Excessive Curl / Hang-up / Bleed-out: 14 incidents
13 - Wet Hand or Fce Tools, Equipment
6 - Wet / Rusty Drain or Skim Pan
2 – Equipment Falling into Trough / Launder
1 – Sow Not Solidified Dumped on Floor
Transfer Explosions by Equipment – Total 862
1980 to 2021

<table>
<thead>
<tr>
<th>Equipment</th>
<th># of Explosions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain Pan</td>
<td>348</td>
</tr>
<tr>
<td>Trough</td>
<td>208</td>
</tr>
<tr>
<td>Crucible</td>
<td>126</td>
</tr>
<tr>
<td>Other</td>
<td>179</td>
</tr>
</tbody>
</table>

FIGURE 29. TRANSFER EXPLOSIONS by EQUIPMENT 1980 – 2021  Sep. 2022
FIGURE 30. TRANSFER EXPLOSIONS - MAJOR CAUSES 2008–2021

**Wet Floor / Spill**
- 16

**Wet Tools**
- 32

**Wet Refractory or Equipment**
- 86

**Wet / Rusty Drain Pan**
- 89

*MAJOR CAUSES OF TRANSFER EXPLOSIONS*
*2008 thru 2021 (w/o 2011)*

*Sep. 2022*
MAJOR CAUSES OF FORCE 2 & 3
TRANSFER EXPLOSIONS - 2008 thru 2021 (w/o 2011)

FIGURE 31. TRANSFER EXPLOSIONS - MAJOR CAUSES 2008–2021
Sep. 2022

Wet Floor / Spill: 4
Wet Refractory or Equipment: 5
Wet / Rusty Drain Pan: 14

FIGURE 32. INJURIES BY OPERATION FOR 2021

<table>
<thead>
<tr>
<th></th>
<th>Minor</th>
<th>Serious</th>
<th>Fatal</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Casting</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transfer</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
FIGURE 33. INJURIES BY OPERATION FOR 1980 - 2021

1612 Injuries by Operation: 1981 – 2021

<table>
<thead>
<tr>
<th></th>
<th>Melting</th>
<th>Casting</th>
<th>Transfer</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>283</td>
<td>382</td>
<td>267</td>
<td>213</td>
</tr>
<tr>
<td>Serious</td>
<td>117</td>
<td>164</td>
<td>81</td>
<td>16</td>
</tr>
<tr>
<td>Fatal</td>
<td>59</td>
<td>30</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>
FIGURE 35. Casting EXPLOSIONS by Month 2017 – 2021

Casting Explosions by Month
2017 to 2021

FIGURE 35. Casting EXPLOSIONS by Month 2017 – 2021  Sep. 2022
FIGURE 35. Casting EXPLOSIONS by Month 2017 – 2021

Casting Explosions by Month
2017 to 2021
FIGURE 37. FORCE LEVEL BY PROCESS PLANT REPORTED FOR 2021

- 3 Force 1: R&D
- 1 Force 2: Foundry

<table>
<thead>
<tr>
<th></th>
<th>Reduction</th>
<th>Extrusion</th>
<th>Rolling</th>
<th>Recycling</th>
<th>Forging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force 1</td>
<td>48</td>
<td>11</td>
<td>26</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Force 2</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Force 3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
FIGURE 37. FORCE LEVEL BY PROCESS PLANT REPORTED FOR 2021

- 3 Force 1: R&D
- 1 Force 2: Foundry

<table>
<thead>
<tr>
<th>Process Plant</th>
<th>Reduction</th>
<th>Extrusion</th>
<th>Rolling</th>
<th>Recycling</th>
<th>Forging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force 1</td>
<td>48</td>
<td>11</td>
<td>26</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Force 2</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Force 3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Melting Incidents</td>
<td>Casting Incidents</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - Wet Charge: Scrap / Sow</td>
<td>26 - Sow Casting - Cracked, Wet or Rusty Molds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - Wet Mg</td>
<td>2 – VDC Start-Up – Wet Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 - Start-Up – Wet Refractory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 – Start-up – Wet Starting Block</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 – Start-up SOP Not Adapted or Not Respected</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 – Termination – Wet Hand Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 – Termination – Wet Drain Pan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Transfer Incidents

<table>
<thead>
<tr>
<th>Incident Description</th>
<th>Reduction Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - Wet / Rusty Tools / Equipment</td>
<td>4 – Wet or Rusty Equipment / Drain Pan – Cryolite Transfer</td>
</tr>
<tr>
<td>4 - Wet / Rusty Sample Mold / Hand Tool</td>
<td></td>
</tr>
<tr>
<td>2 – Wet / Rusty Drain Pan</td>
<td></td>
</tr>
</tbody>
</table>
Reduction Plant Injuries & Incident Causes - 2021

- 2 Minor Injuries - Both Due to Wet / Unpreheated Hand Tool

FIGURE 41. REDUCTION PLANT INJURIES BY OPERATION  2021       Sep. 2022
### Rolling Plant Injuries - 2021

#### FIGURE 42. ROLLING PLANT INJURIES BY OPERATION 2021

<table>
<thead>
<tr>
<th>Operation</th>
<th>Minor</th>
<th>Serious</th>
<th>Fatal</th>
<th>Transfer</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Casting</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transfer</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **4 Casting Injuries**
  - 3 – Termination due to Wet / Rusty Drain Pan (1 Serious)
  - 1 – Termination due to Wet Equipment Falling into Launder
### Extrusion Plant Injuries - 2021

#### FIGURE 43. EXTRUSION PLANT INJURIES BY OPERATION 2021

- **1 Cast Termination Injury Due to Wet/Rusty Drain Pan**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Minor</th>
<th>Serious</th>
<th>Fatal</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Casting</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transfer</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Recycling Plant Injuries - 2021

2 Cast Termination Injury Due to Wet / Rusty Drain Pan – Force 2

FIGURE 44. RECYCLING PLANT INJURIES BY OPERATION 2021

<table>
<thead>
<tr>
<th></th>
<th>Melting</th>
<th>Casting</th>
<th>Transfer</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Serious</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fatal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
### Injury Severity by Process Plant - 2021

<table>
<thead>
<tr>
<th>Process</th>
<th>Minor</th>
<th>Serious</th>
<th>Fatals</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Extrusion</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Rolling</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Recycling</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**FIGURE 45. INJURY SEVERITY BY PROCESS PLANT - 2021**

Sep. 2022
Injury Severity by Process Plant
1980 to 2021

FIGURE 46. INJURIES BY PLANT REPORTED FOR 1980 - 2021

Minor

Serious

Fatal

Reduction
Extrusion
Rolling
Recycling
Foundry
Atomizing
Alloying
BRW
Other
R&D

586
141
203
107
82
0
2
9
7
12

111
70
89
74
34
2
1
1
2
1

12
24
16
29
19
0
0
0
0
0

FIGURE 46. INJURIES BY PLANT REPORTED FOR 1980 - 2021

Sep. 2022
ALUMINUM ASSOCIATION
MOLTEN METAL INCIDENT REPORT

Date of Incident:       Predominant Plant Activity: SELECT ONE:

Explosion Force – Mark One: 

Force 1 Characterization: 

Force 2 Characterization: 

Force 3 Characterization: 

For definition of force, click arrow to see a description

Alloy 

Metal Temperature 

°F 

°C 

Approximate Amount of Metal Involved 

lbs 

kilograms

OPERATION:

Charging / Melting 

Type of Furnace 

SELECT ONE:

Furnace Capacity 

lbs 

mt 

% Full 

Materials Charged 

Outside Storage? Yes 

No 

Preheat? Yes 

No 

Preheat Time/Temp: 

hrs 

°F 

°C

Transfer 

Type 

SELECT ONE:

Casting 

Type 

SELECT ONE:

Type of Product being Cast:

Stage of Operation: 

SELECT ONE:

Other 

Describe

Number of Injuries by Type: Minor 

Severe 

Fatal 

Provide a brief description of the incident and its root cause(s):

If Charging/Melting Incident, please select appropriate Primary and Secondary cause(s):

Other 

Other 

If Contaminations (other than moisture) was selected, please specify:

SELECT ONE:

If Transfer Incident, please select appropriate Primary and Secondary cause(s):

PRIMARY CAUSE:

SECONDARY CAUSE:

If Casting Incident, please select appropriate Primary and Secondary cause(s):

PRIMARY CAUSE:

SECONDARY CAUSE:

If Bleed-out/Bleed-over is selected above, describe reason for Bleed-out or Bleed-Over:

If Explosion due to Bleed-out/Bleed-over was selected above, where was the location of Explosions:

SELECT ONE:

If Metal Level Control Problem was selected above, please specify location of problem:

SELECT ONE:

Please return to:

Curt Wells
Director, Regulatory Affairs
The Aluminum Association.
1400 Crystal Drive, Suite 430
Arlington, VA 22202