REPORT

ANNUAL SUMMARY REPORT ON MOLTEN METAL INCIDENTS IN 2023

September 2024

For the year 2023, 156 molten metal incident reports occurring world-wide were received as compared to 198 reports for 2022 and 140 reports for 2021. The attached figures summarize the reports for 2023 as well as the data for the years 1980 through 2023.

SUMMARY POINTS:

- For 2023, there were 156 explosion incidents reported. This was considerably lower than the 198 incidents reported in 2022 which was the highest ever reported in the 42 years of the Molten Metal Incident Reporting Program initiated in 1981. The 156 total 2023 incidents are slightly lower than the average 164 reported incidents for the 5 previous years, 2018 through 2022.
- This was the second year in a row with 0 reported Force 3 explosions. The previous 5 years, 1018 through 2022, averaged 1 Force 3 explosion per year.
- There were 130 Force 1 explosions, 26 Force 2 explosions and 0 Force 3 explosions reported in 2023.
- Continuing into 2023 was the notable increase in Force 2 explosions that started in 2016, with an average 22/yr. from 2016 through 2023. These last eight years reversed a downward trend that was observed starting around 2008 and continued through 2014.
- The % of Force 2 explosions in 2023, 17%, was notably higher than the 13% average Force 2 incidents for the previous 5 years, 2018 through 2022.
- The chart providing data from 1980 through 2023 for Force 1, 2 and 3 explosions by Operation (Melting, Casting, Transfer and Other) was modified to include the % Force 1, 2 and 3 for each of these 4 operations. Of note is the high percentage of Melting Force 3 incidents, 7% of all Melting incidents, with Force 2 at a smaller rate of 3%. The other three operations are at 1-2% for Force 3 incidents. Also of note is that both Casting and Transfer have the same high percentage of 18% Force 2 explosions.
- A significant number of Casting and Transfer explosions continue to be related to wet/rusty drain pans. For both 2022 and 2023, this reason accounted for 20% of all explosions in these two operations. For 2023, this was 21 of 104 incidents.
- Of significant note, there were again no reported Fatalities in 2023, same as for the years 2015 through 2017 and 2019 through 2022. There have been 99 reported Fatalities for the entire length of the program.
- The Aluminum Association has been made aware via web site searches and media reports that in 2023 a number of large aluminum plant explosions have been reported in the global industry. The Aluminum Association has not received any incident reports from the companies where these incidents occurred. A number appear to be Force 3 explosions with multiple fatalities and

injuries. Often the obtained information does not indicate for certain if these involved casthouse activities or the type of cast house operation (e.g. Melting, Casting or Transfer).
    - There is only one of these incidents where a translated government incident investigation document has been recently obtained. This billet casting incident document does not provide adequate explosion details and information to establish a primary or secondary cause, except that during a VDC cast there was a major molten bleedout into the casting pit due to insufficient mold cooling water present. The document indicated six fatalities and five injured employees.
    - One of the main purposes of the Annual Incident Report is to provide information to member companies that is useful in helping to prevent future explosions, injuries and fatalities. Since the information that we have currently received regarding these 2023 global aluminum industry incidents is generally not sufficiently verified and/or detailed enough for use in assisting in the prevention of future incidents, these incidents are not included in the database.
- There were 17 injuries reported in 2023, with only one being rated as Serious. The injury rate per incident for 2023 was 11%. The is higher than the average injury rate of 8% from 2016 through 2022.
- However, there is a significant difference comparing an injury rate per incident of 8% for 2016 through 2023 versus the years 2000 through 2015 with an injury rate per incident of 40%.
- Over the past ten years there were only two years with Fatalities: 2014 with one and 2018 with eight, which involved two major Casting incidents. The 0.9/yr. average Fatality rate for the past ten years is significantly lower than the 2.3 annual rate for the entire length of the program.
- Of the 17 injuries reported in 2023, Transfer operation accounted for the majority with one Serious and 9 Minor injuries. This compares to only two Transfer injuries reported in 2022.
- Important to note, wet tools accounted for 7 of the 10 Transfer injuries, with 5 of these related to metal sampling. The one Serious injury was due to a wet crucible.
- The 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 the new charts added to the 2020 report. However, Transfer operation continues to have the highest injury rate per incident compared to Melting and Casting. In 2023 Transfer injury rate per incident was 23.8%, considerably higher than Melting at 2.4% and Casting at 7.9%.
- As stated in the past, this lower injury frequency can be attributed at least partially to:
    - The increased use of primary and secondary PPE;
    - Improvements in PPE materials and design;
    - An increased focus on hands-free Casting operations that remove personnel from high-risk Casting operations; and
    - Possibly increased training and hazard awareness.
- There were 5 Casting operation injuries, all Minor. Four injuries occurred during the VDC cast Termination stage as result of wet or rusty drain pans (3) and a wet tool (1).
- For Melting operations in 2023, there was only one Minor injury. There were zero Melting injuries in 2021 and 2022. Over the past six years there have been only four Melting injuries (three Minor and one Serious).
- The highest number of incidents occurred in Reduction plants (84), followed by Rolling (36), Recycling (20) and Extrusion (16) plants.

- Reduction plant injuries accounted for 10 Minor and 1 Serious, followed by Extrusion plants with three Minor injuries, Rolling plants with two Minor and Recycling with one Minor.
- Recycling plants reported a significantly lower number of incidents in 2023 (21), compared to 2022 (49).
- Starting with the 2023 report, new charts and data was initiated examining "by plant type" (Reduction, Rolling, Extrusion and Recycling) incidents, injuries and % injuries per incident for the past 12 years. Differences were noted in the number of incidents as well as % injuries per incident between these four plant types. Reduction plants have the highest number of incidents compared to the others, but with moderately low injury rates. Extrusion plants have the lowest number of incidents and a low number of injuries, but with a high incident rate variability. Recycling plant reported incidents have increased over the past seven years with typically low injury rates. Rolling plant incidents also increased significantly over the past nine years with injury rates higher than Reduction and Recycling. Further investigation and data analysis would seem appropriate to understand these differences, which then could possibly lead to reducing injury rates further.
- As reported in recent annual incident reports, the sharp decrease in injuries starting in 2016 compared to historical values has continued through 2023, although as noted above there has been a 2023 uptick in injury rate per incident. When comparing the average amount of injuries/year for the years 2001-2015 vs. 2016-2023, the latter time period is significantly lower (13.9 vs. 48.1 injuries/yr.) for all categories: Minor, Serious, and Fatal.
- When comparing the average amount of injuries/year for the years 2001-2015 vs. 2016-2023, the latter time period is significantly lower (14.3 vs. 48.1 injuries/yr.) for all categories: Minor, Serious, and Fatal. For these last eight years, the average Fatal/Yr. was 57% lower, the average Serious/Yr. was 72% lower, the average Minor/Yr. was 72% lower, and the average Total Injuries/Yr. was 70% lower.
- As observed often in the past, 62 Casting incidents accounted for the highest number of explosions (57 Force 1 and 5 Force 2). Most explosions, 42, occurred during start-up, which included four of the five Force 2 explosions. Sow or mold Casting accounted for 34 incidents and there were 27 incidents during DC slab and billet Casting.
- For Casting explosions between 2015 through 2023, 49% occur during sow or mold Casting due to wet, cracked or rusty molds. This compares to the next highest at 12% for VDC cast start explosions due to excessive curl, hang- ups and bleed-outs.
- For only Force 2 or Force 3 casting explosions, 16 VDC cast start explosions were the highest, due to excessive curl, hang- ups and bleed-outs. This was followed closely at 15 VDC termination explosions, due to wet and rusty drain pans.
- Force 2 and 3 Transfer incident data from 2008 through 2023 indicate that wet/rusty drain pans account for 59% of all the explosions.
- In 2023 there were 42 melting explosion, compared to 74 in 2022. 26% of the 2023 melting explosions were Force 2. Wet or contaminated scrap accounted for 9 of the 11 Force 2 explosions.
- Starting in 2021 new charts were added and continued this year which display incidents per month for the years 2017 through 2023 for the three operations of Melting, Casting and Transfer. Only Melting displayed any correlation to the time of year. The additional year of data continued to support the previous results showing a higher Melting incident rate for January through

March, most likely related to the higher potential for charging materials to be contaminated with water, snow and ice when it is winter in the Northern Hemisphere. There was a higher volume in November as well, but a lower volume of Melting incidents in December continued, with no correlation to similar results in Casting or Transfer.

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 50, provided after the discussion below, display various charts and tables, including Table 1.

Table 1: Explosion Rating Force Criteria

Guidelines	Force 1	Force 2	Force 3
Property Damage	None	Minor	Considerable
Light	Minimal	Flash	Intense
Sound	Short cracking	Loud Report	Painful
Vibration	Short and sharp	Brief rolling	Massive structural
Metal Dispersion	<15 feet	>15 to 50 feet	>50 feet

Figure 1 displays by year from **1981** through **2023** the total number of reported incidents, **4691**. There were **156** explosions reported in **2023**, compared to a record high **198** in 2022 for the 43 years of the Molten Metal Incident Reporting Program initiated in 1981. The **156** reports in **2023** are slightly lower than the average **164** reported incidents for the five previous years, **2018** through **2022**.

Figures 2 through 6 provide **Force Level** data for all years of the program, 1981 through 2023, in various formats, including the number of incidents and rates. **Figure 2** displays the reported incidents each year for all three Force Levels. **Figure 3** displays the same data but broken down by **Force Levels 1, 2 and 3** for each year. In 2023 there were **130 Force 1**, **26 Force 2** and **zero Force 3** explosions. The **26 Force 2** explosions were three higher than in 2022.

From **2008 through 2023** 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 **five** and **ten** years (**0.6/yr.** and **0.8/yr.** respectively) continues to show a much lower level compared to the **2.6/yr.** average for the entire reporting history from **1981 through 2023**. The notable downward trend of **Force 2** explosions observed in **Figure 3,** starting around 2008 and continuing through 2014, was reversed beginning in 2016 and has continued through 2023 with an average of **22/yr.** over the past **eight years**.

Figures 5 and 6 display a comparison of all three **Force Levels** for the entire reporting history from 1981 through 2023 in two different formats: 1) bar graph and 2) pie-chart. **Force 1** incidents account for **77.1%** of all incidents, which has been increasing slightly over the last few years since 2019 at **75.6%.** The **Force 2** and **Force 3** incident rate in 2023 both lowered slightly compared to 2021 from **20.5%** to **20.4%** and from **2.7%** to **2.6%** respectively.

Figures 7 through 13 provide various formats of injury incident data (**Minor, Serious and Fatal**) for the years 1981 through 2023. There were a total of **1645 injuries** reported over the entire lifetime of the program. The **Figure 7** bar chart shows **Minor, Serious and Fatal** injuries for each year. In 2023 there were **zero Fatalities**, same as for the years 2015 through 2017 and 2019 through 2022. Last year there were a total of **17 injuries**, 16 **Minor** and **one Serious**.

There have been **99** reported **Fatalities** for the entire length of the program, starting in 1981. Over the past ten years there were only two years with **Fatalities**: 2014 with **one** and 2018 with **eight**, which involved two **Force 3 Casting** incidents. The **0.9/yr.** average **Fatality** rate for the past ten years is significantly lower than the **2.3/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. The reduction in injuries over the past eight years is displayed more clearly in **Figures 8** and **9**. Both charts present data from 2001 through 2023. **Figure 8** was a new chart last year. The chart displays **% Injuries per total annual incidents** and clearly shows the rate of injuries per incidents reported declining starting in 2016. **Figure 9** was started three years ago for the 2020 summary report. When comparing average injuries/yr. for the years 2001-2015 versus 2016-2023, the latter time frame is significantly lower for all categories of injury: **Minor, Serious and Fatal**. For these last eight years, the average **Fatal/Yr**. was **57% lower**, the average **Serious/Yr**. was **72% lower**, the average **Minor/Yr.** was **72% lower**, and the average **Total Injuries/Yr.** was **70% lower**. Additionally, this data includes the two 2018 **Force 3** explosions with injuries (**eight Fatalities, two Serious and two Minor**).

From 1981 through 2023, there are now a total of **1645 Minor, Serious and Fatal** reported injuries with **Figure 10** showing the total injuries in these three categories. The **Figure 11** pie chart breaks this down into percentages: **70.5% Minor**, **23.5% Serious** and **6.0% Fatal**.

Figure 12 presents the likelihood of no injury per hundred incidents versus the likelihood of an injury in each injury category. This indicates that for every hundred incidents reported there is a **24.7%** rate for **Minor** injuries, an **8.2%** rate for **Serious** injuries and a **2.1%** rate of **Fatalities** versus a **64.9%** rate of **No Injury**. All three of these injury rates decreased in 2023 versus 2022 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 the actual data if all explosions were reported. However, this does provide an indication of the potential rate of an injury per incident.

Figure 13 displays data only related to **Fatalities** for the entire reporting program from 1981 through 2023. There have been **nine Fatalities** over the past 10 years, with eight of the ten reported in 2018, as previously noted, due to the **two Force 3** Casting explosions. The **0.9/yr.** average Fatality rate for the **past ten years** is significantly lower than the **2.30/yr.** annual rate for the entire length of the program.

Figures 14 through 50 provide more detailed information regarding the **198** reported explosions in **2023** along with similar charts comparing this year's data with the entire database from 1980 through 2023. 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 16-21**); and 2) Summaries of the major causes of **Casting and Transfer** incidents over recent years (**Figures 27, 28, 31 and 32**).

Figure 14 shows the 2023 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 through 2023 in **Figure 15**. In 2023, most explosions occurred in **Casting (63)**, with **Melting (42)**, **Transfer (42)** and **Other (9)** being the lowest as in the past. All **Other** explosions occurred in the **Reduction** Process. It was notable and perhaps concerning that the number of **Transfer** and **Melting** incidents were the same in 2023. The total number of **Melting** incidents were on the low side of typical, while **Transfer** incidents were high considering the total number of incidents had decreased considerably in 2023. In 2023 the highest number of **Force 2** incidents occurred in **Melting (11)**, followed by **Transfer (eight), Casting (five) and Other (two).**

Figure 15, showing data from 1980 through 2023, was modified this year to now include the % of **Force 1, 2 and 3** incidents for each of the four operations discussed above. Notable is the relatively high percentage of **Melting Force 3** incidents, **5%** of all **Melting** incidents. While the other three operations are at **1-2%** for **Force 3** incidents. Also of note is that **Melting Force 2** incidents have a high percentage at **27%**; while both Casting and Transfer have the same high percentage of **18% Force 2** explosions.

As reported in previous years and shown and discussed above, when reviewing **Figures 7 through 9**, there is a general decrease in the number of injuries, especially when comparing the last eight years to the previous 15 years. **Figures 16 through 22** 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 2023, excluding 2011. Unfortunately, the data is not available for program years prior to 1990 and 2011.

In general, the data shows an upswing in incidents in the early 2000's and a higher incident volume for the last 8-10 years in all three operation categories. However, the injury rates per incident are much different compared to operation categories. The **Melting Injury Rate** been very low for the last 15 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. The **Casting and Transfer Injuries** and **Injury Rates** are variable and especially notable for **Transfer**. **Transfer Injuries** are trending upward over the last 8-10 years. The **Injury Rates** for **Casting** and **Transfer** (**Figures 19 and 21**) are much higher than for **Melting** (**Figures 17**), on the order **10X** higher for **Casting** and **20X** higher for **Transfer**. The general Injury Rate trends over the last 35 years have certainly been downward, however the data is scattered as evidenced by very low R2 values shown in the three **Injuries** per **Incident** graphs. For **Transfer** and **Casting** there is a trend toward leveling off or even slightly upward for **Transfer**.

There are probably numerous reasons for the **Injury Rate** general long downward trend including: 1) improvements with primary and secondary PPE materials, design and use; 2) movement toward 'hands-free' casting removing personnel from the Casting pit during cast starts; and 3) increased training and hazard awareness.

Figure 22 provides 2023 data regarding the type of charge materials involved in the **42 Melting** incidents. The leading cause of the explosions (**35** of the **42**) was wet scrap, sows, RSI or T-Bar. All **10 Force 2 Melting** explosions occurred in these **42** incidents. Wet alloy materials (Mg and Mn) accounted for **four Force 1** explosions.

A compilation of the **Melting** explosion data over the years 1980 through 2022 for the various types of charging materials involved is shown in **Figure 23**. 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. By a high margin, 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 24 provides a breakdown of the **62 Casting** incidents in 2023 in two different ways: by stage in the process and by type of Casting process. There were **5 Force 2** and **zero Force 3** explosions in 2023. As typically seen in the past, most of the explosions occurred during the **Start- up (42),** with **four** being **Force 2**. At cast **Termination** there were **nine** explosions, with **one** being **Force 2**. There were **12 Steady-State** incidents, all **Force 1**. Most of the **Casting** explosions (**34**) occurred during the Casting of sow or mold Casting, with **two** being **Force 2**. Slightly less, (**27**) incidents, occurred with **DC Slab** and **Billet Casting, 3 being Force 2**. There was **one Force 1 strip/coil Casting** incident.

Figure 25 shows **DC Casting** incidents by drop segment for years 1980 through 2023. The historical data is similar to the 2023 data shown in **Figure 24** in that most explosions occur during **Start-up**. Starting in 2021, the total **End-of Cast** explosions outnumber the total **Steady-state** explosions**.**

For 2023, **Figure 26** provides the major causes of the **62 Casting** incidents. They are listed by cast stage for VDC **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-bleed-outs, and equipment failures. The main DC **Casting** termination issues were wet/rusty drain pans and wet tools. The main sow and mold **Casting** incidents were due to wet, unpreheated and cracked. Drain pan rust and debris was the main reason for the strip/coil **Casting Termination**.

Figures 27 and **28** were new charts started in 2021 that provide additional analysis of the primary causes of **Casting** explosions, looking at data from 2015 and forward. **Figure 27** shows the major causes for all Force Levels, while **Figure 28** is data for only **Force 2** and **3 Casting** explosions. By a factor of 4X, the highest number occur during sow or mold **Casting** due to wet, cracked or rusty molds (**235**) compared to the next highest, VDC **Cast Start** explosions due to excessive curl, hang-ups and bleed-outs (**58**). When only **Force 2** or **Force 3** explosions are considered, **Figure 28**, then VDC **Start**, for these same reasons, has the highest number (**16**) with VDC **Termination** explosions due to wet and rusty drain pans being the next highest (**15**). These are followed by DC **Cast Start** due to wet/rusty bottom blocks (**11**) and sow and mold Casting with wet/cracked/rusty molds (**10**).

There were **42 Transfer** explosions (34 **Force 1** and **8 Force 2**) in 2023, as shown in **Figure 14**. The reasons for these explosions are provided in **Figure 29**. Wet hand, furnace tools or other equipment accounted for **25** of these incidents, including **2 Force 2**. Wet, rusty skim or drain pans accounted for **14 Transfer** incidents, including **4 Force 2**. There were also **three** incidents due to metal on the wet floor, including **one Force 2**.

Figure 30 provides a bar chart showing the equipment involved in the **927 Transfer** explosions for the years 1980 through 2023. The highest number of **Transfer** explosions are related to **Drain Pans**, followed by **Trough** and then **Other**.

Like **Figures 27 and 28** presented above for **Casting**, **Figures 31 and 32** were first presented in 2021, providing further detail regarding the major causes of **Transfer** explosions. **Figure 31** provides the data regarding the major causes of all **Transfer** explosions for the years **2008 through 2023** (excluding 2011), while **Figure 32** provides this information for only **Force 2** and **3** explosions. **Figure 31** indicates that the highest number of **Transfer** incidents are related to wet/rusty drain pans (**148**) followed by wet tools (**131**). Wet/rusty drain pans are the leading cause of **Force 2** and **3** explosions (**19**) with wet refractory or equipment second (**8**).

When combining **Casting** and **Transfer 2023** incident data for wet/rusty drain pans, this source of explosions accounts for **20%** (21 of 104) of all the explosions in these two operations. In **2022**, it was also **20%**.

Injuries by Operation (**Melting, Casting, Transfer and Other**) resulting from the **156** explosions in **2023** is provided in **Figure 33** showing that there were **16 Minor** injuries and **1 Serious** injury. **Transfer** accounted for the highest number, **nine Minor** and **one Serious**. **Casting** had **five Minor. Melting** and **Other** each had **one Minor.**

Figure 34 provides **Injury by Operation** data for 1980 through 2023. The highest number of **Minor** and **Serious** injuries have occurred in **Casting** operations. **Melting** operations account for the highest number of **Fatalities,** as well as the highest number of **Force 3** explosions as seen In Figure 15 as well as the highest number of **Force 3** explosions as seen in **Figure 15**. It should be noted that a significant number of injuries have occurred in relatively straightforward **Transfer** operations, including **82 Serious** and **seven Fatalities.**

As noted above, the highest number of **Fatalities** and **Force 3** explosions occur during **Melting** operations. Initially presented in the 2021 report was new data analysis investigating if there was a correlation between the “time of year” vs. the number of incidents. **Figure 35** provides this **Melting** incident updated to include the last seven years (2017 through 2023). All causes of **Melting** incidents were part of the analysis, which primarily included wet or contaminated charge materials and wet equipment and tools.

The additional 2023 data continued to support the analysis presented previously that showed higher explosion rates in some of the “winter months”, especially January through March. This result would be expected since at this time of the year in the northern hemisphere, where most of the incident reports originate, there is a higher potential for winter weather of snow, ice, and rain to contaminate scrap and sows. Looking at earlier “winter months”, November is fourth highest in the year, slightly lower than March. December explosion are much lower and more similar to Summer months. The lower amount of

December incidents may be explained by more maintenance and holiday shutdowns/slowdowns occurring typically during 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 especially during the months of January through March, which may have relaxed during the summer months.

Incident frequency by month is also provided in **Figures 36 and 37** 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. Also, December does not show the same lower frequency as was observed in the **Melting** data. Conversely, for **Transfer**, the highest number er of incidents occur in December. The lowest **Transfer** incidents occur in May through July, which cannot be easily explained with this being a high vacation time of year. For **Casting**, the lowest number of incidents occurs in February with a number of months through the year showing a similar high volume of incidents.

It should be noted that the incident database used for these charts does not include month of the year data 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 by some companies.

Figures 38 and 39 provide incident data versus the type of **Process Plant** (**Reduction, Extrusion, Rolling** and **Recycling**) for 2023 and for 1980 through 2023 respectively.

In 2023, the highest number of incidents occurred in **Reduction** operations (**84**), compared to the next highest in **Rolling** operations (**36**). **Reduction** and **Rolling** also had the highest number of **Force 2** incident, **nine** each. **Recycling** reported **seven Force 2** explosions and **Extrusion 1**. For the entire reporting period, 1980 through 2023, the highest number of incidents have occurred in **Reduction** and the second highest are in **Rolling**, which by far has reported highest number of **Force 3** explosions.

The main causes of the 84 **Reduction** facility explosions in 2023 are presented in **Figures 40** and

41. They are listed by **Melting**, **Casting**, **Transfer** and **Reduction** incidents. **Melting** incidents were related to wet charging materials (scrap, RSI, sow and alloy) and wet tools. Most of the **Reduction** facility incidents occurred during **Casting**, primarily sow or mold **Casting**. The primary reason in sow **Casting** was for cracked, wet or rusty molds. Start-up VDC **Casting** incidents were related to wet refractory and equipment. **Termination** VDC **Casting** incidents occurred due to wet/rusty drain pans and wet tool. **Transfer** and **Reduction** incidents were primarily related to wet/rusty equipment, tools and drain or skim pans as well as wet alumina and anode.

Figure 42 provides the main causes for **21 Recycling** incidents in 2023**,** which is a significantly lower amount compared to the **49 Recycling** incidents reported in 2022. Most incidents occurred in **Melting** (**14**), including **six Force 2** explosions. All incidents were due to wet charge material: scrap, sow and dross. The other **Force 2** incident was the result of a wet sow mold.

In **Reduction** facilities there were **10 Minor** and **1 Serious** injury in 2023, as shown in the **Figure 43** bar chart. **Transfer** operations accounted for six injuries, including the **1 Serious**, due to a wet crucible. Wet

sampling tools accounted for **five Minor Transfer** injuries. There were **four Casting** injuries with three of the four occurring during cast VDC **Termination**, related to a wet drain pan, wet tool and SOP procedure.

There were only **two Rolling** plant injuries in 2023, both **Minor**, which occurred during **Transfer** operations, as shown **Figure 44**. One was due to a wet crucible, the other due to a wet drain pan.

For **Extrusion** in 2023**, Figure 45**, there were **three** injuries, all **Minor**, **two** during **Transfer** and **one** during **Melting** operations. Both **Transfer** injuries were the result of a wet tool and wet scrap accounted for the **Melting** injury.

There was one 2023 **Minor** injury in **Recycling (Figure 47),** during VDC cast **Termination**, related to a wet drain pan. There were **21 Recycling** incidents in 2023.

Figure 47 summarizes the 2023 injury data by type of **Process Plant** and **Figure 48** shows this same data for 1980 through 2023.

Starting last year there were four new charts introduced, **Figures 29 and 50**, that provided further incident and injury data analysis of the four **Process Plants** (**Reduction, Extrusion, Rolling** and **Recycling**). These charts provide incident, injury and injuries per incident rates for these four plant categories for the past 12 years (2012 through 2023). Severity of injury (**Minor, Serious** and **Fatal**) was not investigated separately in this analysis.

Figures 49 and **50** show that there is a significantly higher number of **Reduction** plant incidents compared to the other three plant types. However, starting in 2016 there was a large drop in the number of **Reduction** plant injuries and the incident per injury rate. Both the number of injuries and injury rate have remained below 2016 and prior values through 2023. Reporting of **Recycling** plant incidents increased significantly starting in 2016 from approximately five per year to an average of 35 per year over the past seven years. Along with the higher number of injuries during these eight years, the injury rate variability has varied between 0% to 5%. In comparing **Reduction** and **Recycling** plant injury rates over the last eight years, they averaged 7% and 4% respectively, with significantly more incidents in **Reduction** plants.

Both the **Reduction** and **Recycling** plant injury rates are lower than the **Extrusion** and **Rolling** plant rates, as shown in **Figure 50**. The number of reported incidents is approximately 3-4X higher in **Rolling** plants compared to **Extrusion** plants. The **Extrusion** injury rate is often the highest of the four plant types and is extremely variable, ranging from 0% to 87%. This may be related to the very low number of **Extrusion** incidents that are reported compared to the other three plant types.

Rolling plant injuries and injury rates are high compared to **Reduction** and **Recycling.** The number of **Rolling** incidents were very low for the years 2012 through 2014, averaging ten per year in that time frame, similar to **Extrusion**. From 2015 through 2023 the average number of **Rolling** incidents increased to 41 per year with an average injury rate of 10%. This average **Rolling** injury rate is slightly higher than **Reduction** (**7%**) and more than 2X higher than **Reduction** (**4%**).

The newer plant incident and injury data indicates that further investigation, analysis and discussion should be pursued to determine why higher injury rates are observed in **Rolling** and **Extrusion** compared to **Reduction** and **Recycling.** A possible explanation may be the higher application of the billet and slab

VDC Casting processes in **Rolling** and **Extrusion** compared to **Reduction** and **Recycling**. Additional understanding could lead to reducing injury rates.

The Aluminum Association Molten Metal Incident Report Form for use in reporting incidents can be found at: https://www.aluminum.org/health-safety

R T Richter – September 2024

Annual Summary of Molten Metal Incidents in 2023

September 2024

The Aluminum Association

Explosion Rating Force Criteria

Guidelines	Force 1	Force 2	Force 3
Property Damage	None	Minor	Considerable
Light	Minimal	Flash	Intense
Sound	Short cracking	Loud Report	Painful
Vibration	Short and sharp	Brief rolling	Massive structural
Metal Dispersion	<15 feet	>15 to 50 feet	>50 feet

TABLE 1. Explosion Rating Force Criteria **Sep. 2024**

Incidents by Year
1981 – 2023 (Total 4693)

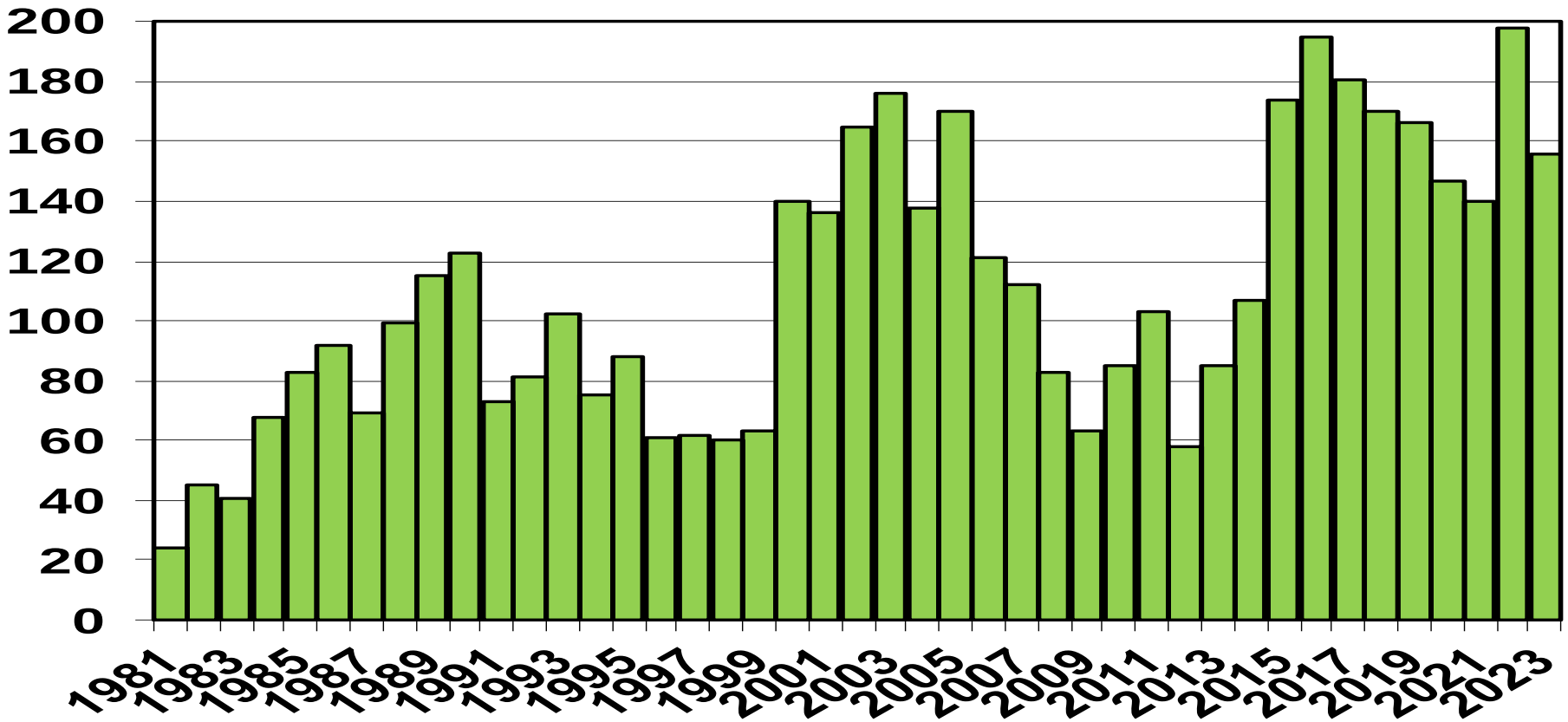


FIGURE 1. Incidents Reported For The Period 1981 – 2023 Sep. 2024

Incidents by Force Level
1981 – 2023 (Total 4693)

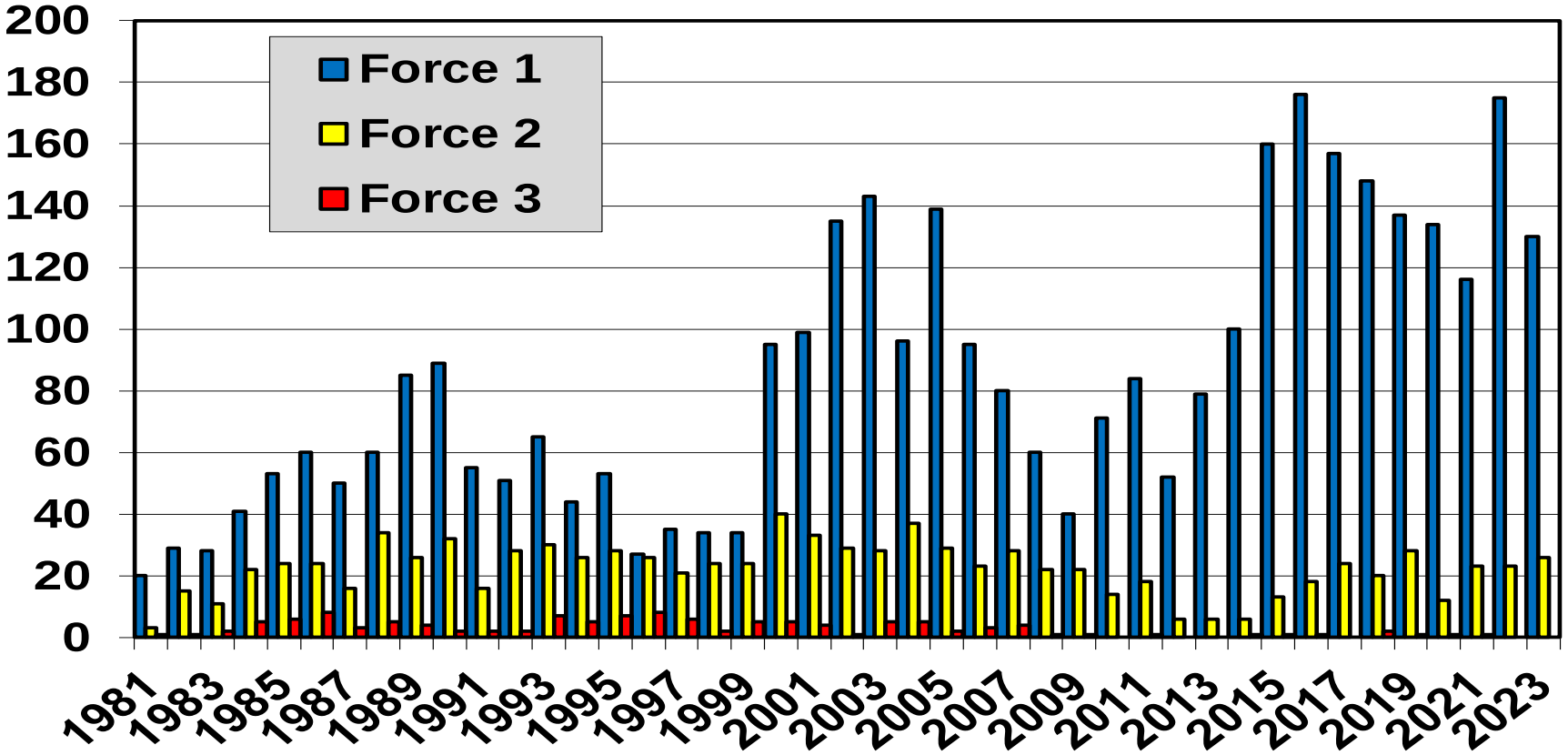


FIGURE 2. Incidents By Force Level 1981 – 2023 Sep. 2024

Incidents by Force Level
1981 – 2023 (Total 4693)

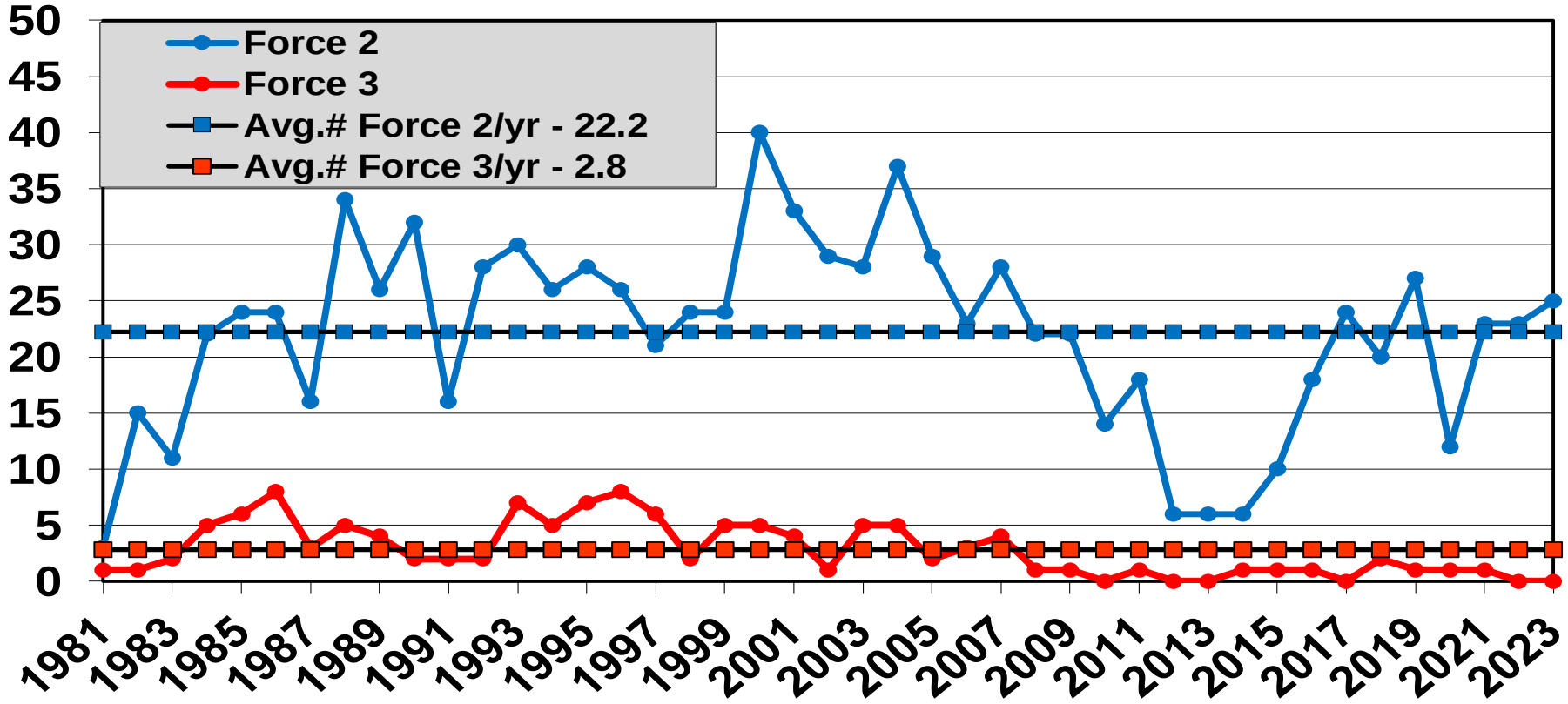


FIGURE 3. Incidents By Force Levels 2 & 3 For 1981 – 2023 Sep. 2024

Force 3 Incidents Only
1981 – 2023

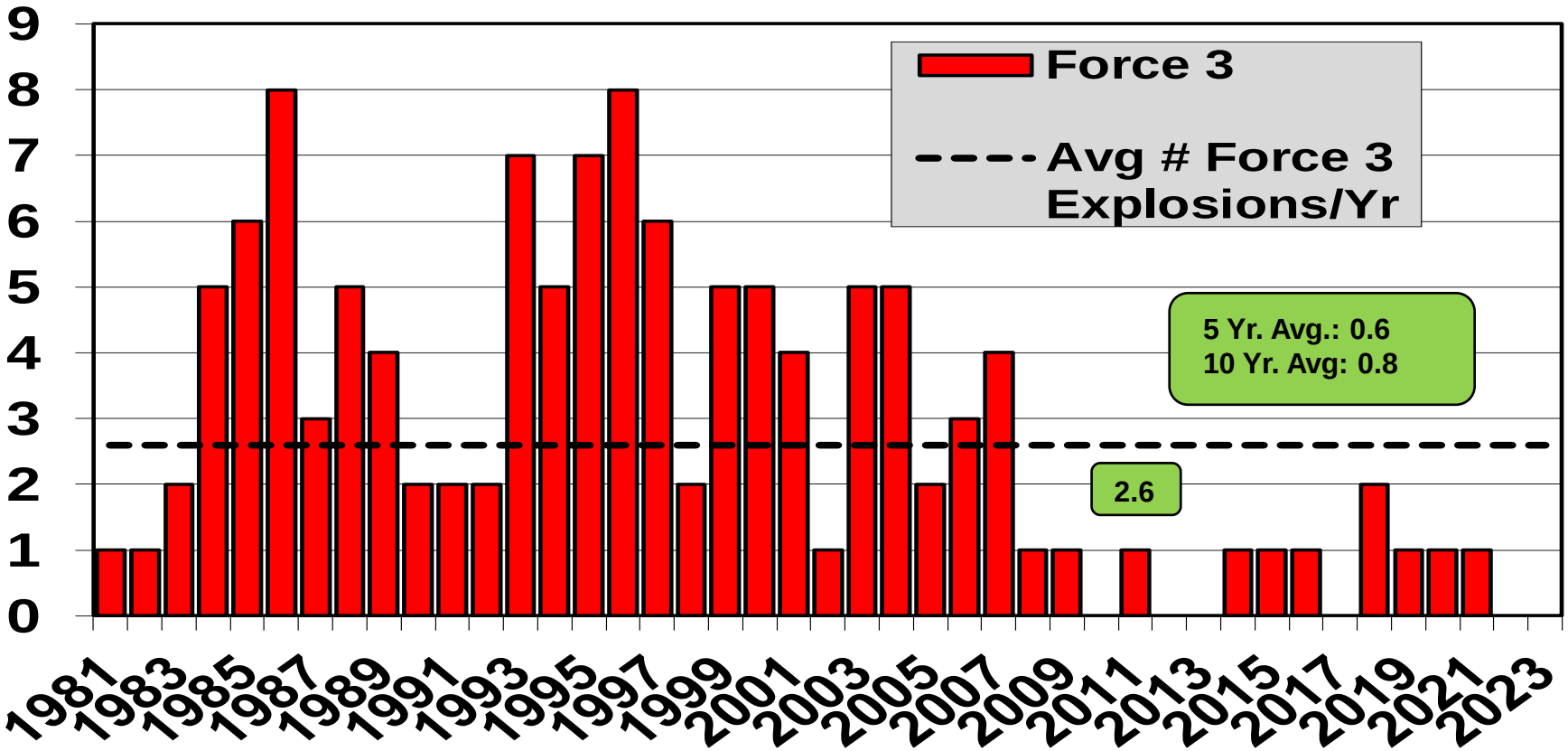


FIGURE 4. Force 3 Incidents For 1981 – 2023 **Sep. 2024**

Incidents by Force Level
1981 – 2023 (Total 4693)

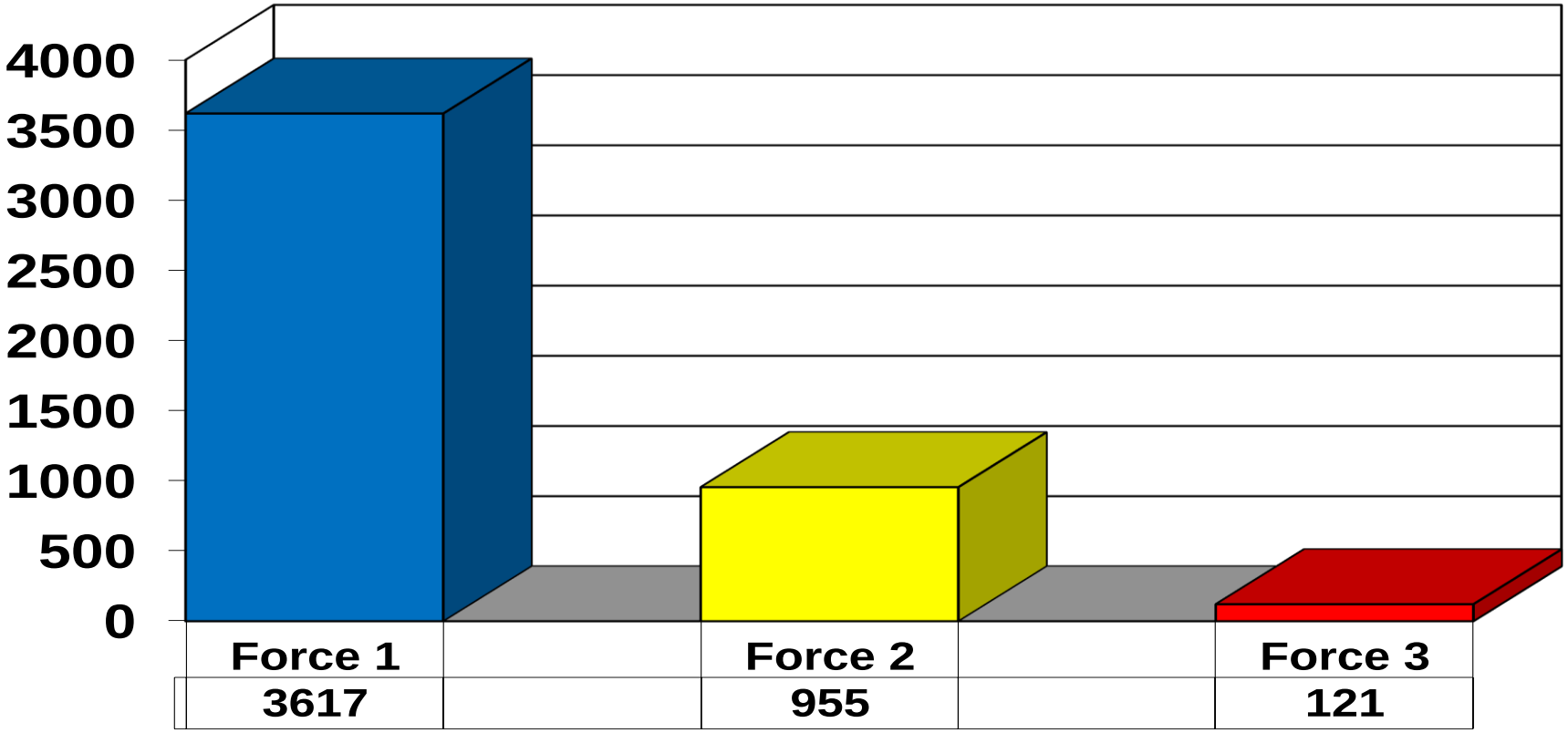


FIGURE 5. Incidents By Force Level 1981 – 2023 **Sep. 2024**

All Force Levels by Percentage 1981 – 2023

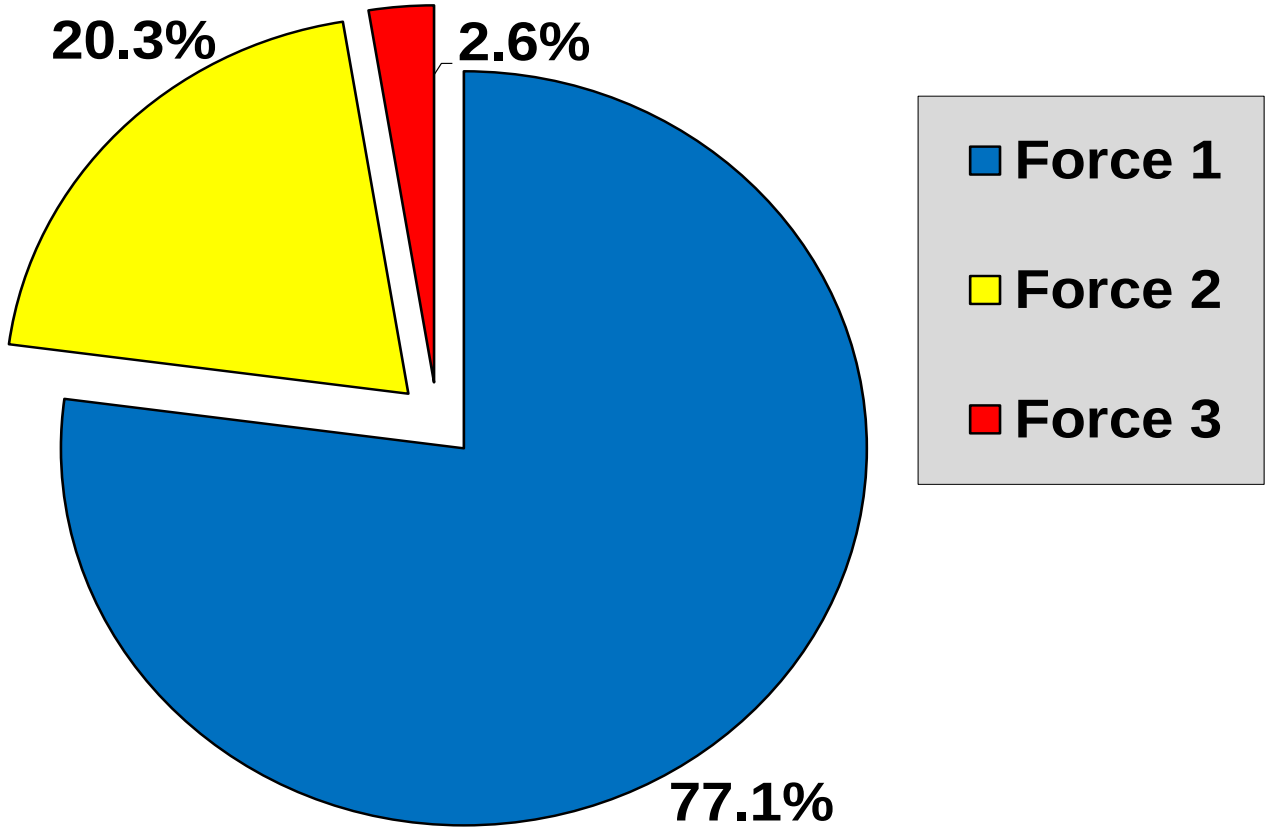


FIGURE 6. All Force Levels By Percentage 1981 – 2023 Sep. 2024

Injuries from Incidents 1981 – 2023 (Total 1645)

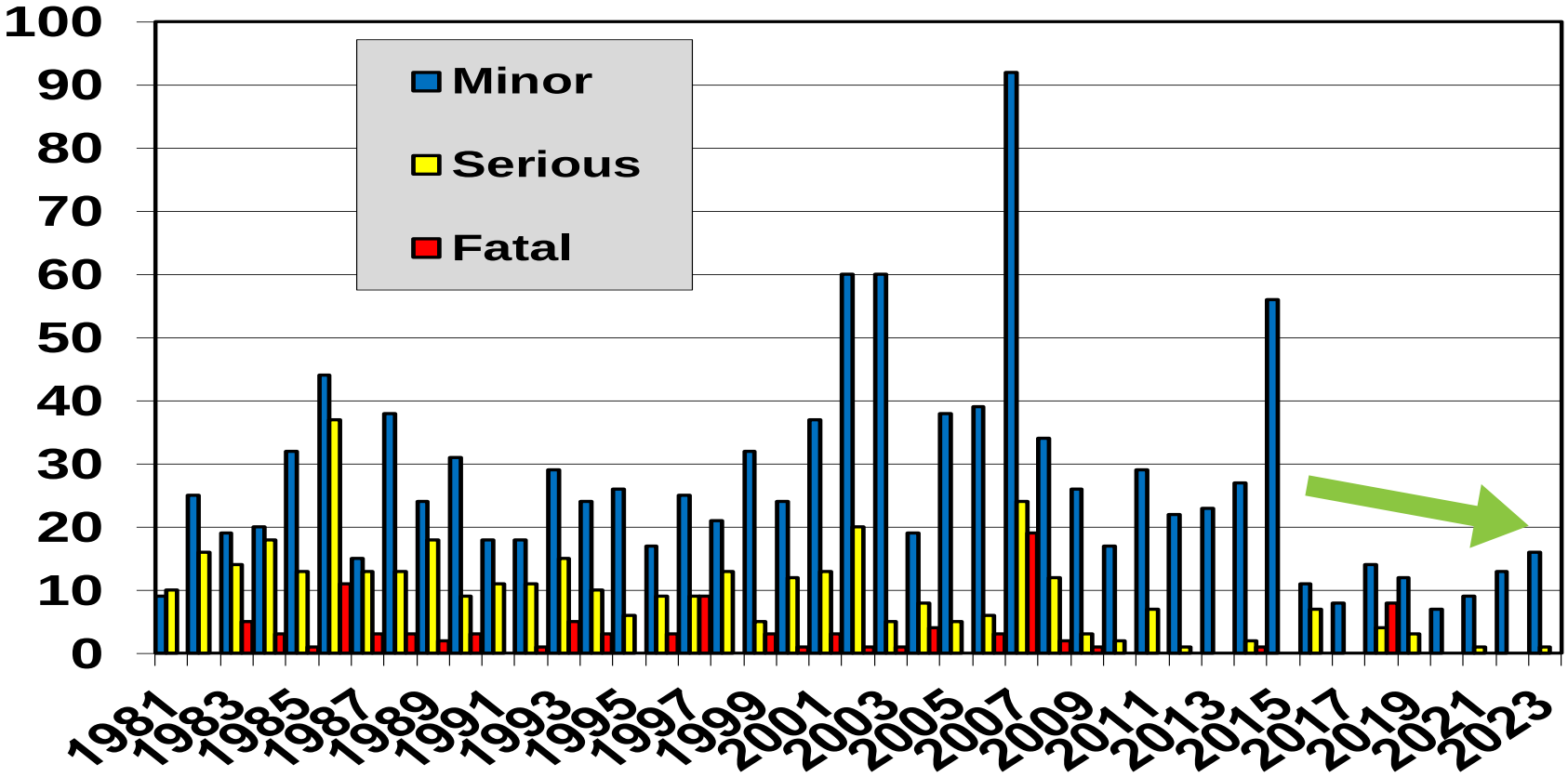


FIGURE 7. Injuries From Incidents For 1981 – 2023 **Sep. 2024**

% Injuries per Total Annual Incidents 2001 – 2023 (Total 836 Injuries)

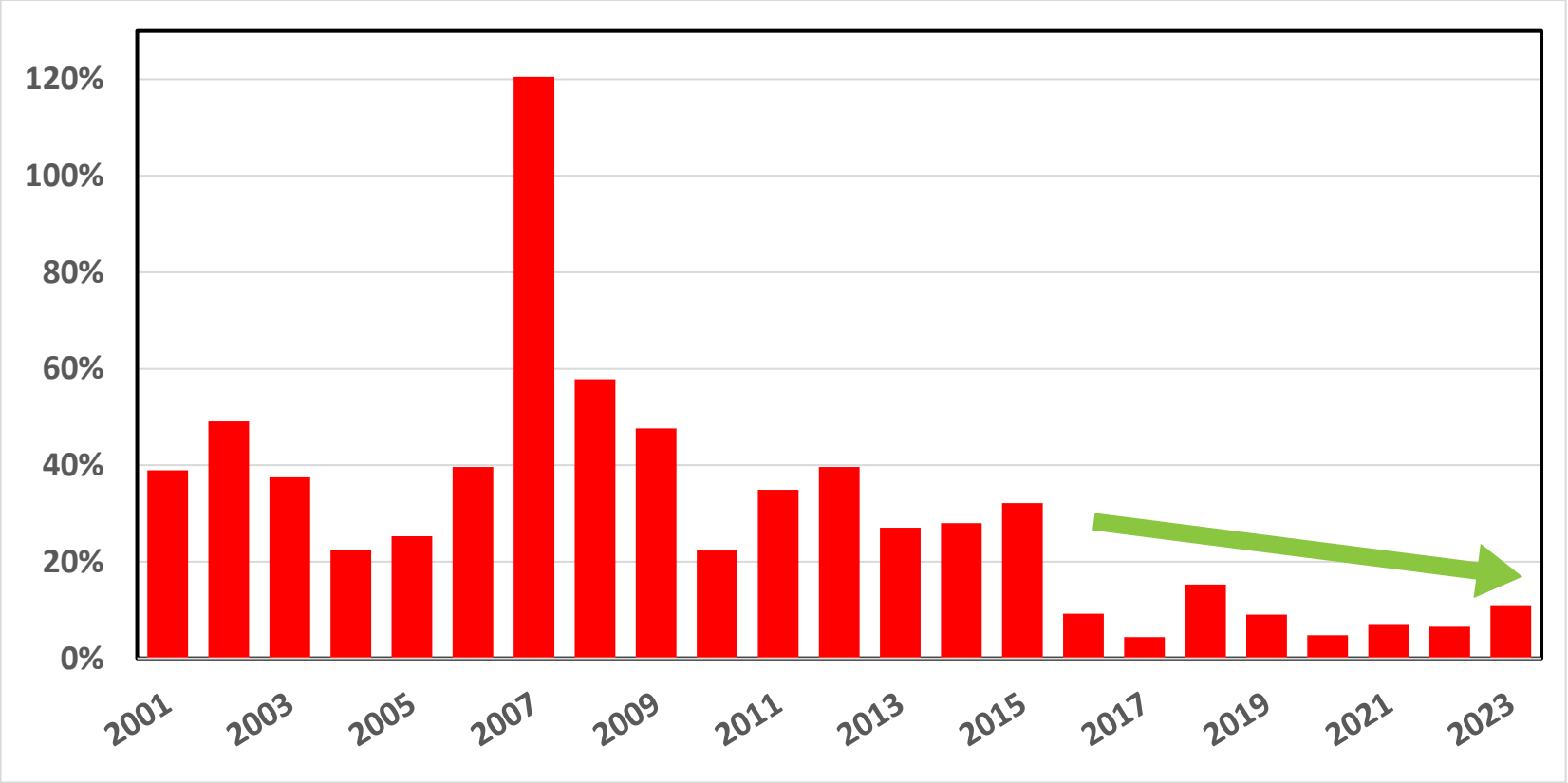


FIGURE 8. % Injuries/Total Annual Incidents 2001 – 2023 **Sep. 2024**

Average # of Injuries / Year from Explosions

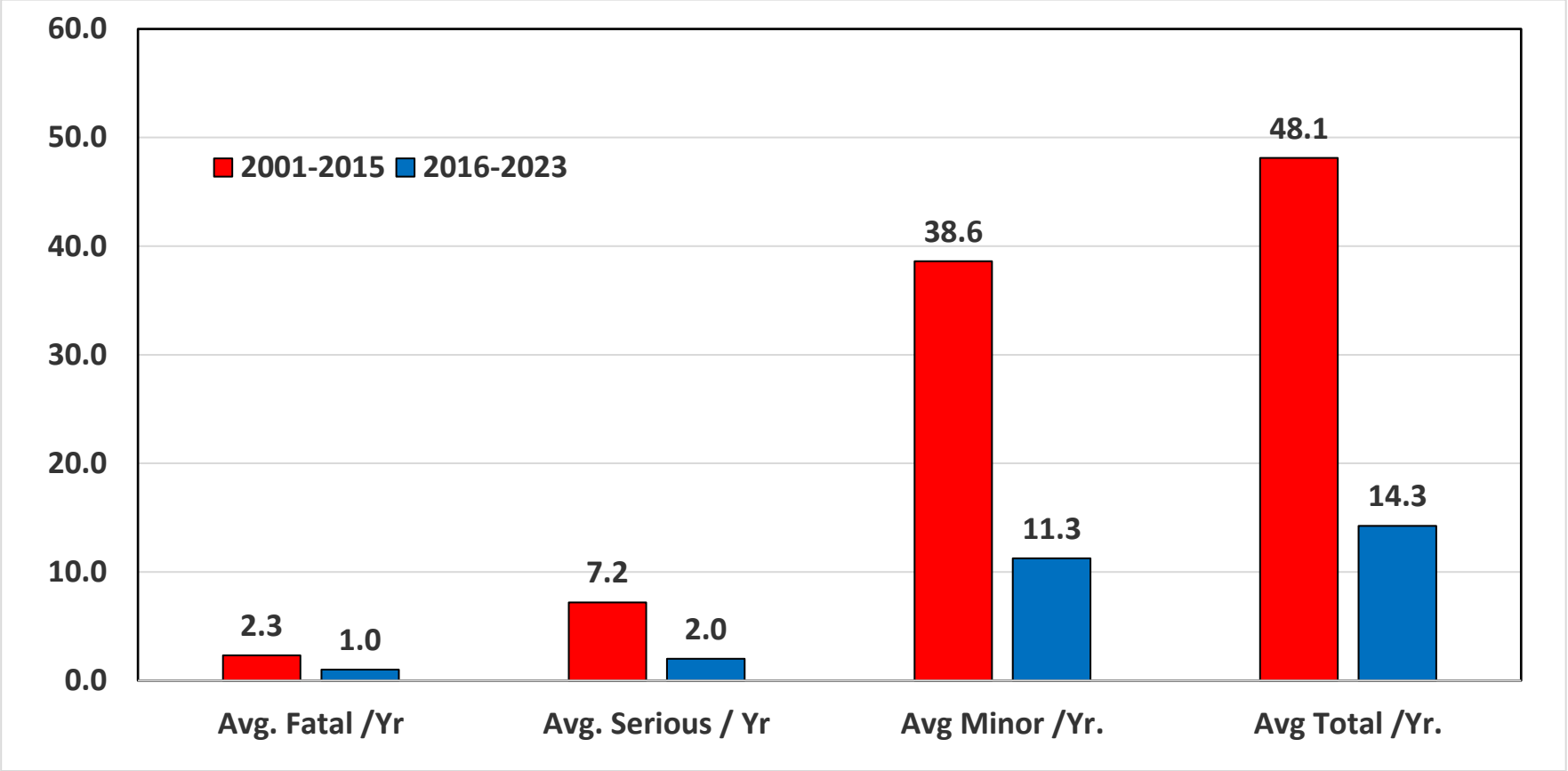


FIGURE 9. Avg. # Injuries / Yr. For 2001-2015 & 2016-2023 Sep. 2024

Injuries by Severity – Total 1645
1981 – 2023

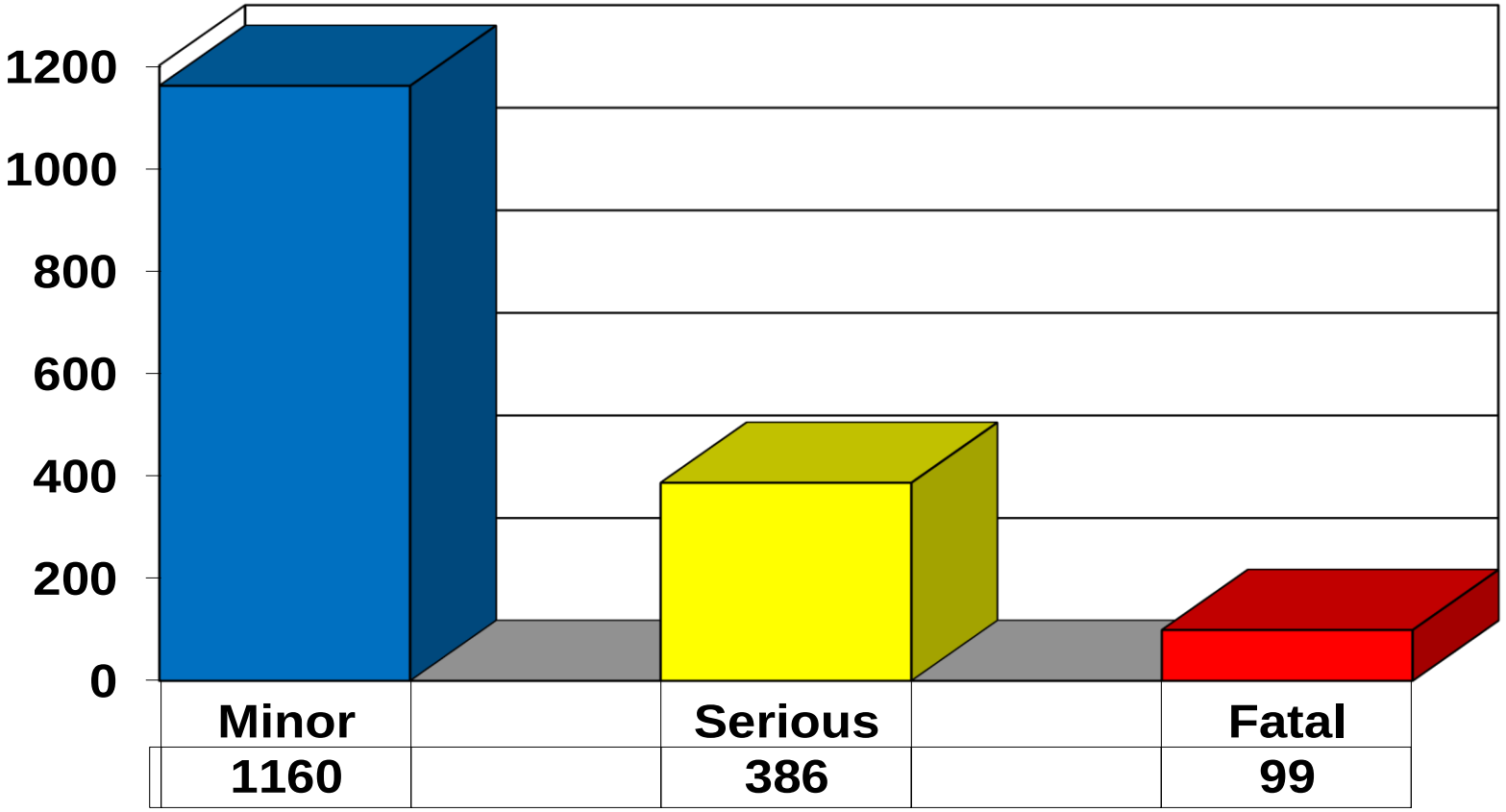


FIGURE 10. Injuries By Severity For 1981 – 2023 Sep. 2024

Injury Levels by Percentage
1981 - 2023

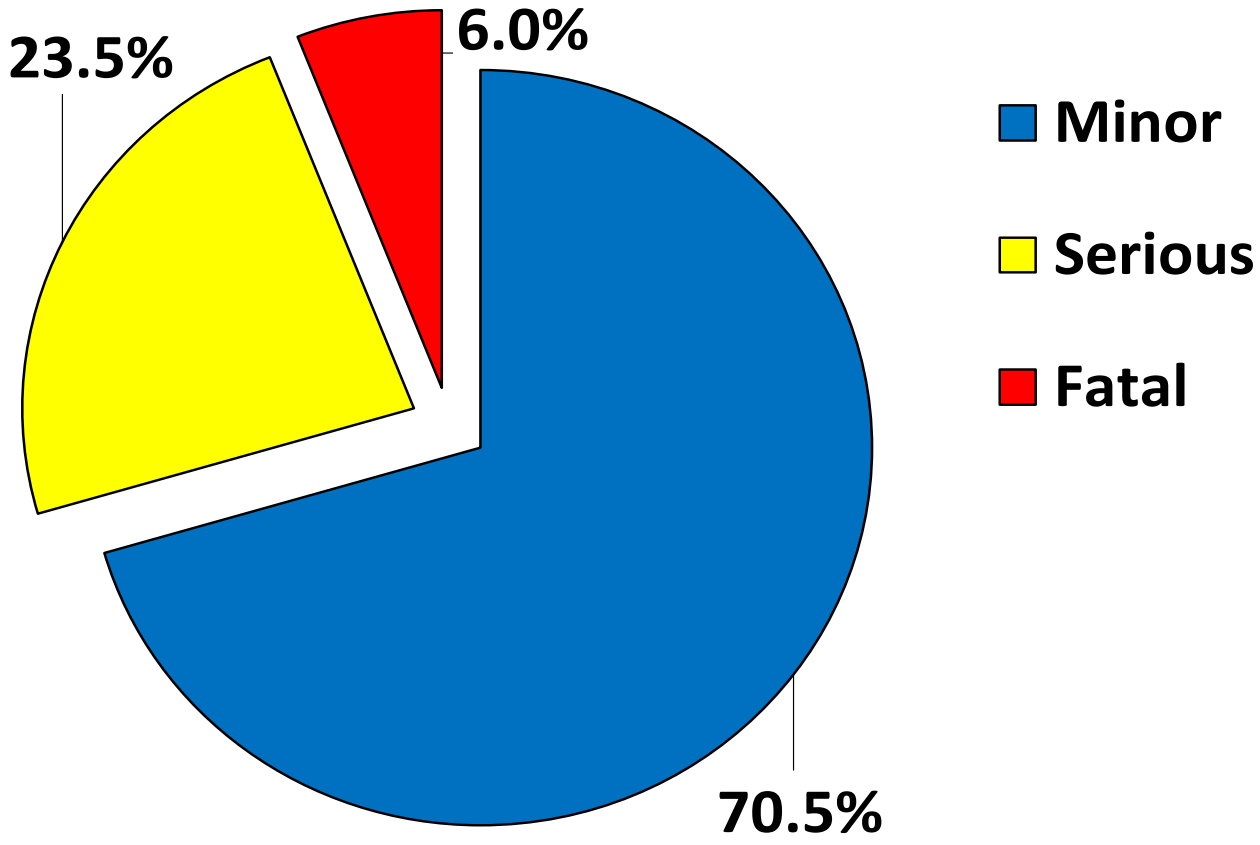
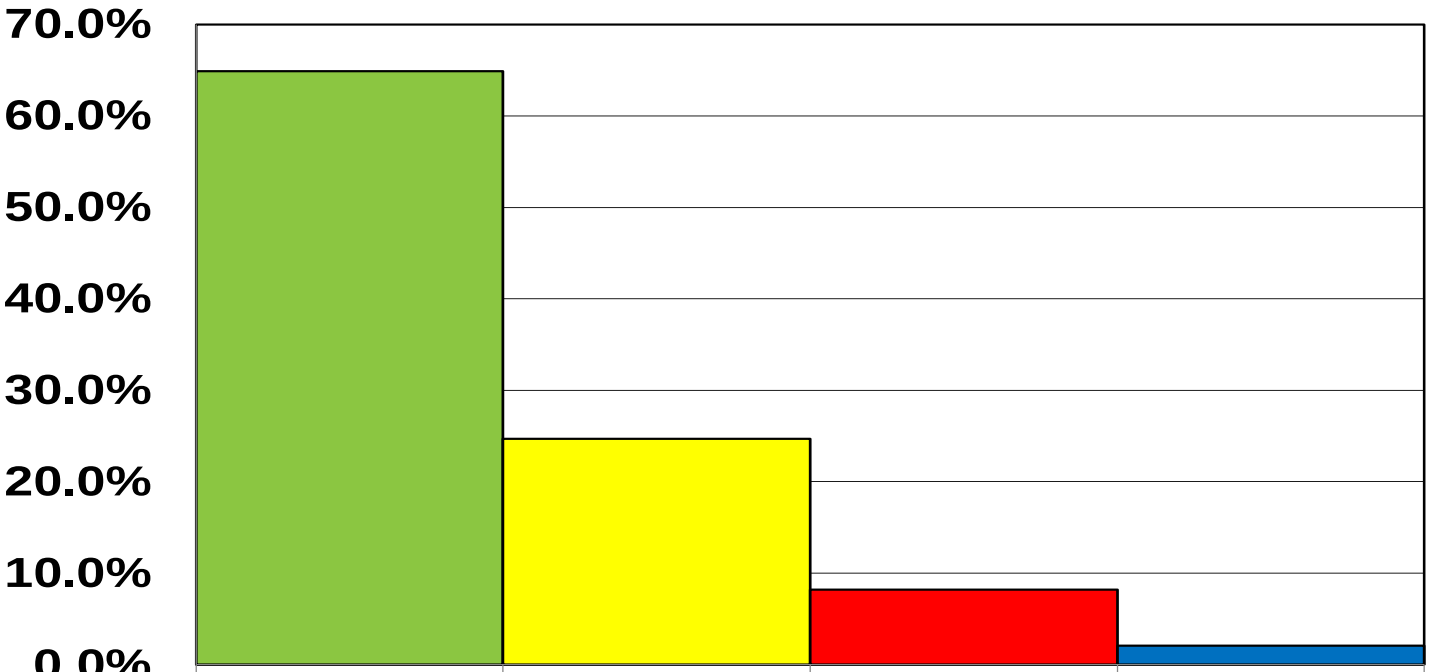


FIGURE 11. Injuries Levels By Percentage For 1981 – 2023 **Sep. 2024**

Injury Risk per 100 Explosions
1981 - 2023



	No Injury	Minor	Serious	Fatal
%Injury / 100 Explosions	64.9%	24.7%	8.2%	2.1%

FIGURE 12. Injury Risk Per 100 Explosions For 1981 – 2023 Sep. 2024

Fatalities from Explosions
1981 - 2023

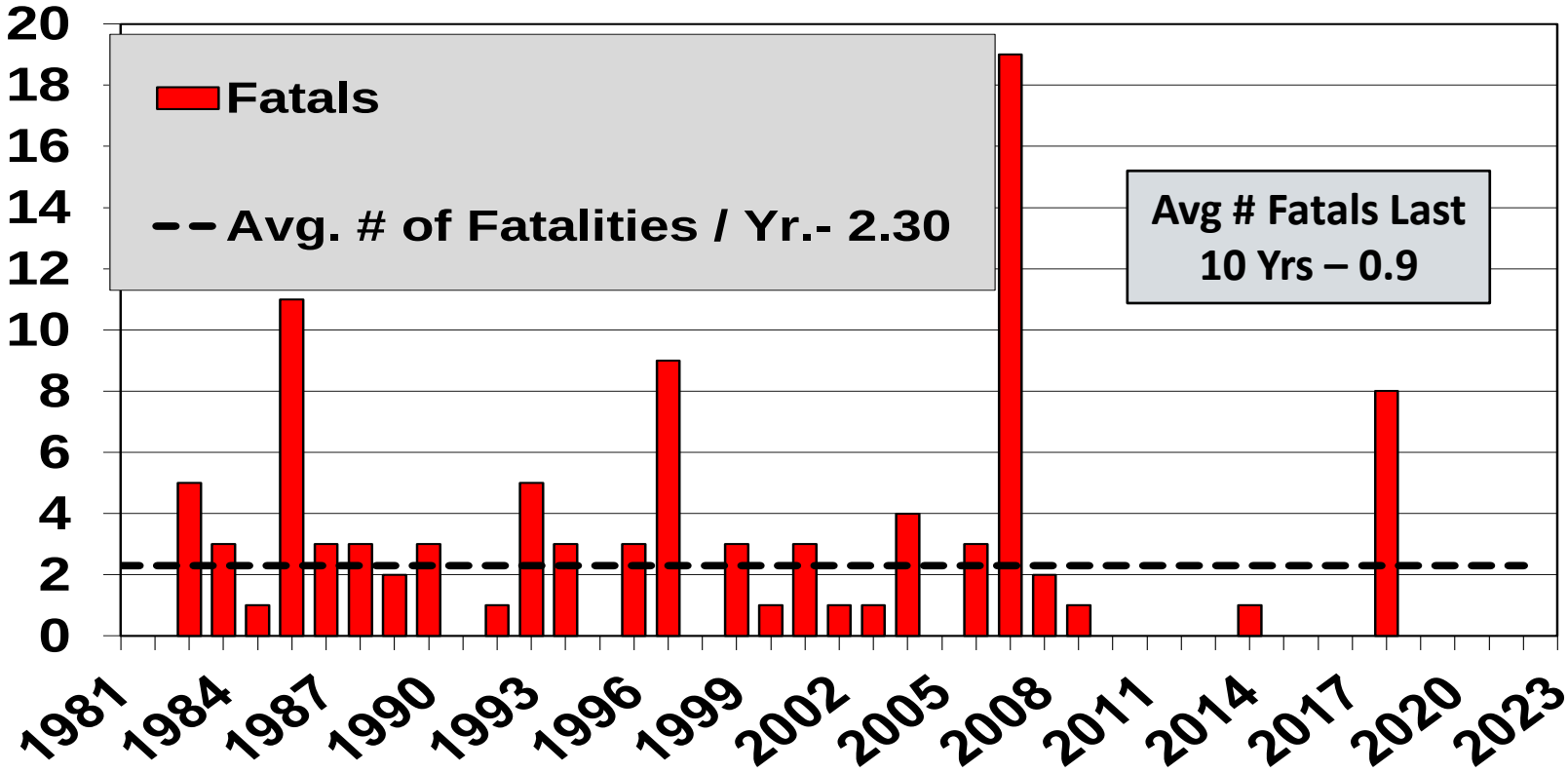
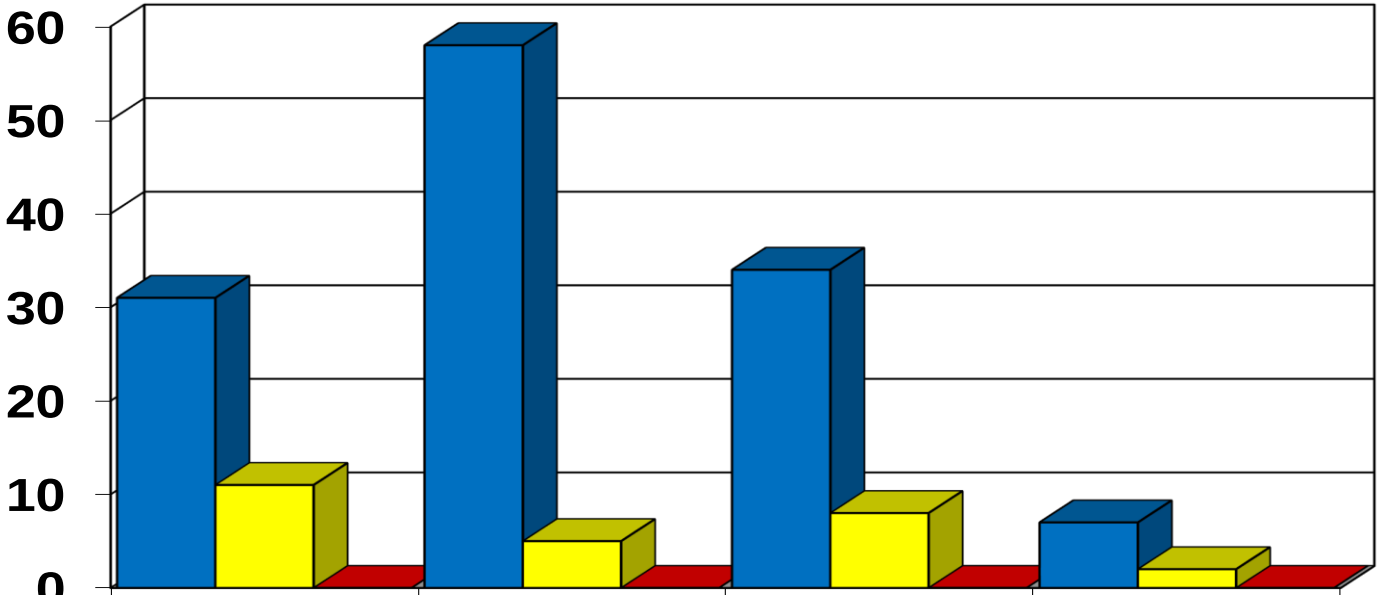


FIGURE 13. Fatalities From Explosions For 1981 – 2023 Sep. 2024

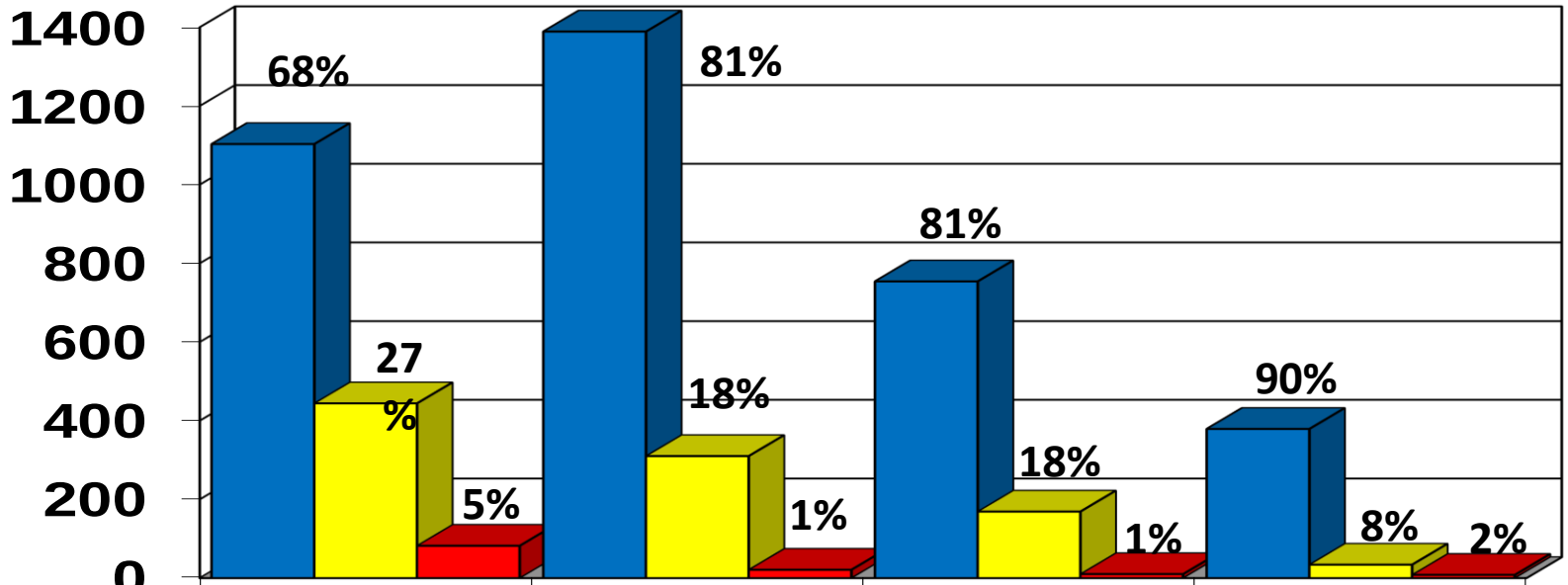
Force Level Incidents by Operation – 2023



	Melting	Casting	Transfer	Other
Force 1	31	58	34	7
Force 2	11	5	8	2
Force 3	0	0	0	0

FIGURE 14. Force Level Incidents By Operation For 2023 **Sep. 2024**

Force Level & % Incidents by Operation 1980 – 2023



	Melting	Casting	Transfer	Other
Force 1	1103	1389	754	379
Force 2	444	310	169	34
Force 3	82	21	10	8

FIGURE 15. Force Level & % Incidents By Operation For 1980 – 2023 Sep. 2024

Melting Injuries and Incidents
1990 – 2023 (Total 335 Injuries)

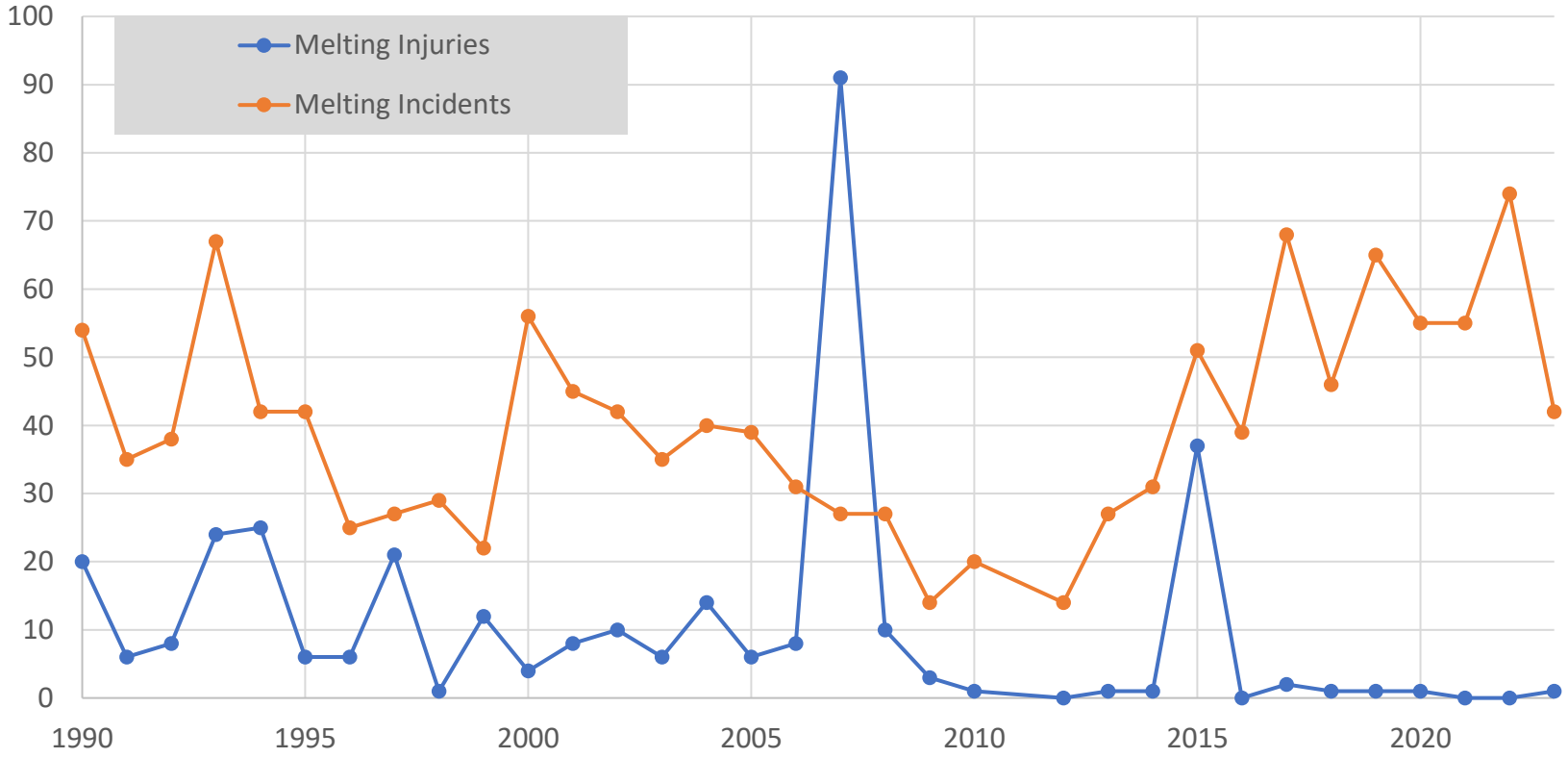


FIGURE 16. Melting Injuries and Incidents 1990 – 2023 Sep. 2024

Melting Injuries per Incidents
1990 – 2023

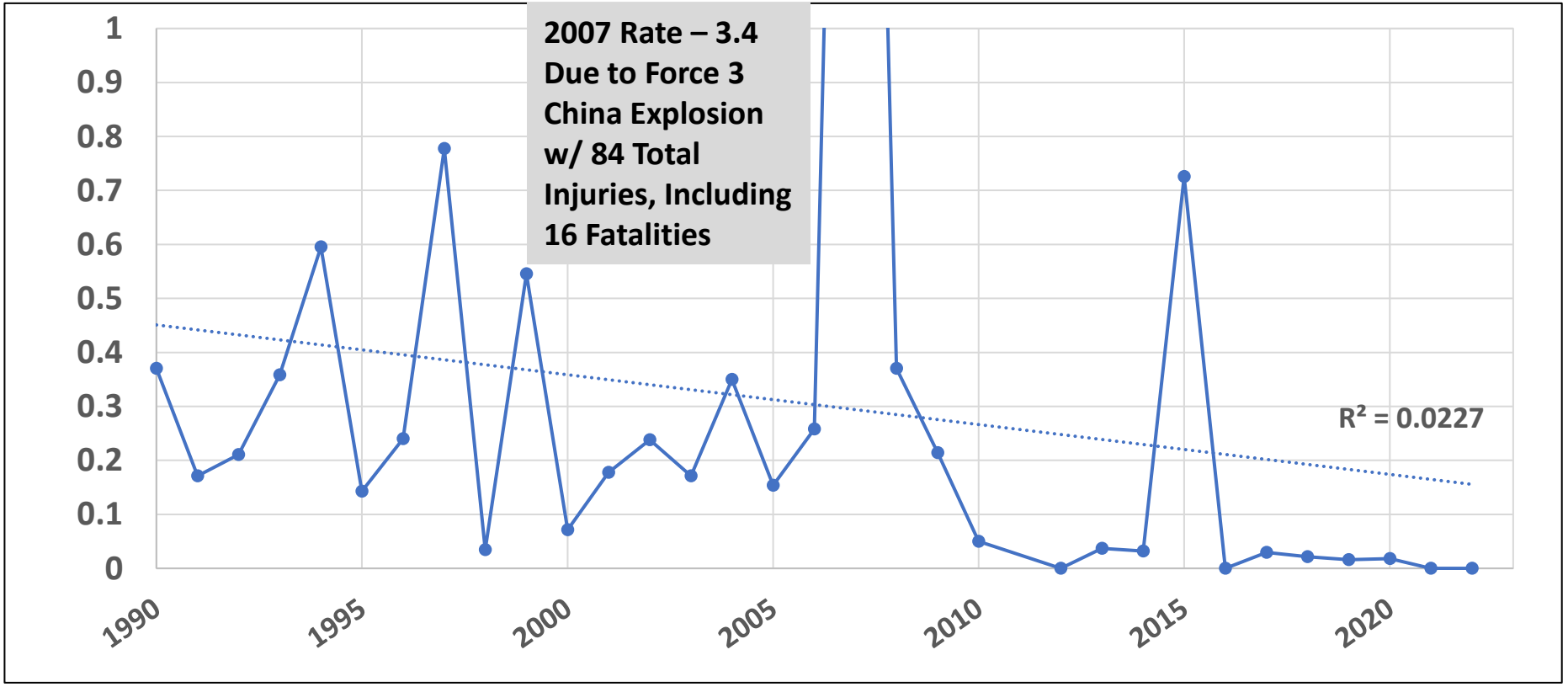


FIGURE 17. Melting Injuries Per Incidents 1990 – 2023 Sep. 2024

Casting Injuries and Incidents
1990 – 2023 (Total 348 Injuries)

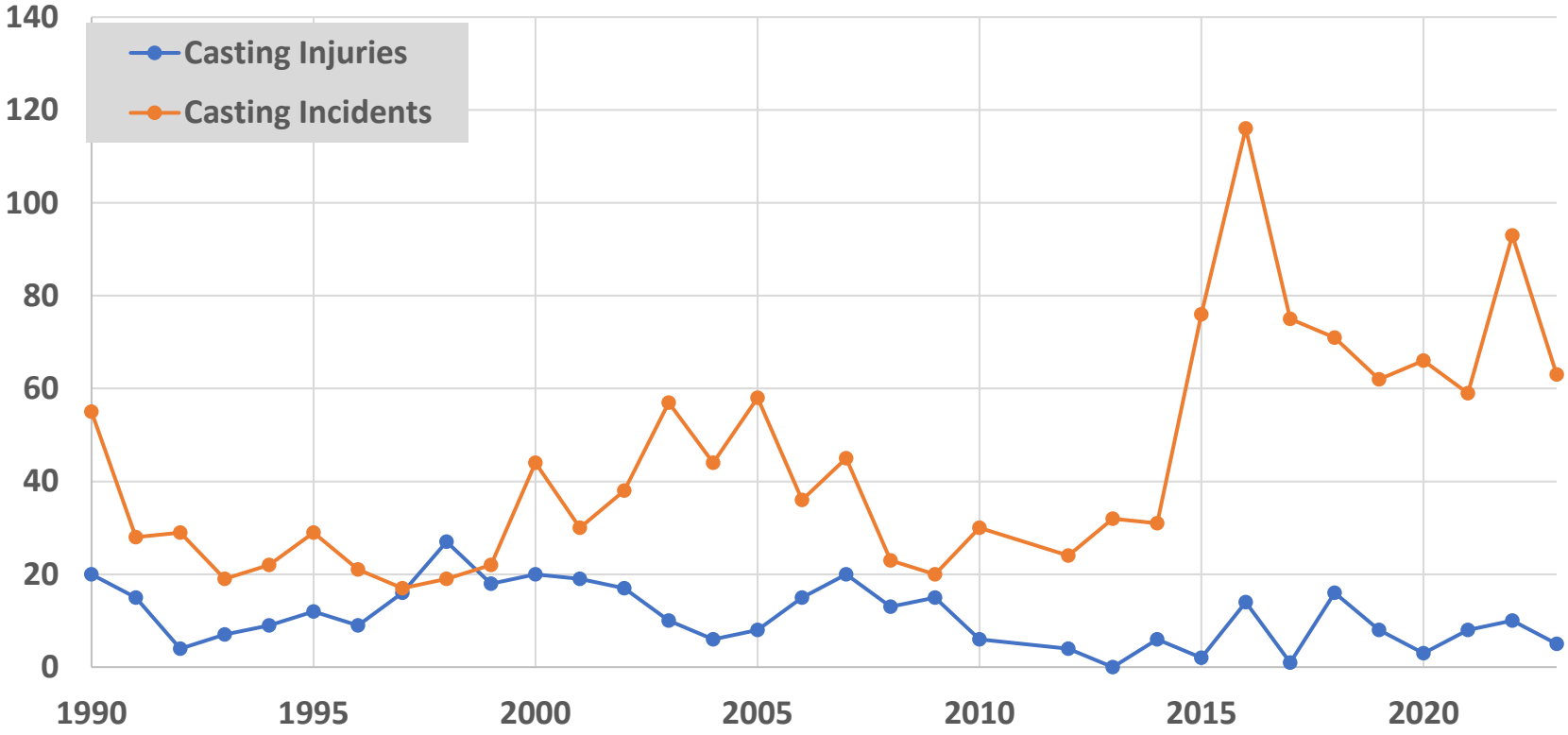


FIGURE 18. Casting Injuries and Incidents 1990 – 2023 **Sep. 2024**

Casting Injuries per Incidents
1990 – 2023

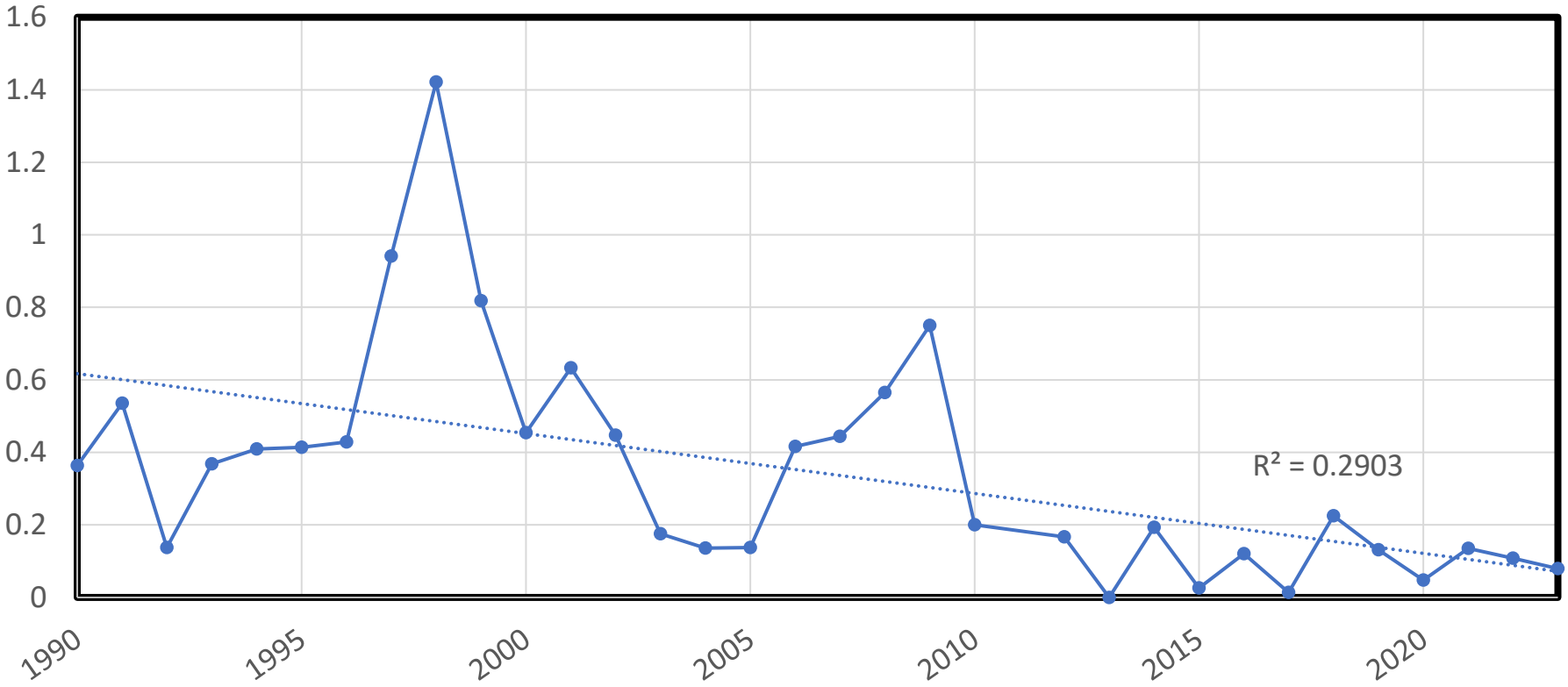


FIGURE 19. Casting Injuries Per Incidents 1990 – 2023 Sep. 2024

Transfer Injuries and Incidents
1990 – 2023 (Total 260 Injuries)

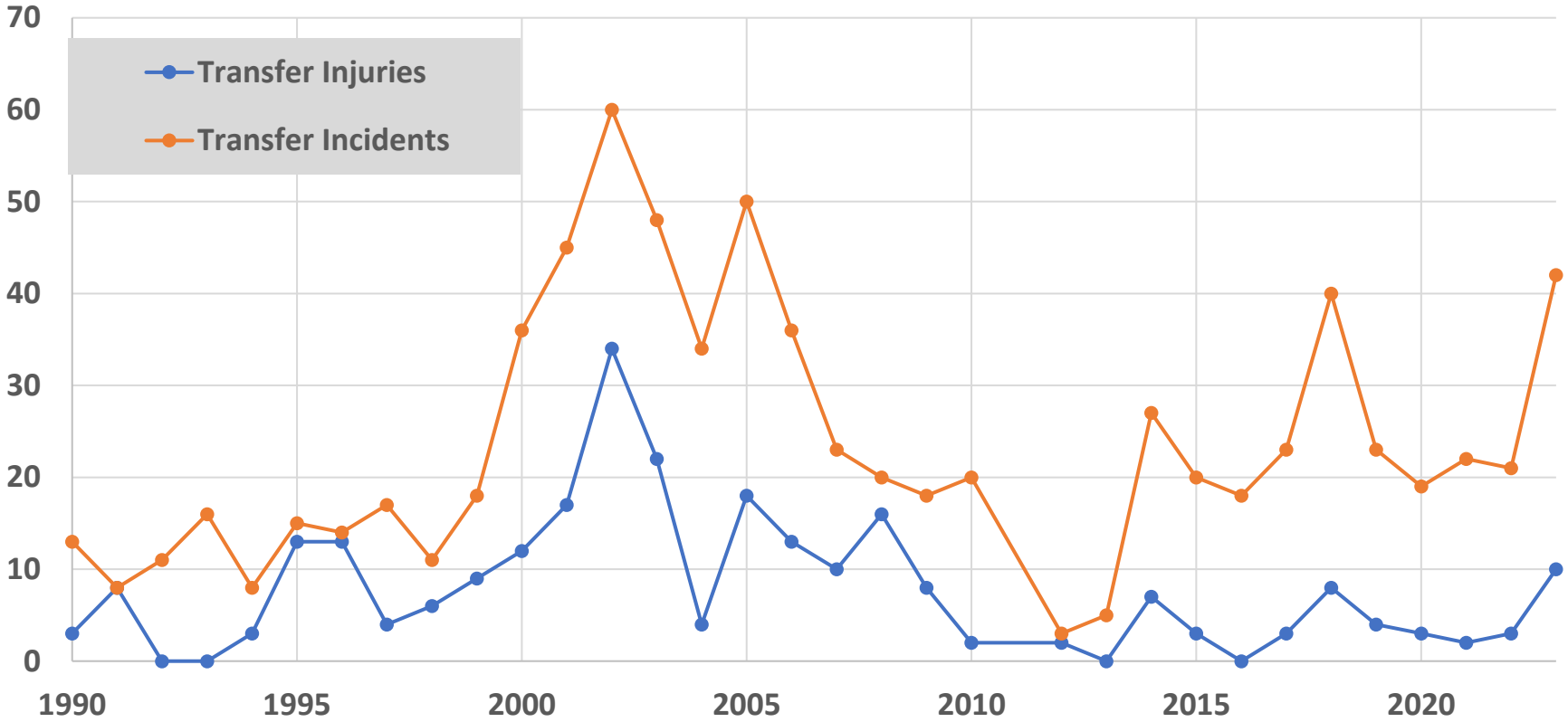


FIGURE 20. Transfer Injuries and Incidents 1990 – 2023 Sep. 2024

Transfer Injuries per Incidents
1990 – 2023

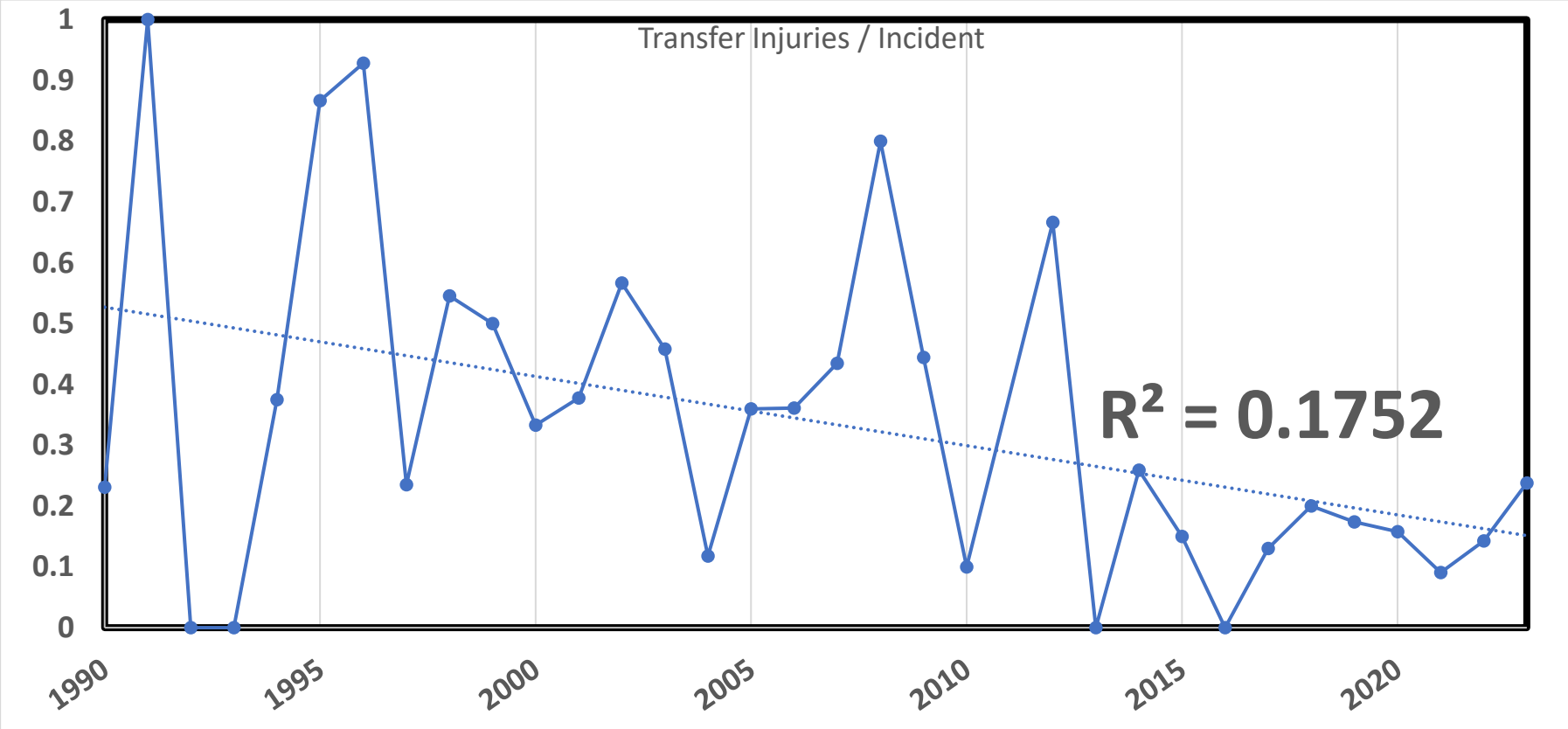
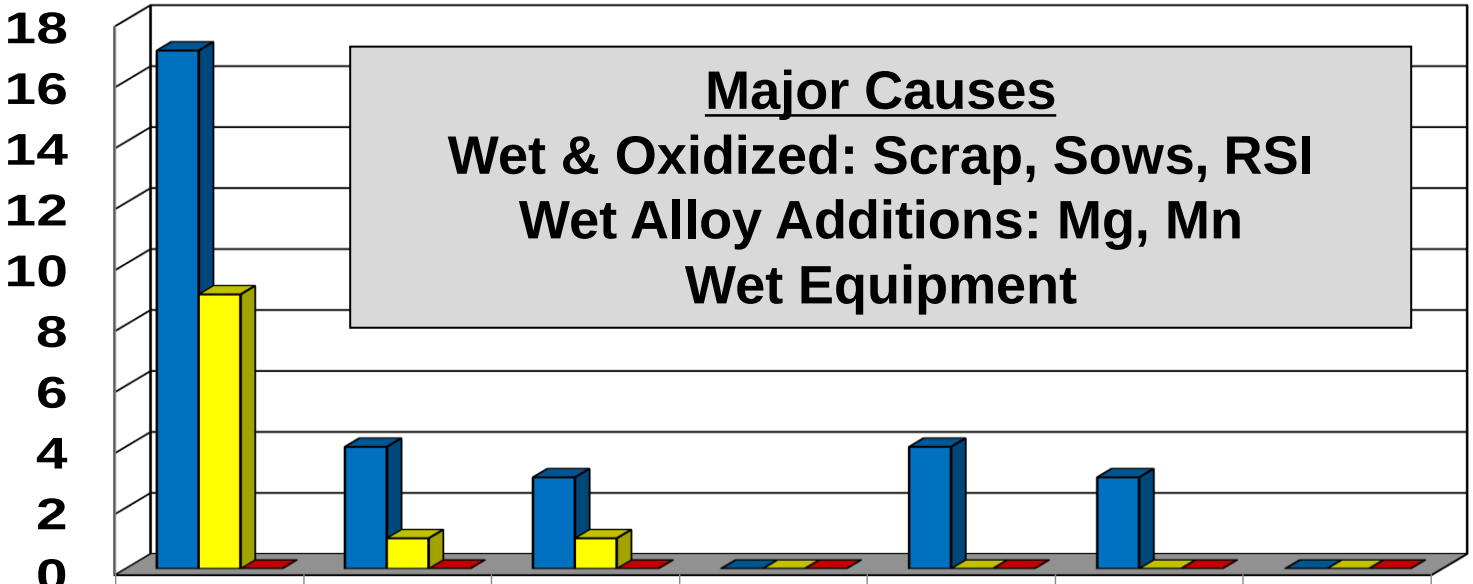


FIGURE 21. Transfer Injuries Per Incidents 1990 – 2023 Sep. 2024

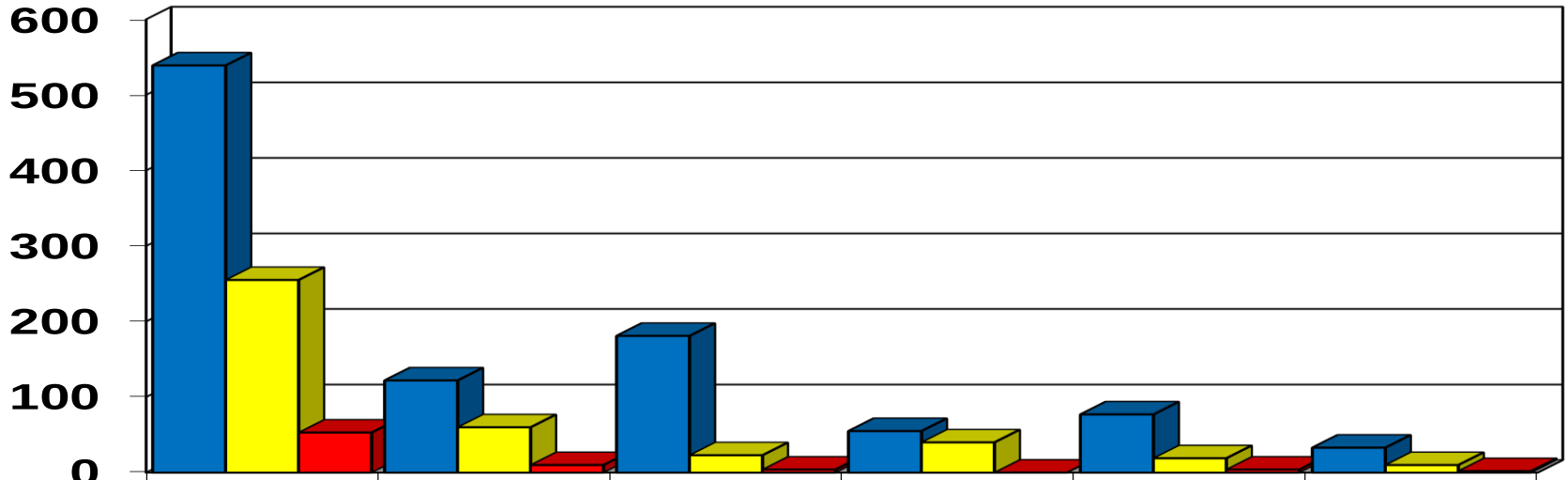
42 Melting Explosions – 2023



	Scrap Charge	Sow Charge	RSI Charge	T-Bar	Alloy-ing Mg / Other	Tools / Pans	Other
Force 1	17	4	3	0	4	3	0
Force 2	9	1	1	0	0	0	0
Force 3	0	0	0	0	0	0	0

FIGURE 22. Melting Explosions By Cause For 2023 Sep. 2024

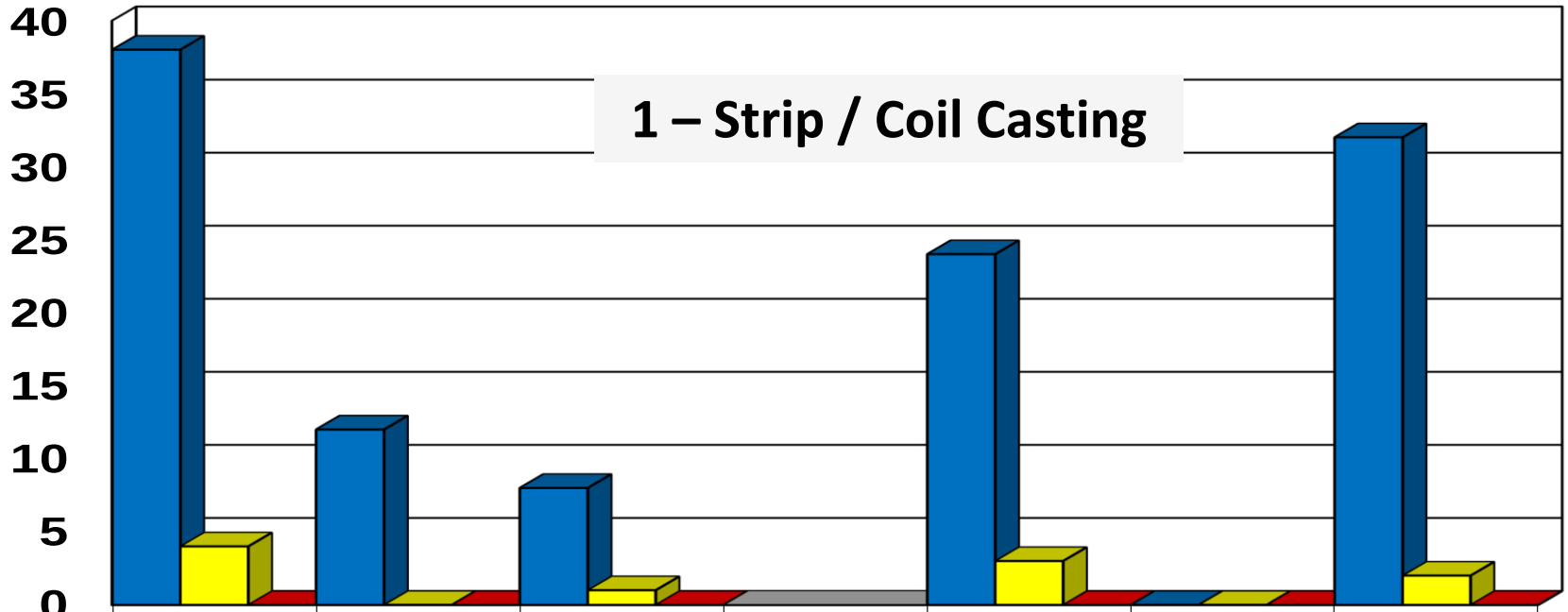
Melting Explosions – Charge Material Involved 1980 – 2023



	Scrap	Sow	Alloy Adds	Ingot / Tbar	Other	Scrap / Sow
Force 1	539	122	181	55	77	33
Force 2	255	60	23	40	19	10
Force 3	53	10	4	0	4	2

FIGURE 23. Melting Explosions By Charge Material 1980 – 2023 **Sep. 2024**

62 Casting Explosions – 2023



	Start-up	Steady State	Termina-tion		DC Slab & Billet	Rod	Sow or Mold
Force 1	38	12	8		24	0	32
Force 2	4	0	1		3	0	2
Force 3	0	0	0		0	0	0

FIGURE 24. Casting Explosions For 2023 **Sep. 2024**

DC/HDC/EMC Explosions by Cast Segment 1980 – 2023

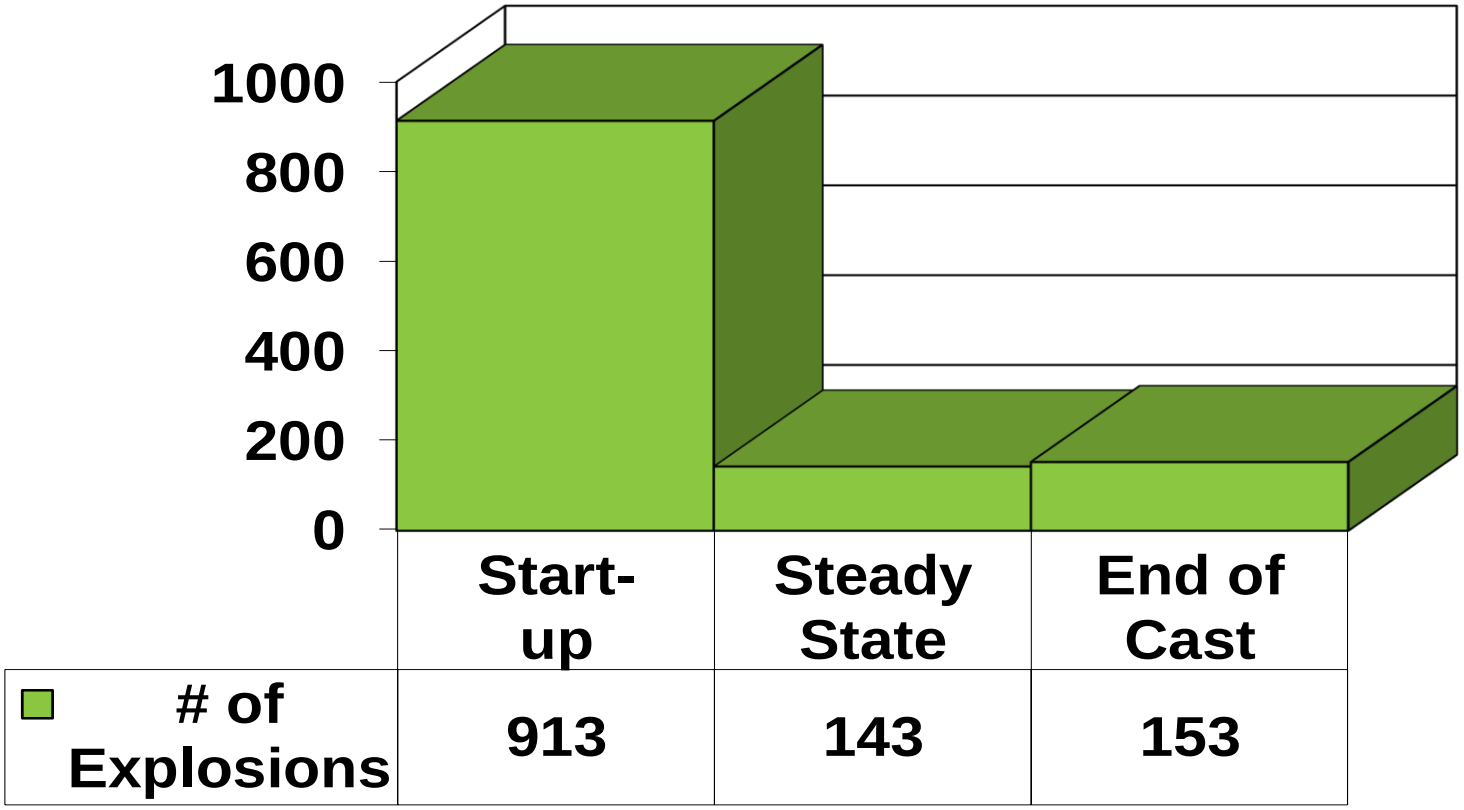


FIGURE 25. Casting Explosions By Cast Segment 1980 – 2023 Sep. 2024

Major Causes of 62 Casting Incidents – 2023

- **DC Start-up Issues: Wet Starting Blocks, Wet Equipment, Butt Curl –Bleed-outs, Equipment Failures**
- **DC Steady State Issues: Power Loss / Equipment Failure**
- **DC Termination Issues: Wet / Rusty Drain Pan, Wet Hand Tool**
- **Strip / Coil Casting Termination Issues: Drain Pan Rust & Debris**
- **Sow / Mold Casting Issues: Wet / Unpreheated / Cracked Molds**

FIGURE 26. Major Causes of Casting Incidents For 2023 Sep. 2024

Major Causes of Casting Explosions 2015 – 2023

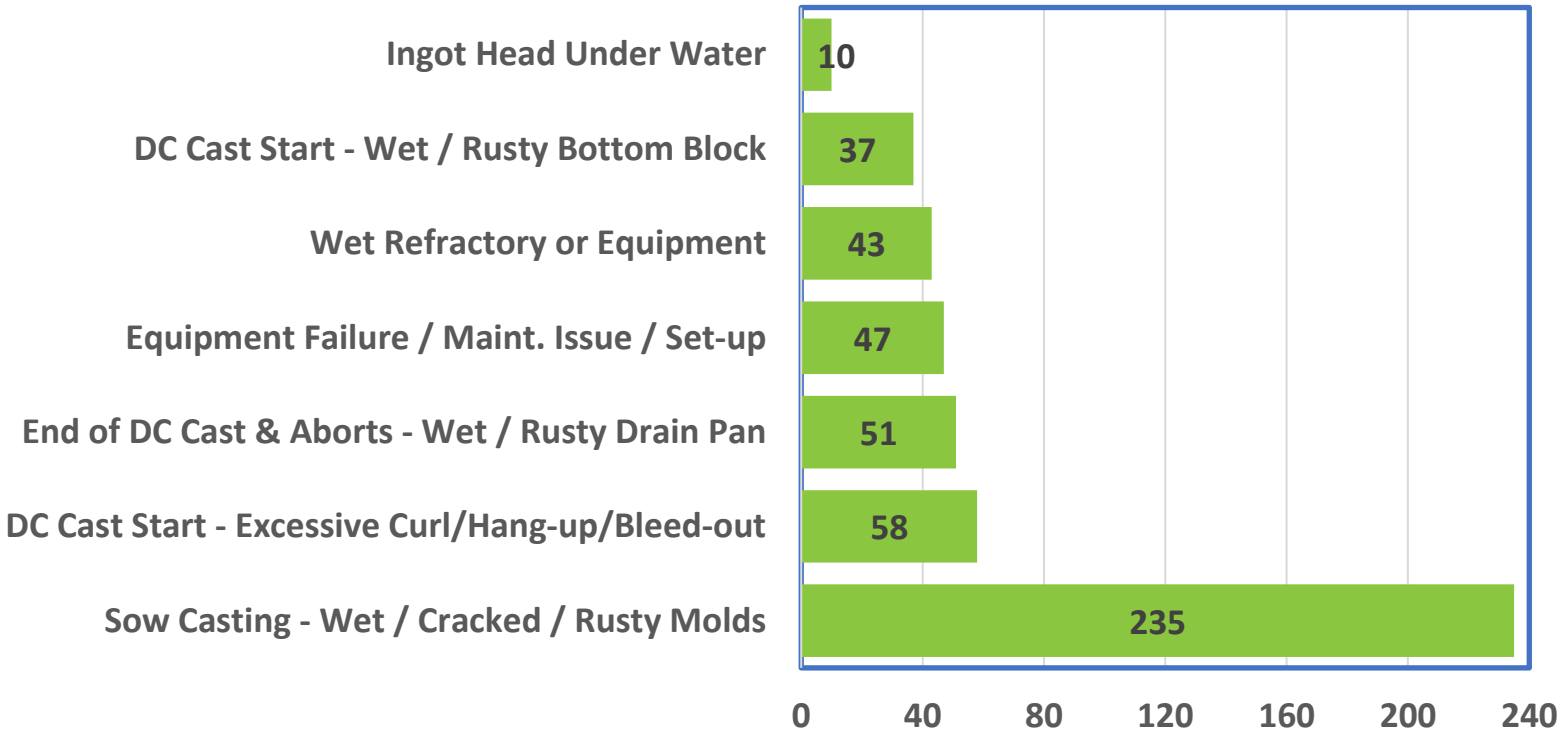


FIGURE 27. Casting Explosions by Major Causes 2015 – 2023 Sep. 2024

Major Causes of Force 2 & 3 Casting Explosions 2015 – 2023

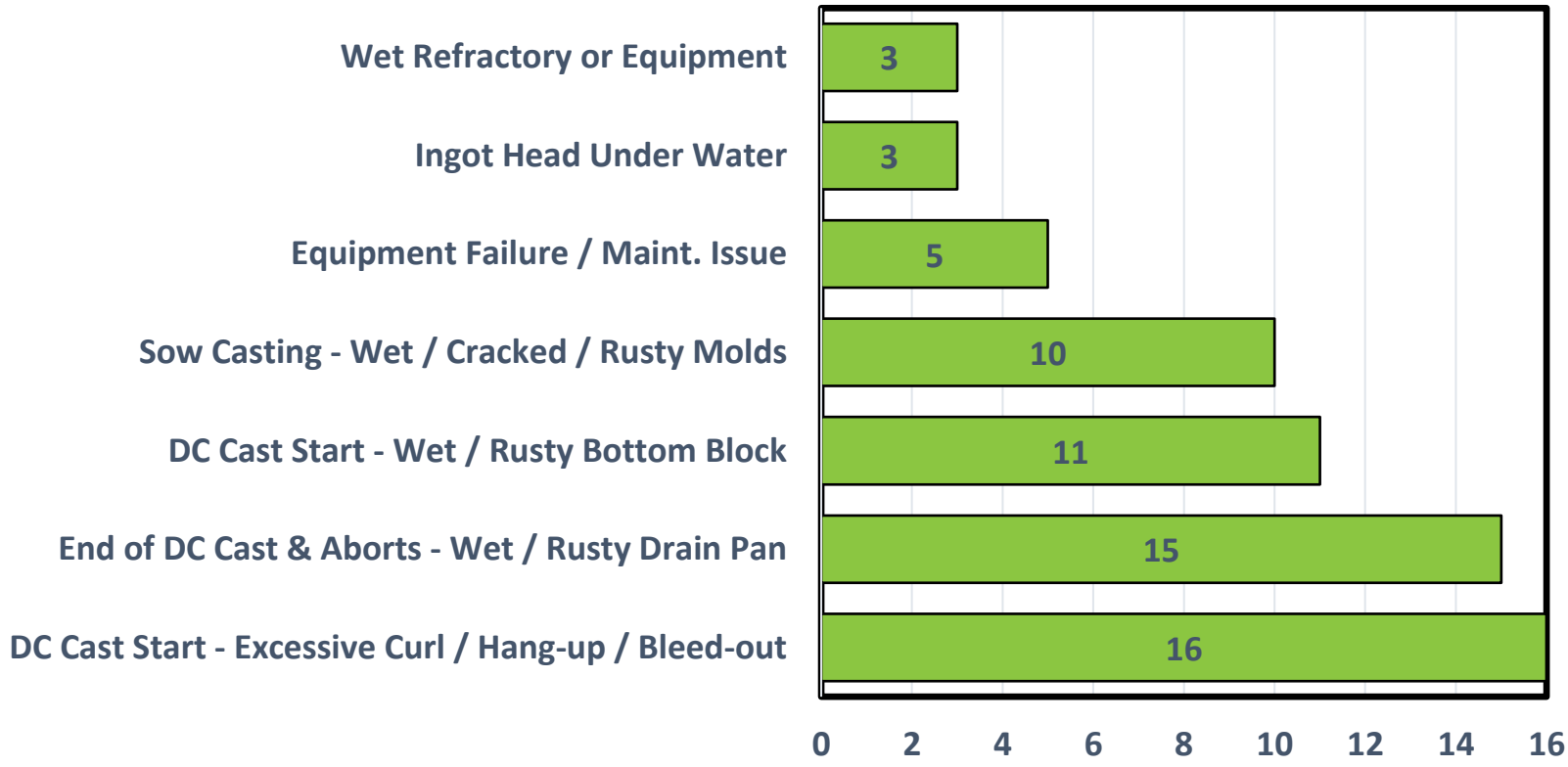


FIGURE 28. Casting Explosions by Major Causes 2015 – 2023 Sep. 2024

Major Causes of 42 Transfer Explosions – 2023

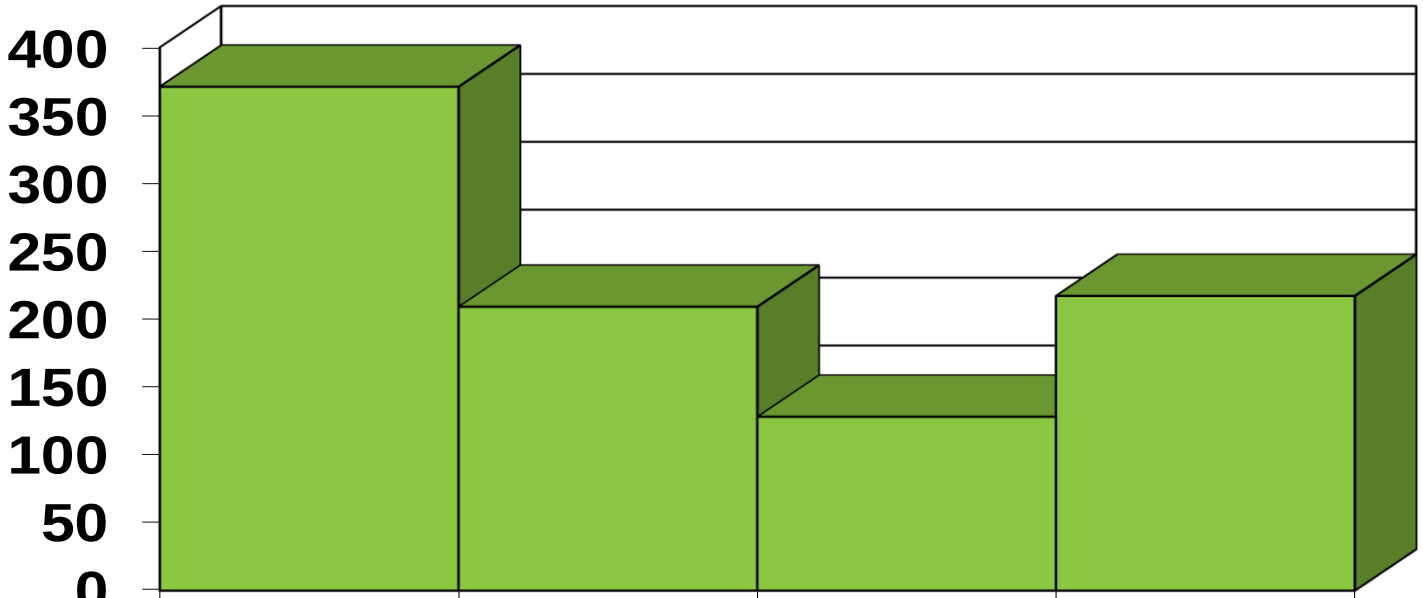
25 - Wet Hand or Furnace Tools, Equipment (2 Force 2)

14 – Wet / Rusty Drain or Skim Pan (4 Force 2)

3 – Metal on Floor (1 Force 2)

FIGURE 29. Causes of Transfer Explosions For 2023 **Sep. 2024**

Transfer Explosions by Equipment 1980 – 2023 (Total 927)



	Drain Pan	Trough	Cruci-ble	Other
# of Explosions	371	209	128	217

FIGURE 30. Transfer Explosions by Equipment 1980 – 2023 Sep. 2024

Major Causes of Transfer Explosions 2008 – 2023 (w/o 2011)

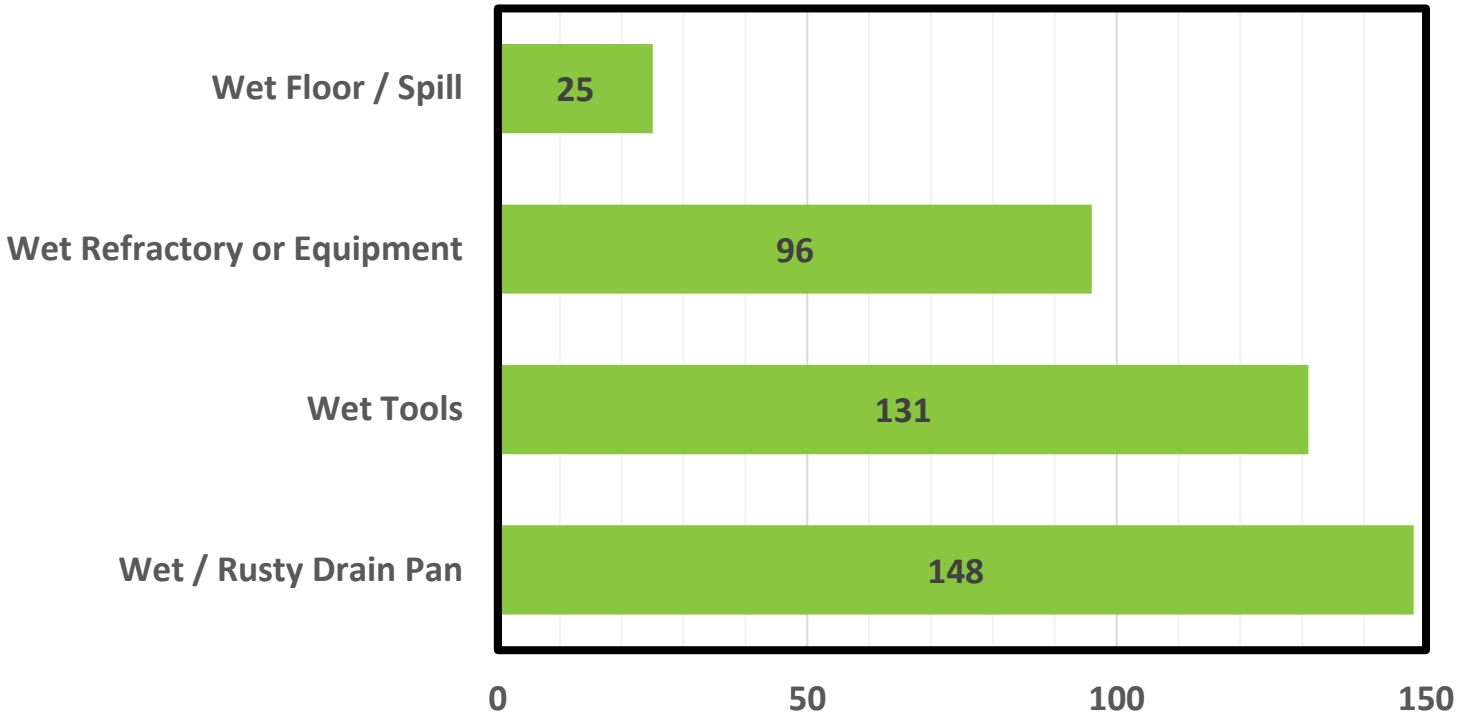


FIGURE 31. Transfer Explosions – Major Causes 2008 – 2023 Sep. 2024

Major Causes of Force 2 & 3 Transfer Explosions 2008 – 2023 (w/o 2011)

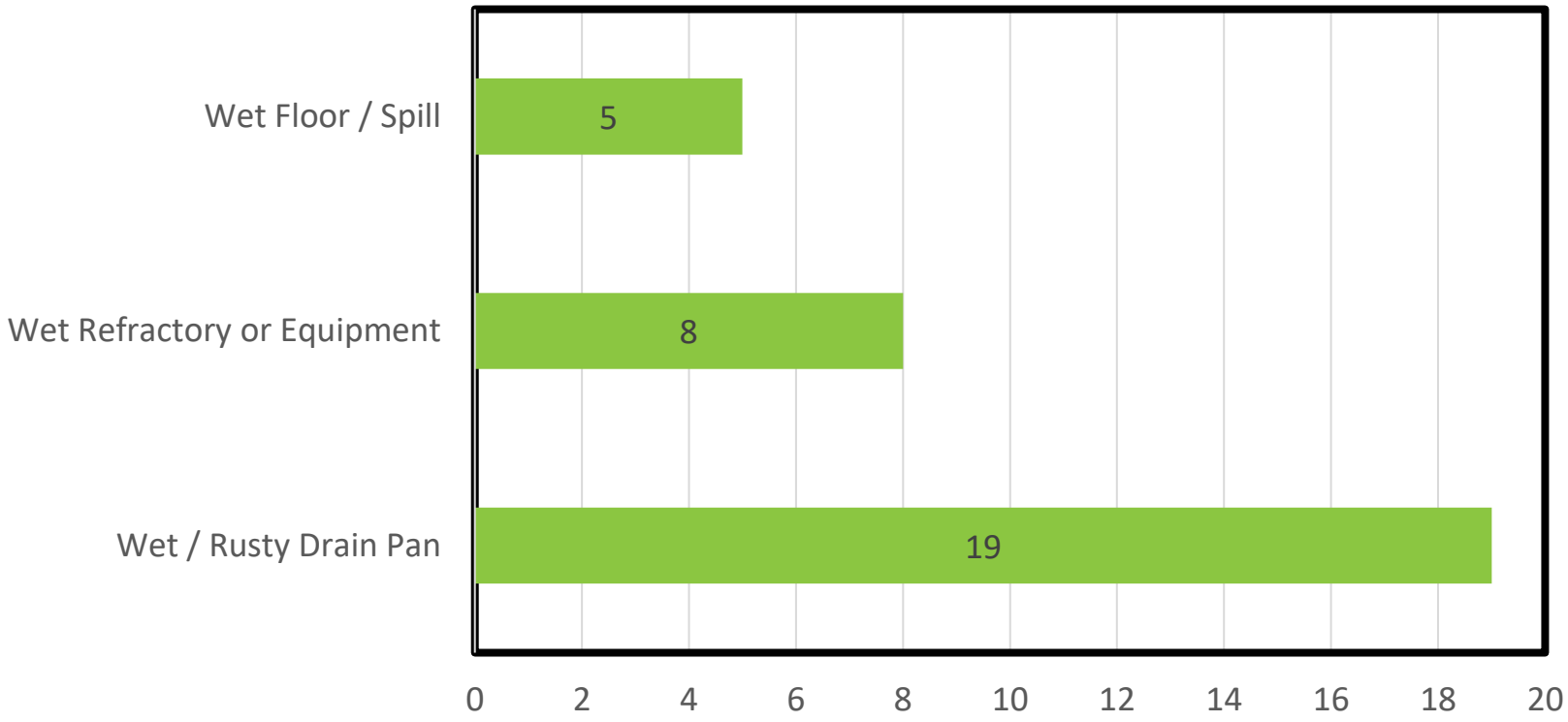
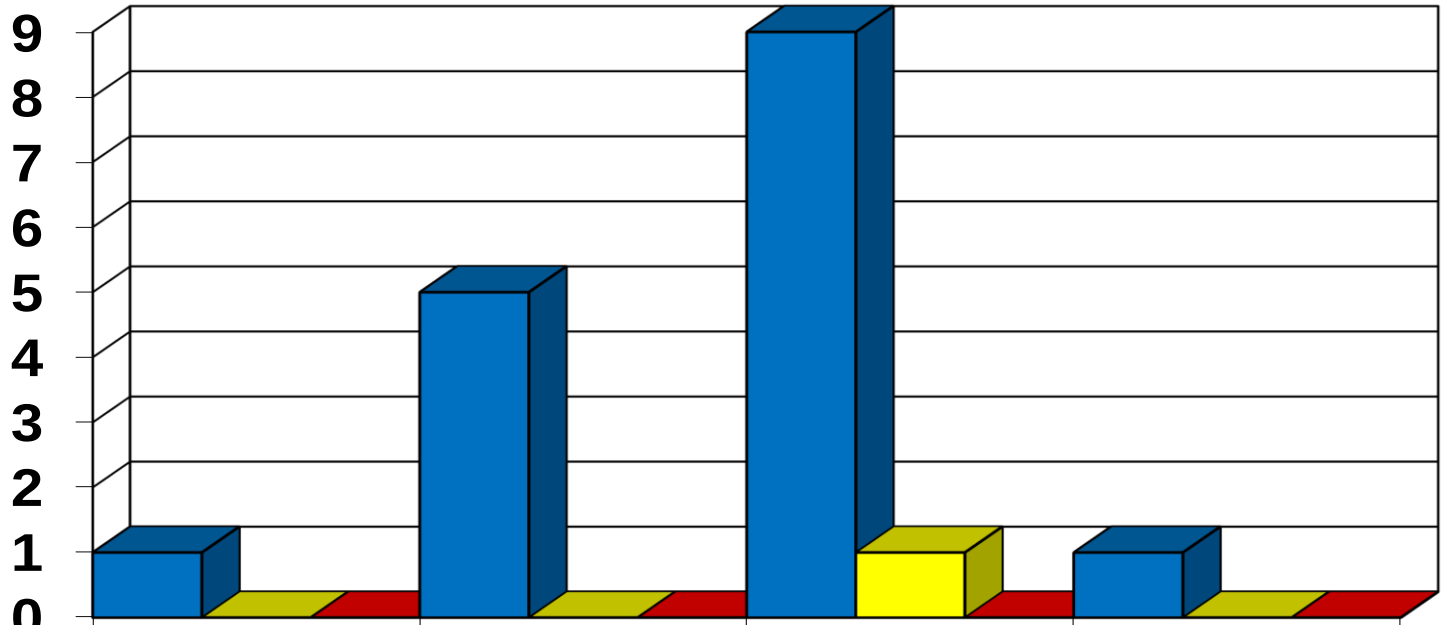


FIGURE 32. Transfer Explosions – Major Causes 2008 – 2023 Sep. 2024

17 Injuries by Operation – 2023

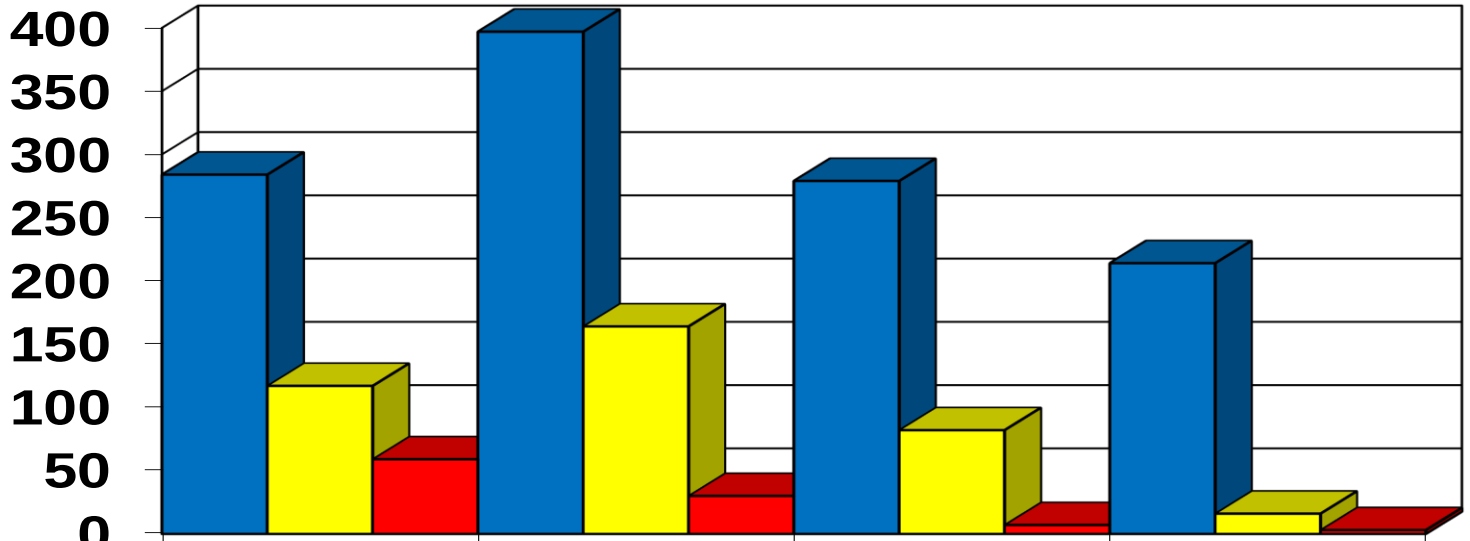


	Melting	Casting	Transfer	Other
Minor	1	5	9	1
Serious	0	0	1	0
Fatal	0	0	0	0

FIGURE 33. Injuries By Operation For 2023 **Sep. 2024**

1652 Injuries by Operation:

1980 – 2023



	Melting	Casting	Transfer	Other
Minor	284	397	279	214
Serious	117	164	82	16
Fatal	59	30	7	3

FIGURE 34. Injuries By Operation For 1980 – 2023 Sep. 2024

Melting Explosions By Month
2017 – 2023

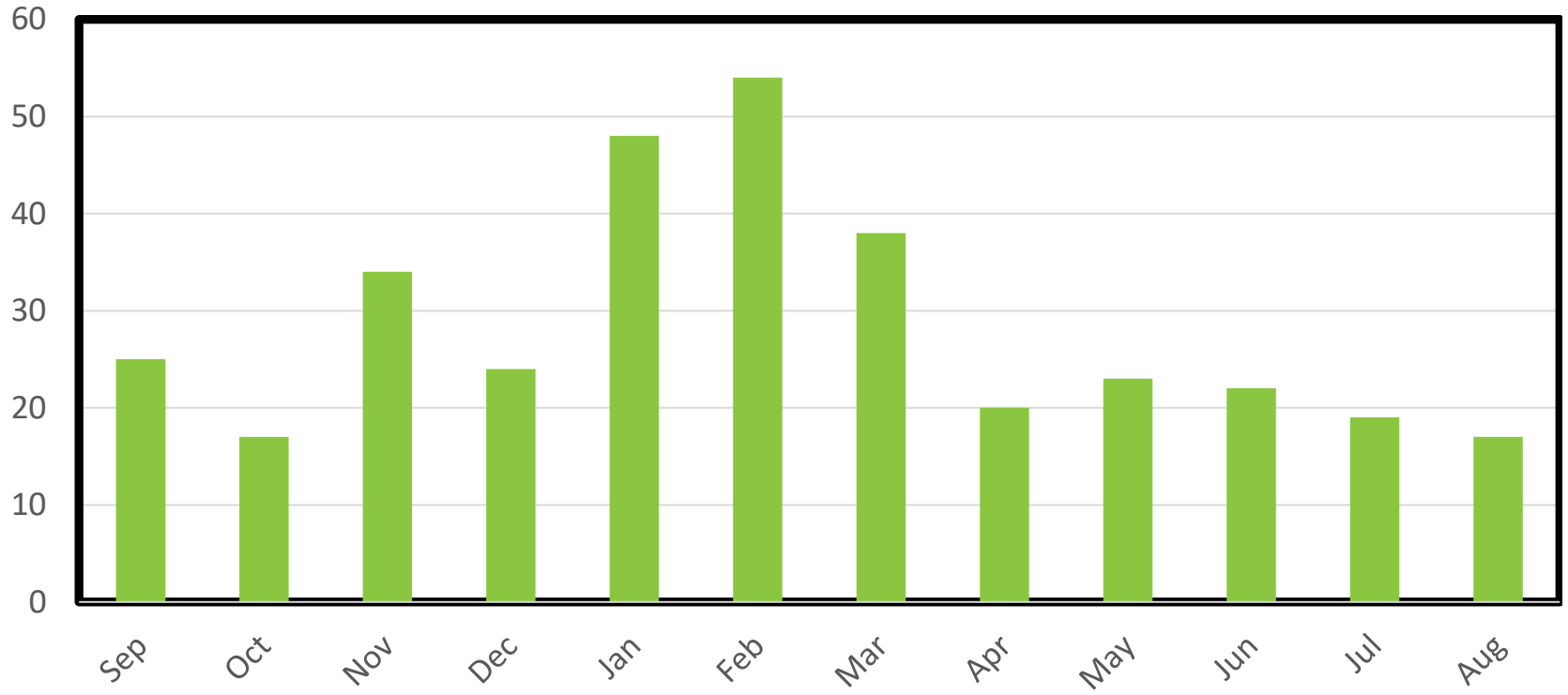


FIGURE 35. Melting Explosions By Month 2017 – 2023 Sep. 2024

Casting Explosions By Month
2017 – 2023

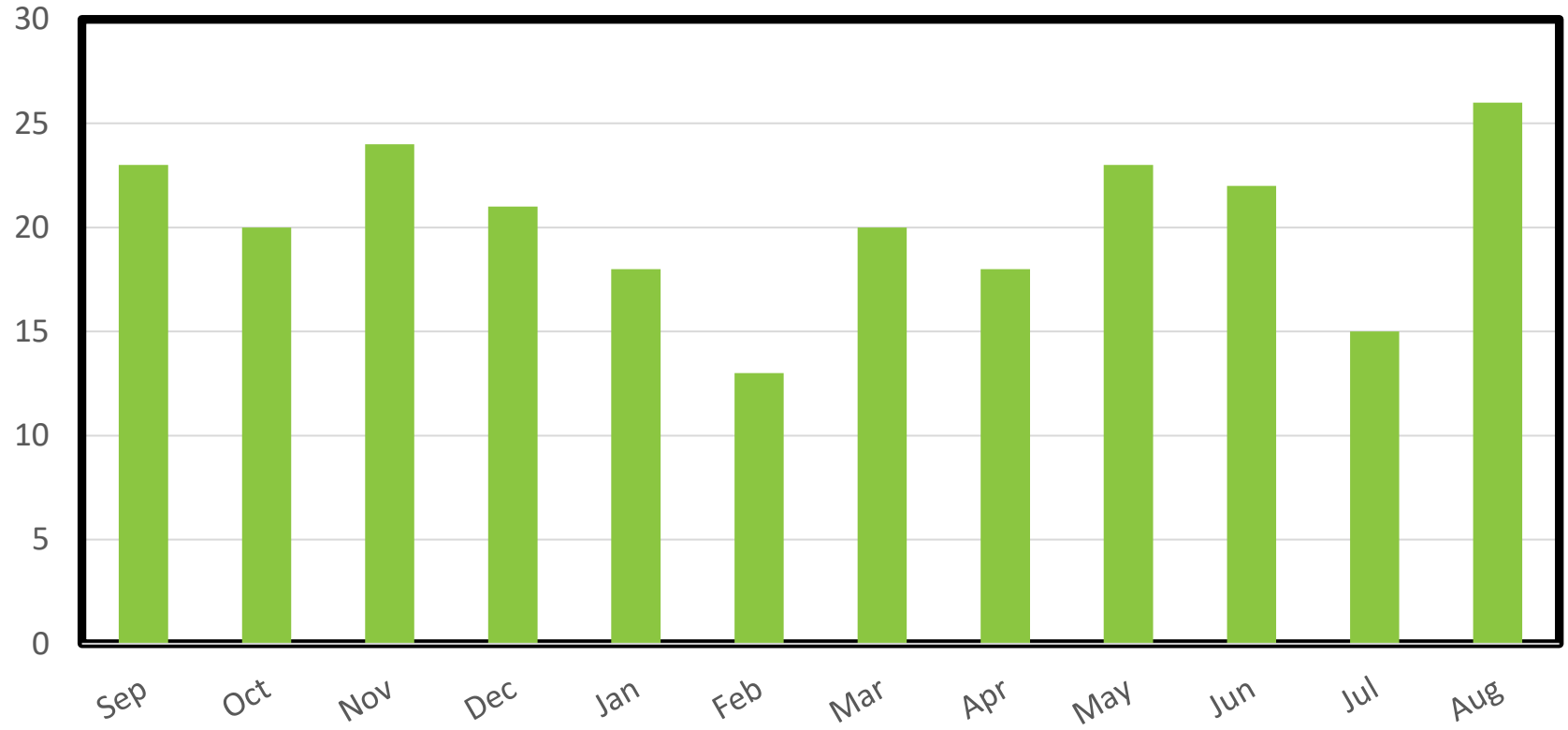


FIGURE 36. Casting Explosions By Month 2017 – 2023 Sep. 2024

Transfer Explosions By Month
2017 – 2023

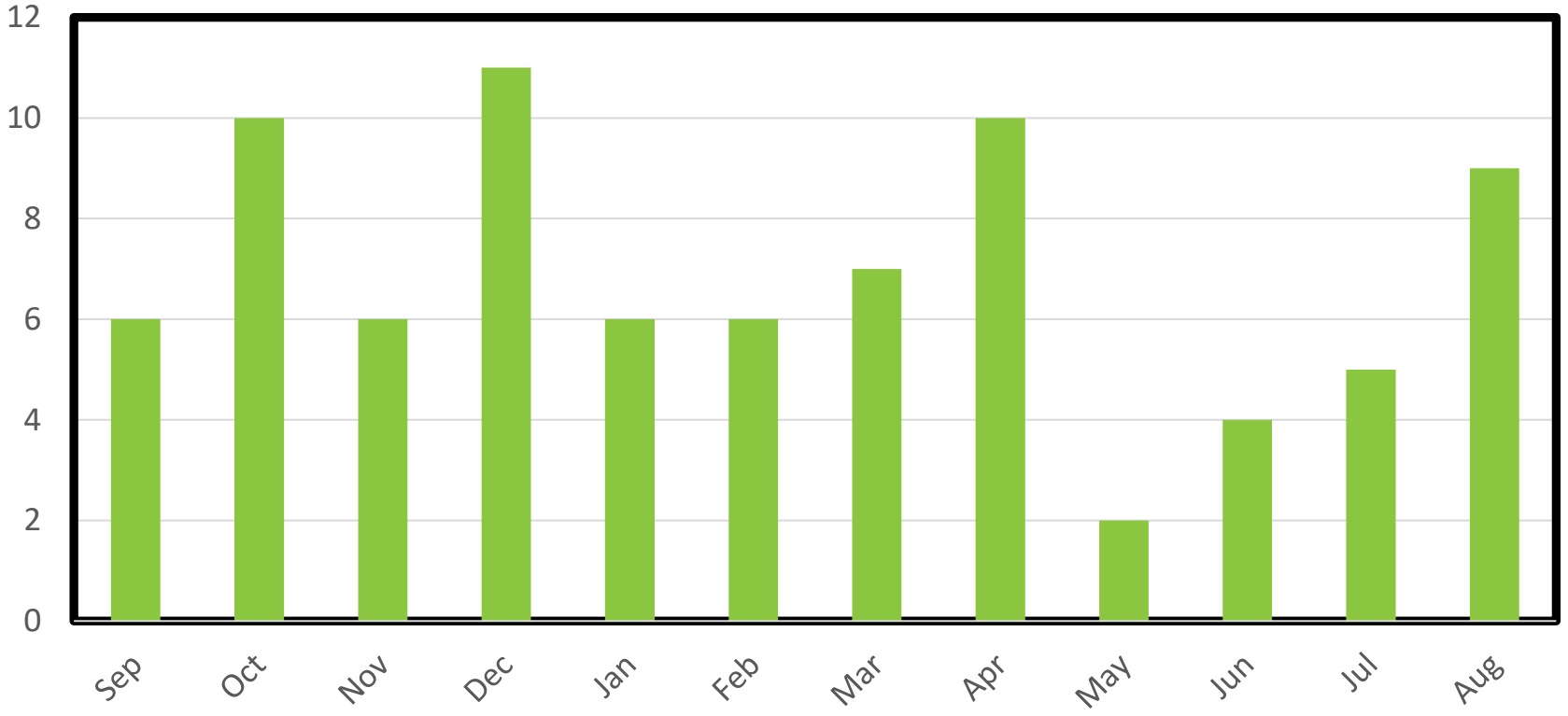
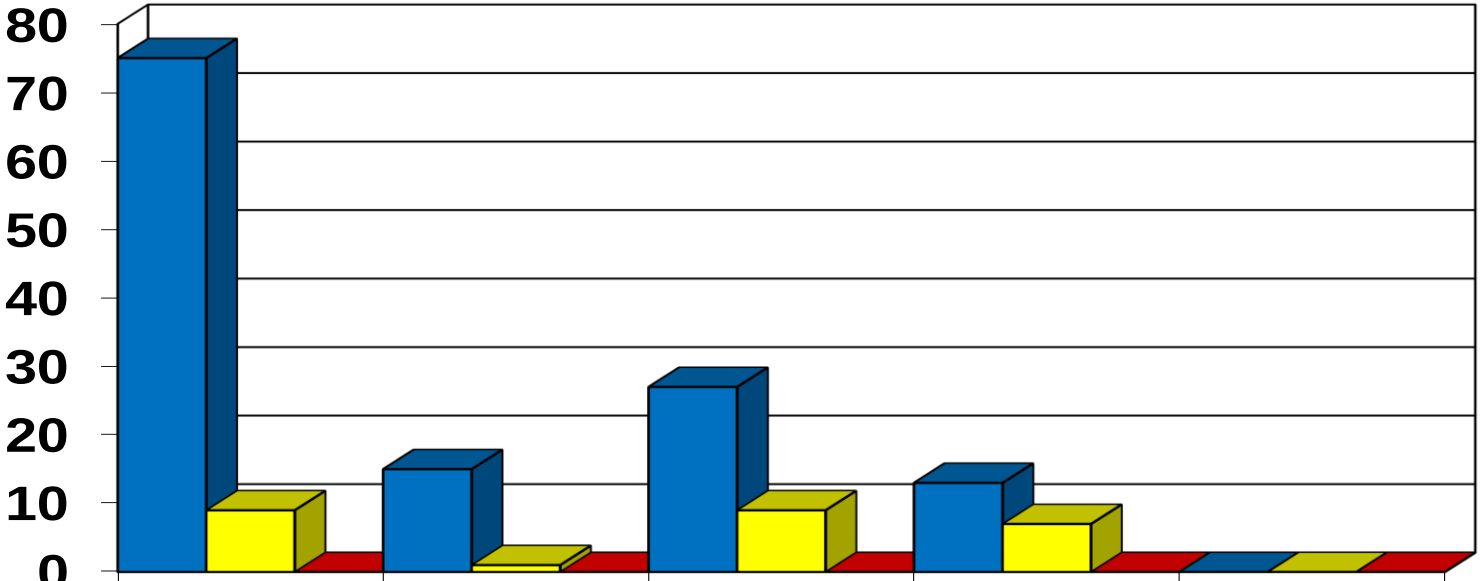


FIGURE 37. Transfer Explosions By Month 2017 – 2023 Sep. 2024

Force Level By Process Plant – 2023

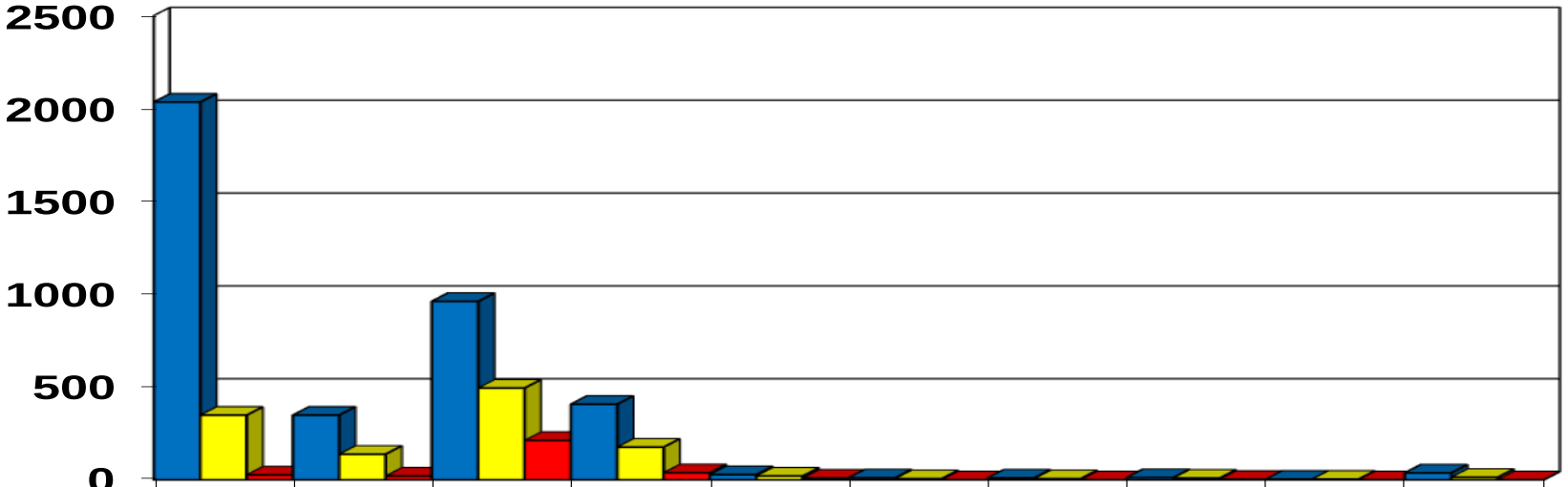


	Reduc-tion	Extru-sion	Rolling	Recycl-ing	Forg-ing
Force 1	75	15	27	13	0
Force 2	9	1	9	7	0
Force 3	0	0	0	0	0

FIGURE 38. Force Level By Process Plant Reported For 2023 Sep. 2024

Force Level By Process Plant

1980 – 2023



	Reduction	Extrusion	Rolling	Recycling	Foundry	Atomizing	Alloying	BRW	Other	R&D
Force 1	2034	348	961	407	28	11	10	12	3	37
Force 2	348	138	494	176	20	6	6	9	3	13
Force 3	26	20	212	38	9	0	0	2	0	0

FIGURE 39. Force Level By Process Plant Reported For 1980 – 2023 Sep. 2024

Reduction Plant

Main Causes of 84 Incidents – 2023

Melting Incidents	Casting Incidents
4 – Wet Charge: Scrap / Sow 2 – Wet Charge: Wet RSI 2 – Wet Tool 1 – Wet Alloy	Sow Casting: 33 – Cracked, Wet or Rusty Molds 1 – Tool Maintenance
	VDC – Billet & Slab 4 –Start-up – Wet Refractory / Equip. 2 –Termination – Wet/Rusty Drain Pan 1 – Termination – Hand Tool 1 – SOP Unadapted or Not Respected

FIGURE 40. Reduction Plant Incidents Summary 2023
Sep. 2024

Reduction Plant
Main Causes of 84 Incidents – 2023

Transfer Incidents	Reduction Cell
12 – Wet Tools & Equipment	**3 – Contact with Wet Alumina**
7 –Wet Refractory / Equip.	**2 – Wet Tool**
6 –Wet / Rusty Drain or Skim Pan	**1 – Wet Anode**
1 **– Crucible**	**1 – Spill on Wet Ground**
1 **– Rusty Mold**	**1 – Wet Tabular**
1- Spill on Concrete	

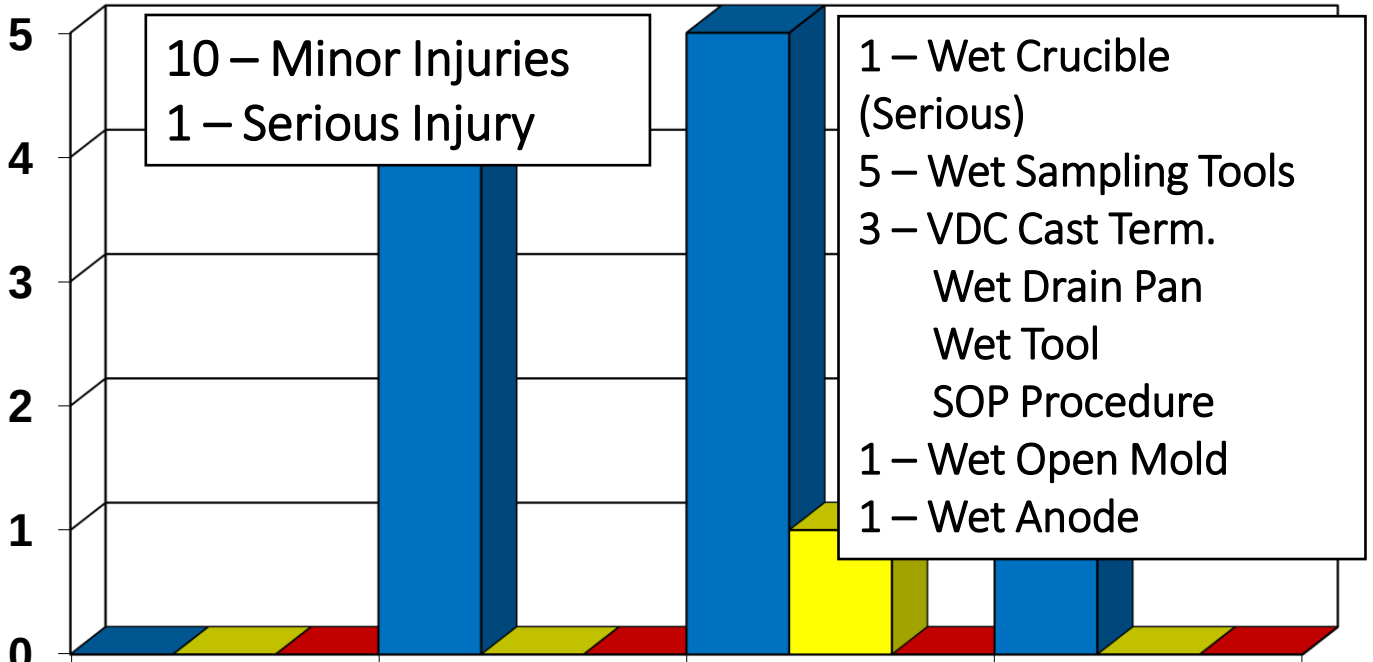
FIGURE 41. Reduction Plant Incidents Summary 2023 Sep. 2024

Recycling Plant
Main Causes of 21 Incidents – 2023

Melting Incidents	Casting Incidents
14 - Wet Charge: Scrap, Sow, Dross (6/14 – Force 2)	Sow Casting: 1 - Wet Mold (Force 2)
Transfer Incidents 1 - Wet Tool	VDC – Slab: 1 - Start-up – Wet Bottom Block 1 - Start-up – Bleedout

FIGURE 42. Recycling Plant Incidents Summary 2023
Sep. 2024

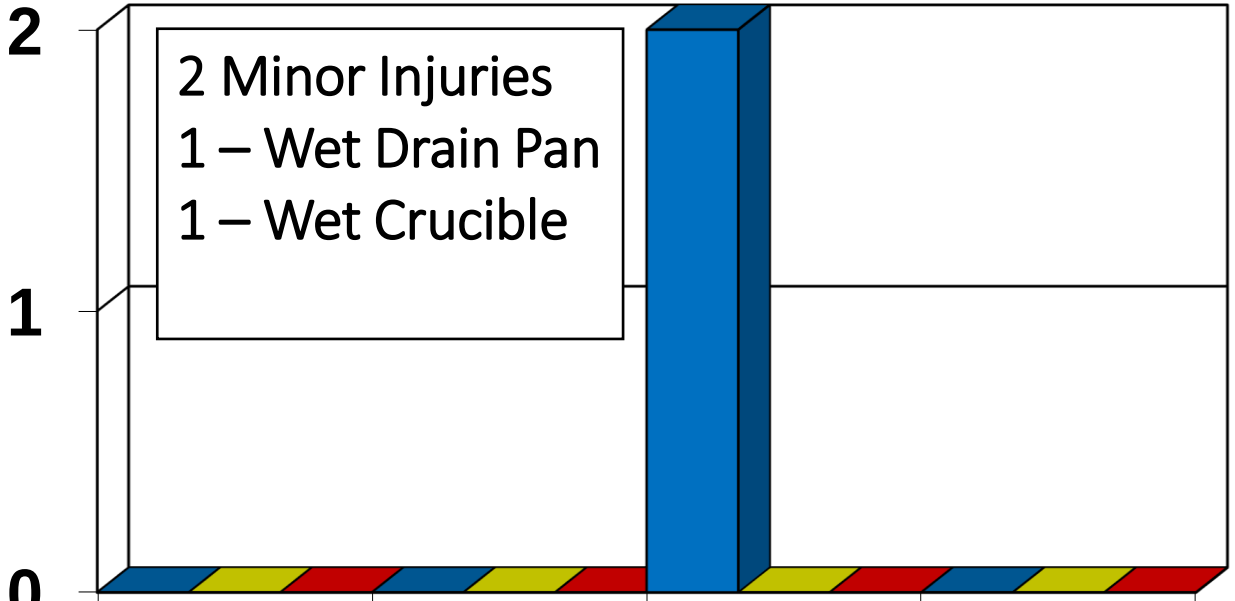
Reduction Plant Injuries & Incident Causes – 2023



	Melting	Casting	Transfer	Other
Minor	0	4	5	1
Serious	0	0	1	0
Fatal	0	0	0	0

FIGURE 43. Reduction Plant Injuries By Operation 2023 Sep. 2024

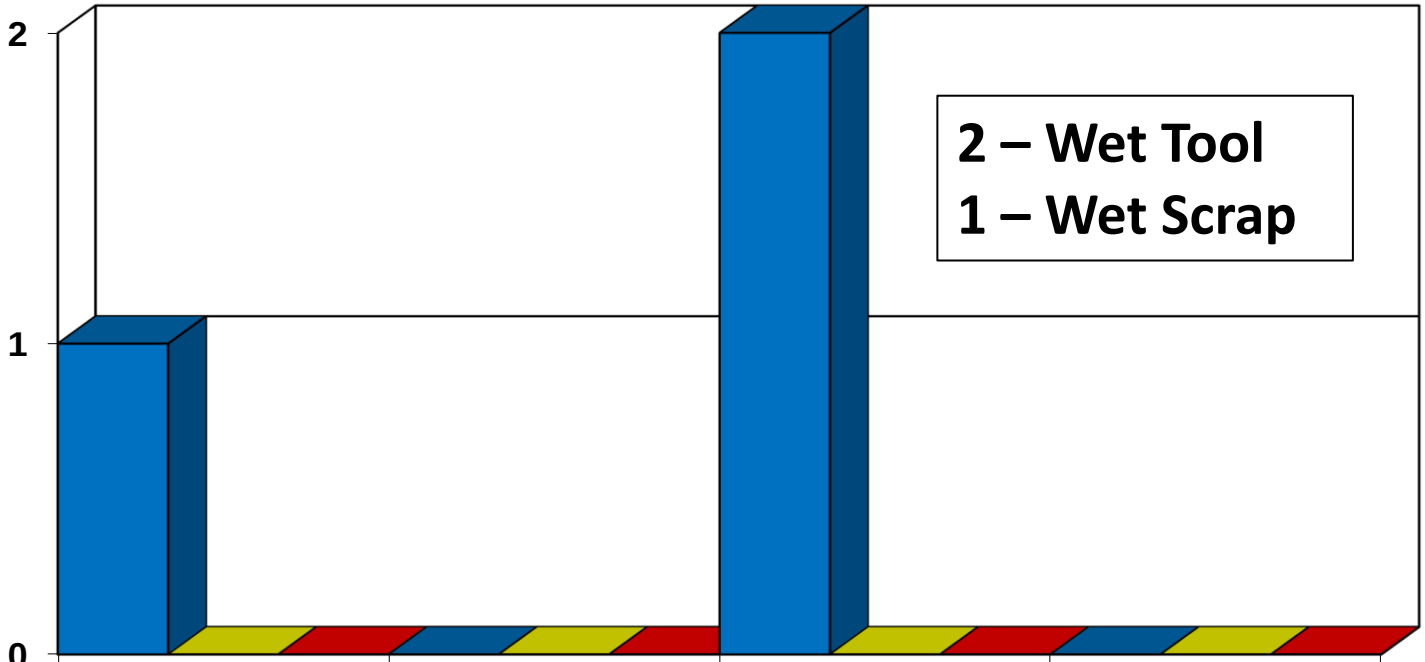
Rolling Plant Injuries – 2023



	Melting	Casting	Transfer	Other
Minor	0	0	2	0
Serious	0	0	0	0
Fatal	0	0	0	0

FIGURE 44. Rolling Plant Injuries By Operation 2023 Sep. 2024

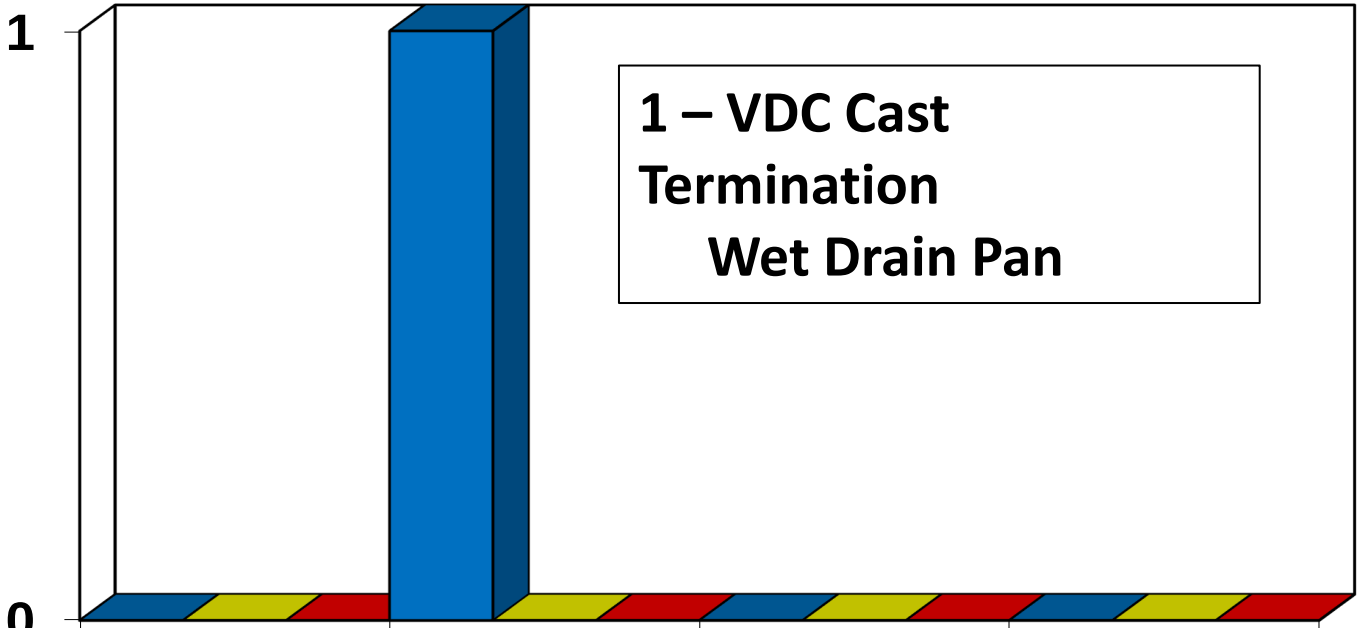
Extrusion Plant Injuries – 2023



	Melting	Casting	Transfer	Other
Minor	1	0	2	0
Serious	0	0	0	0
Fatal	0	0	0	0

FIGURE 45. Extrusion Plant Injuries By Operation 2023
Sep. 2024

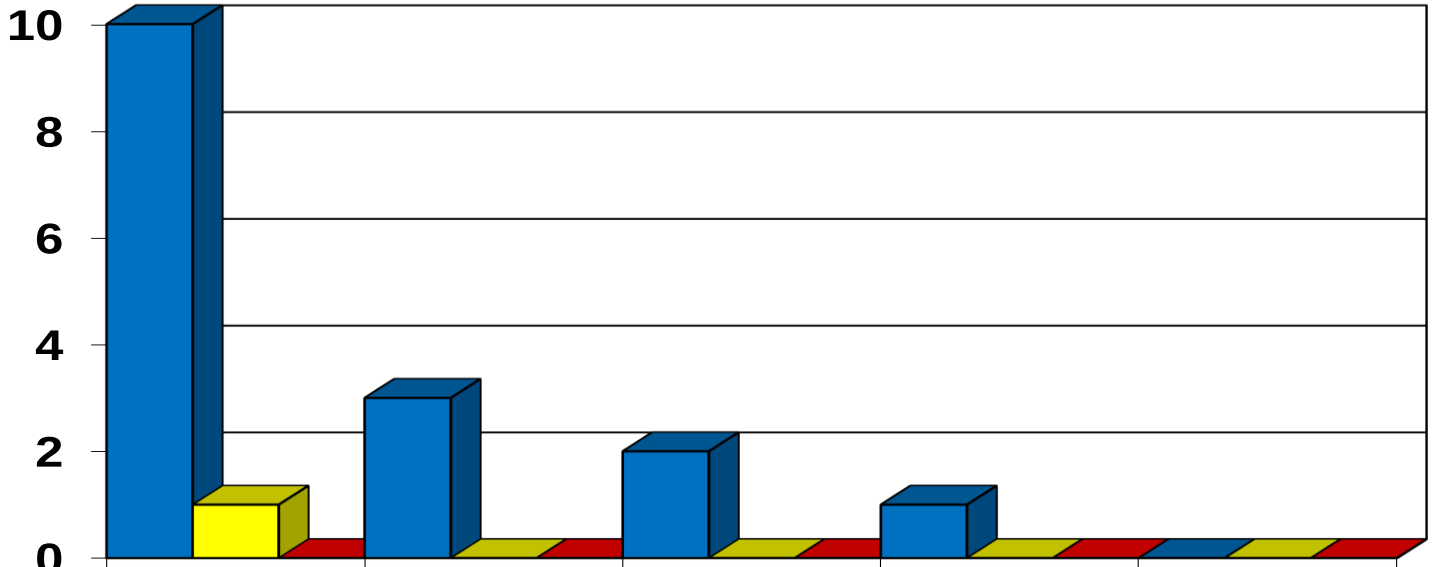
Recycling Plant Injuries – 2023



	Melting	Casting	Transfer	Other
Minor	0	1	0	0
Serious	0	0	0	0
Fatal	0	0	0	0

FIGURE 46. Recycling Plant Injuries By Operation 2023 Sep. 2024

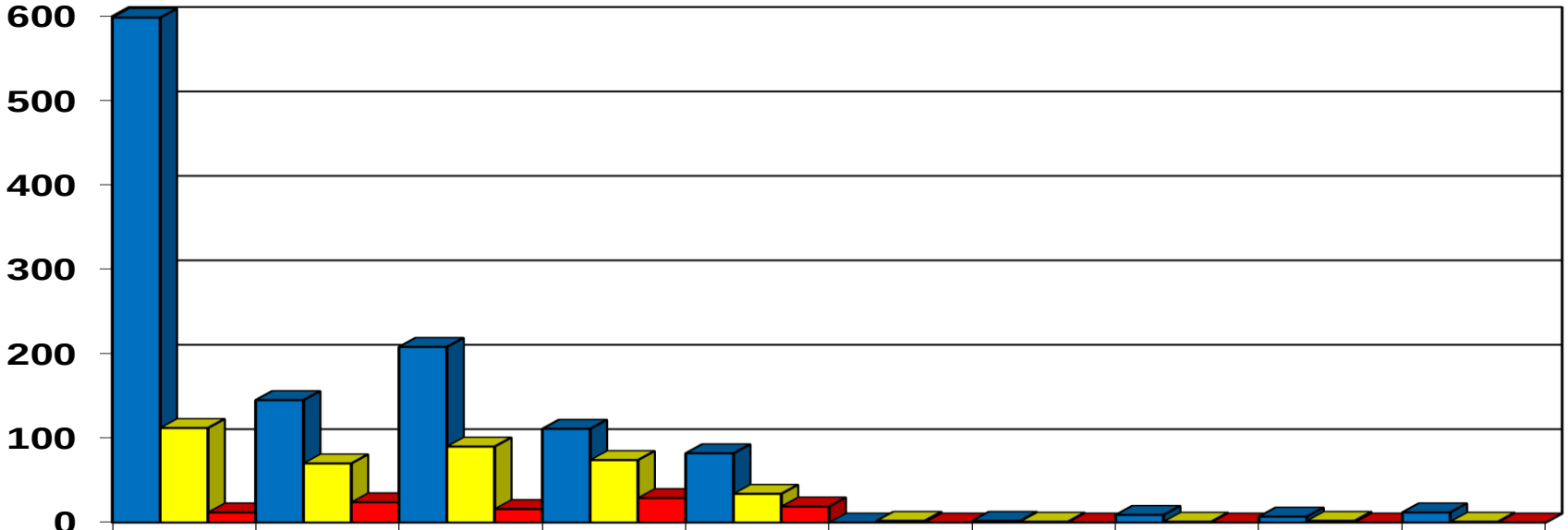
Injury Severity by Process Plant – 2023



	Reduc-tion	Extru-sion	Rolling	Recylin g	Other
Minor	10	3	2	1	0
Serious	1	0	0	0	0
Fatals	0	0	0	0	0

FIGURE 47. Injury Severity By Process Plant – 2023 Sep. 2024

Injury Severity by Process Plant
1980 – 2023

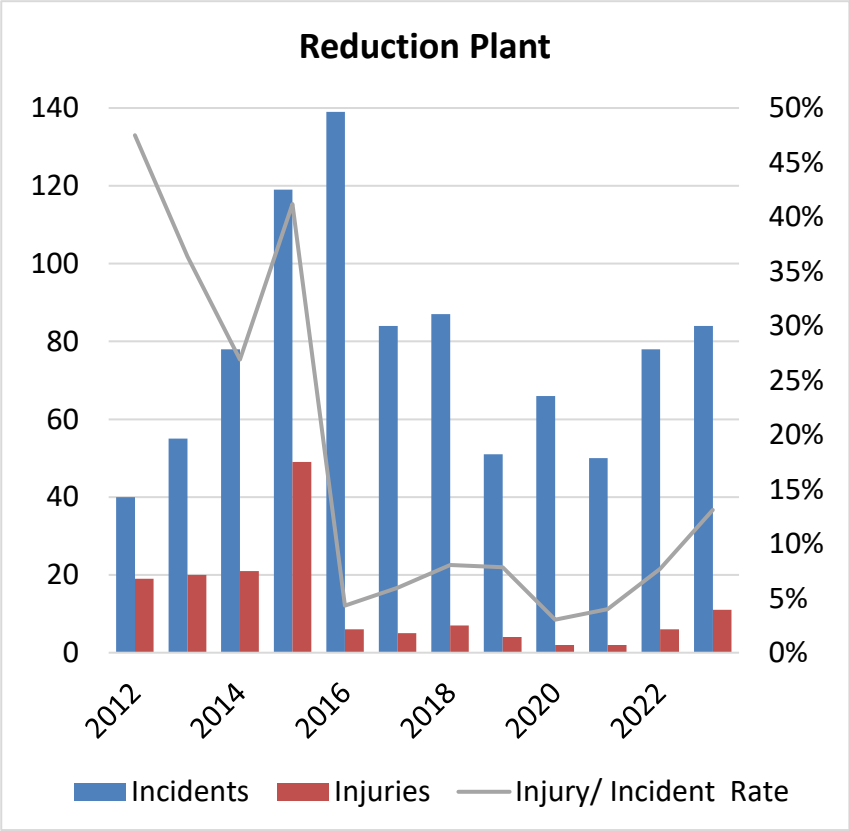


	Reduction	Extrusion	Rolling	Recycling	Foundry	Atomizing	Alloying	BRW	Other	R&D
Minor	598	145	208	111	82	0	2	9	7	12
Serious	112	70	90	74	34	2	1	1	2	1
Fatal	12	24	16	29	19	0	0	0	0	0

FIGURE 48. Injuries Severity By Plant Reported For 1980 – 2023 Sep. 2024

Reduction & Recycling Plant Incidents, Injuries / Incident Rate

2012 – 2023



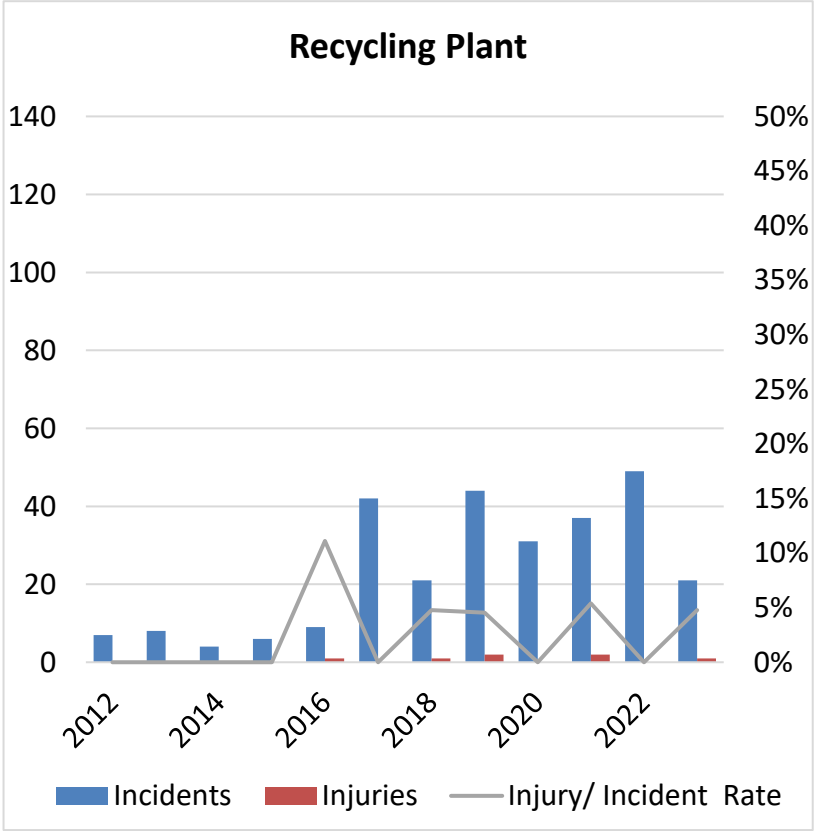
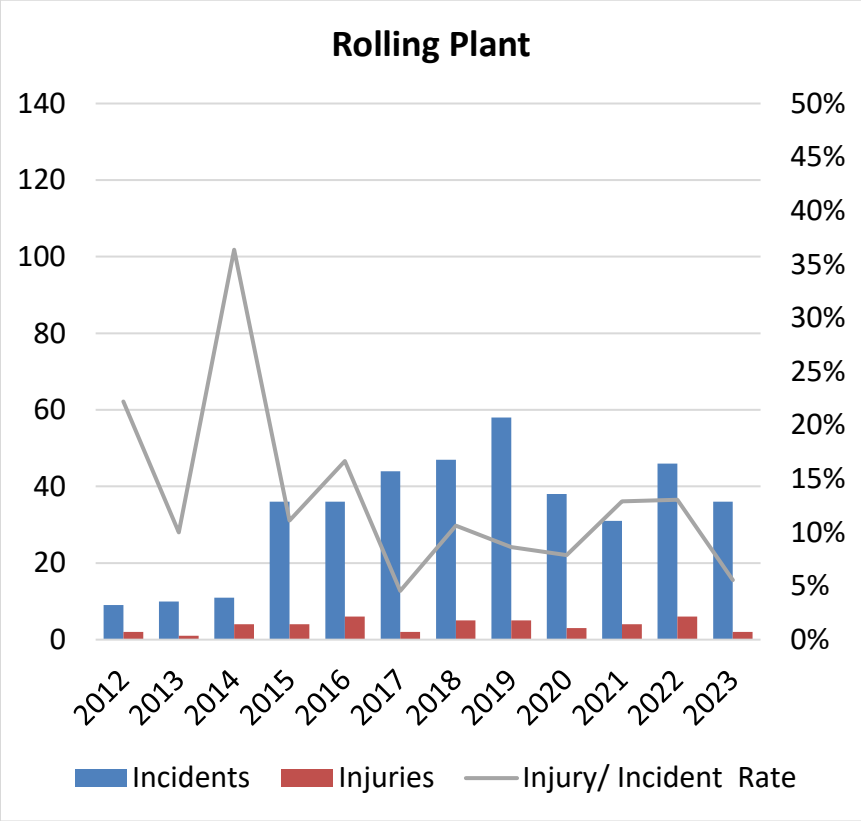


FIGURE 49. Reduction & Recycling Incident, Injury & Injury Rate 2012-2023 Sept. 2024

Rolling & Extrusion Plant Incidents, Injuries / Incident Rate

2012 – 2023



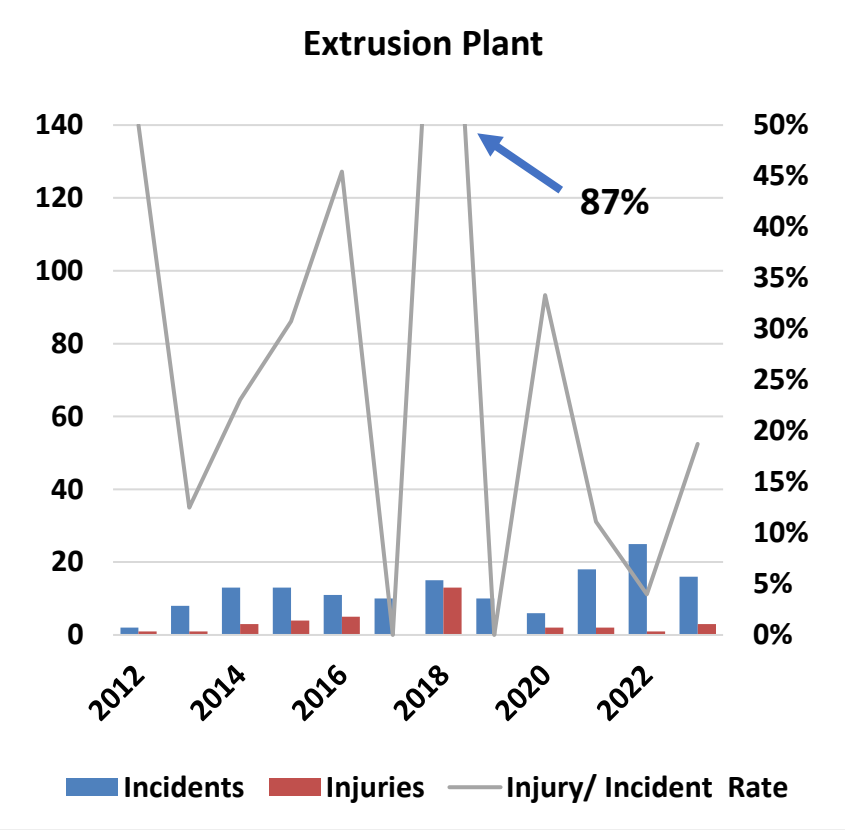


FIGURE 50. Rolling & Extrusion Incident, Injury & Injury Rate 2012-2023 Sept. 2024

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