VG513

Instrumented sphere assessment of tomato handling equipment in Queensland

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HAL

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VG513

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SUMMARY

This report examines the importance of handling impacts in causing injuries that result in quality loss and waste of Queensland grown tomatoes. An instrumented sphere (IS) was passed with tomatoes through handling associated with picking, sorting, grading and packing. A total of 15 packing sheds at Bowen and Bundaberg were assessed which handle about 70% (or 98,000 tonnes) of Queensland's fresh tomato crop.

The sphere is an electronic device about the size of a medium tomato. It contains an accelerometer for measuring the size of impacts, and associated power supply and hardware for recording data. The passage of the sphere through equipment is video-filmed and by matching footage to computer generated results, it is possible to precisely locate where damaging impacts have occurred during handling.

The IS proved to be well suited to studies of tomato handling. It was revealed that large impacts in tomato packing sheds often occur at the transition zones between different functional components that make up the handling chain. These transitions are often characterised by changes in elevation, presence of ramps, and changes in direction and speed. Forty-five percent of large impacts (i.e. greater than 150G) occurred as the sphere moved onto ramps. Other important problem areas were transfers onto rollers, contact with unpadded or under-padded walls, neglected overflow returns and drops onto the collection belts of older style, belt sizers.

Based on all sheds, the most direct route for first class fruit between bin-tip and carton entailed passage through an average of 25 impact sites (40G threshold). But the majority of these are unlikely to cause serious damage to `Tempest', the popular tomato variety grown in North Queensland. Laboratory tests using a pendulum impact rig defined mechanical injury types and correlated drop heights to injury severity. These tests showed that `Tempest' fruit is able to tolerate impacts that would generally be considered extreme in most handling situations for fresh produce. However, when `Tempest' fruit are cold, green, large and fully hydrated they are slightly more vulnerable to poor handling. For this resilient variety, impacts of 185G are probably required to cause readily identifiable injury such as internal bruising.

On the handling routes for first class tomatoes, less than 4% of impacts between bin-tip and carton exceeded 185G. With a minimum threshold of 40G (to exclude small impacts that aren't damaging), overall impact size across the 15 packing lines between bin-tip and the carton averaged 91G (based on averages per site), and 50% of impacts were less than 80G.

Overall, the sheds were of a good standard for handling of damage resistant varieties, many incorporated some of the latest handling technologies. Nevertheless, each shed generally included a couple of sites that could be improved to avoid impact damage, even to `Tempest' fruit. Similarly, a number of major impact sites were noted on harvesting platforms.

Although tipping of bulk-bins filled with fruit is popularly considered to be damaging, it was found in this study that very few large impacts were associated with this process. Use of fully filled bins, gentle tipping actions and unloading through bin side gates were probably common reasons for avoiding damaging impacts. Fruit on the surface of a bin load can be exposed to impact against the bin lid/tipper.

Impact sizes can often be reduced by simple and inexpensive modifications to equipment. Add cushioning to hard surfaces, replace solid ramps where possible with vinyl sling-chutes, use rubber curtains to impede movement through drops, and remove solid supporting materials under conveyor belts. In the field, angling of picking buckets while filling the first layer of tomatoes is recommended.

INTRODUCTION

Physical injuries to fresh horticultural produce can be caused by a number of factors but mechanical forces are the most important and of these, impacts (drops, knocks & collisions) are usually responsible for the majority of quality loss and waste. Impacts are a form of shock loading, they are short sudden stresses which are common on mechanical equipment used for handling produce.

This investigation undertaken for the Tomato Committee of the Queensland Fruit and Vegetable Growers, used an instrumented sphere to locate potentially damaging impact sites on equipment used for harvest, grading and packing of tomatoes in the Bowen and Bundaberg districts.

Queensland currently produces up to 70% of Australia's fresh market tomatoes. However, recent outturn assessments at central wholesale markets have identified bruising as a major defect of North Queensland tomatoes (Anning *et al.*, 1995). Mechanical injuries are believed to affect about 5% of Queensland's annual production of 14 million cartons worth in excess of $140 million.

Some tomato injuries brought about by impact are unsightly and directly reduce the aesthetic appeal of fruit. However, other impact injuries are more subtle and may simply facilitate shrivelling through water loss, or reduce storage life by providing entry points for disease organisms. Anning *et al.* (1995) found that any factor that caused even minute damage to the integrity of the tomato cuticle resulted in major increases in susceptibility to postharvest rots. The predominant decay organisms present on Florida and California tomatoes are those that require mechanical injury to enter and infect fruit (Ceponis & Butterfield, 1979).

MATERIALS AND METHODS

A. Tomato injury and drop height

INJURY TYPES

Injury resulting from impact can be associated with various physical disruptions to tomato tissues. The aim in describing impact injuries in this early stage of the report is to provide commercial tomato handlers with some picture of how injury severity relates to different sized impacts, generated by various drop heights.

To streamline assessment of sampled fruit and simplify interpretation of results, two descriptive categories of impact injury were chosen.

Category i) `surface splitting' visible at the fruit's surface, i.e. splitting of the skin through to the pulp.

Category ii) `internal injury', often only revealed by opening the fruit but may be associated with surface darkening or softening. More extreme cases are termed `internal bruising'. See Table 1 for rating scale and fuller descriptions.

Similar subjective ratings for tomato injury have been successfully used by MacLeod *et al.* (1976a) and Sargent *et al.* (1989). Previous studies have also described internal bruising (McColloch, 1962; Hatton & Reeder, 1963; Sargent *et al.*, 1989). Internal bruising is usually not readily apparent until the tomato is nearly at table ripe stage. Consequently, detection of internal bruising is normally not possible in packing houses but consumers notice the disorder. Fig. 1 illustrates internal bruising as defined in Table 1.

CORRELATING INJURY SEVERITY TO DROP HEIGHTS IN THE LABORATORY

In order to study details of tomato injury brought about by impact and to consider the effects of fruit characteristics on manifestation of injury, it was necessary to subject tomatoes to impact in the laboratory. The easiest way to achieve this was by dropping fruit.

Along typical packing lines drop heights of 1 or 2 cm may be of interest but in the laboratory it is difficult to control such small drops. To accurately quantify damage, fruit must not be allowed to bounce or experience more than one impact. The problem is solved by using a pendulum impact rig on which a tomato moves through an arc to simulate a vertical drop (Fig. 2). The rig incorporates a flat impact surface of steel which can be covered with various types of sheet padding typically used in packing lines.

In this study, impact surfaces were covered with a layer of chalk dust which was transferred to the tomato skin following impact (Fig. 3c). This enabled the location of inflicted bruises to be accurately determined on test fruit.

A series of trials was undertaken with "Tempest", a popular variety grown around Bowen. Unless otherwise stated the experiments also employed:

- medium-sized (see Fig. 3), green fruit
  or coloured fruit approximately at the stage of "half-colour" development
- fruit core temperatures of 20°C
- a flat steel impact surface on the pendulum rig
- 9 mm thick padding (over flat steel) = PVC closed-cell, nitrile sponge-rubber sheet with a smooth skin on the impact side. Density 88kg/m^3 . Compression deflection i.e. force required to compress 645mm^2 [1 square inch] 25% = 14-28kPa.

Findings are typically based on 40 impacts per treatment (i.e. for each combination of drop height and fruit characteristic). However, smaller samples were sometimes used when fruit availability was restricted.

Unless otherwise stated, two impacts were inflicted on each tested fruit at opposite points on the equator. However, when a fruit was split following the initial impact, a second impact was not inflicted.

Following impact with the rig, tomatoes were stored for 5 days at 20°C+/-2°C before assessment. Firmness of injury sites relative to uninjured surrounding surfaces was judged by hand pressure.

Table 1: Rating scale for internal injury (i.e. <u>not</u> surface splitting) of `Tempest' tomatoes caused by impact through drops

RATING	INJURY DESCRIPTION
1	No evidence of injury.
2	Flat spot or softening (relative to adjacent surfaces) at impact site.
3	Connection of locular seed & gel contents to pericarp wall is broken. Beginnings of hollow cavity may be present.
4	<u>Internal bruising</u>. Greater evidence of internal disruption. Distinct cavity present between locular contents and pericarp wall. Disrupted and scattered seeds, placental gel breakdown.
5	<u>Severe internal bruising</u>. Symptoms build on rating '4' to include: greater development of cavities in locule, narrowed and discoloured pericarp (yellowing), stringyness/desication of locular gel, often microbial spoilage.

Fig. 1 : Internal injuries of `Tempest' caused by impact

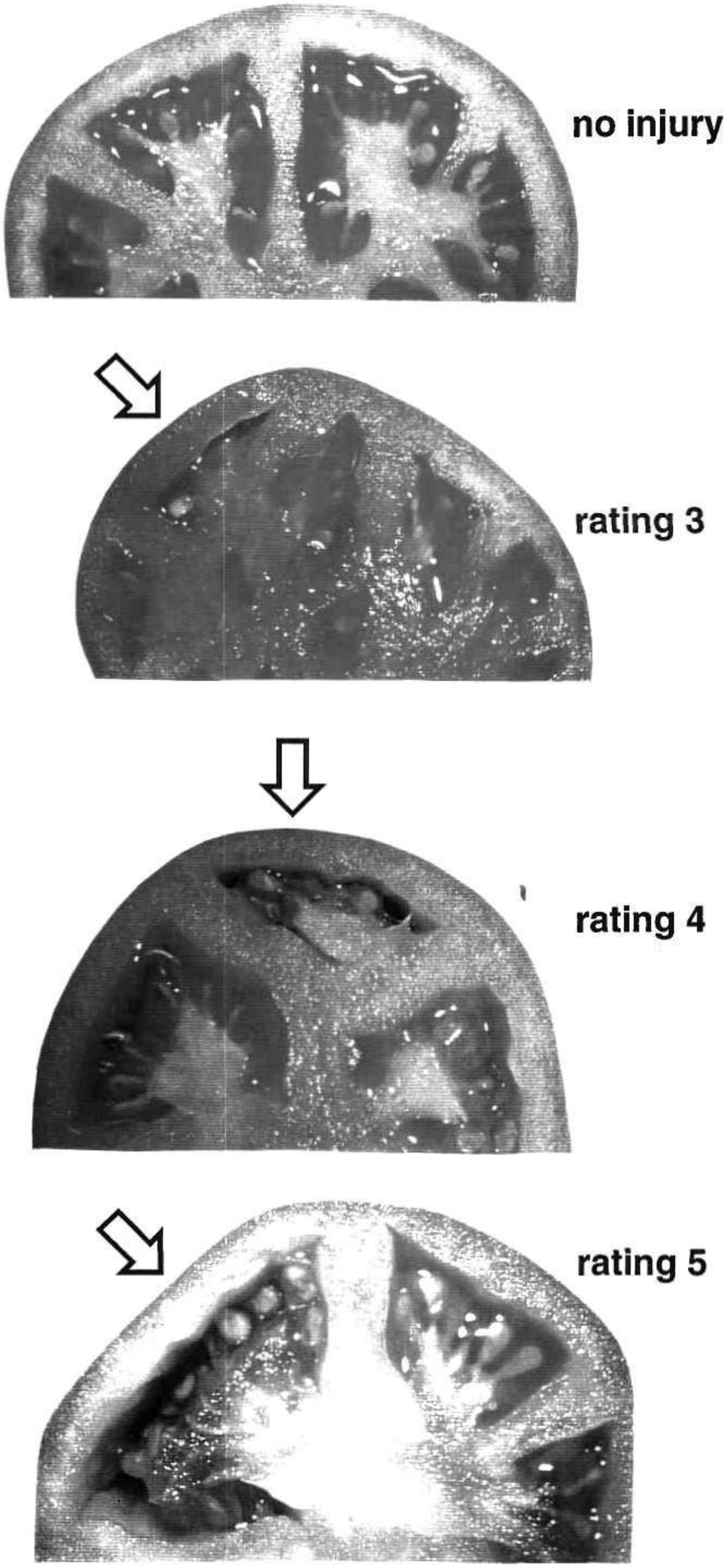


Fig.2: Diagram of pendulum impact rig

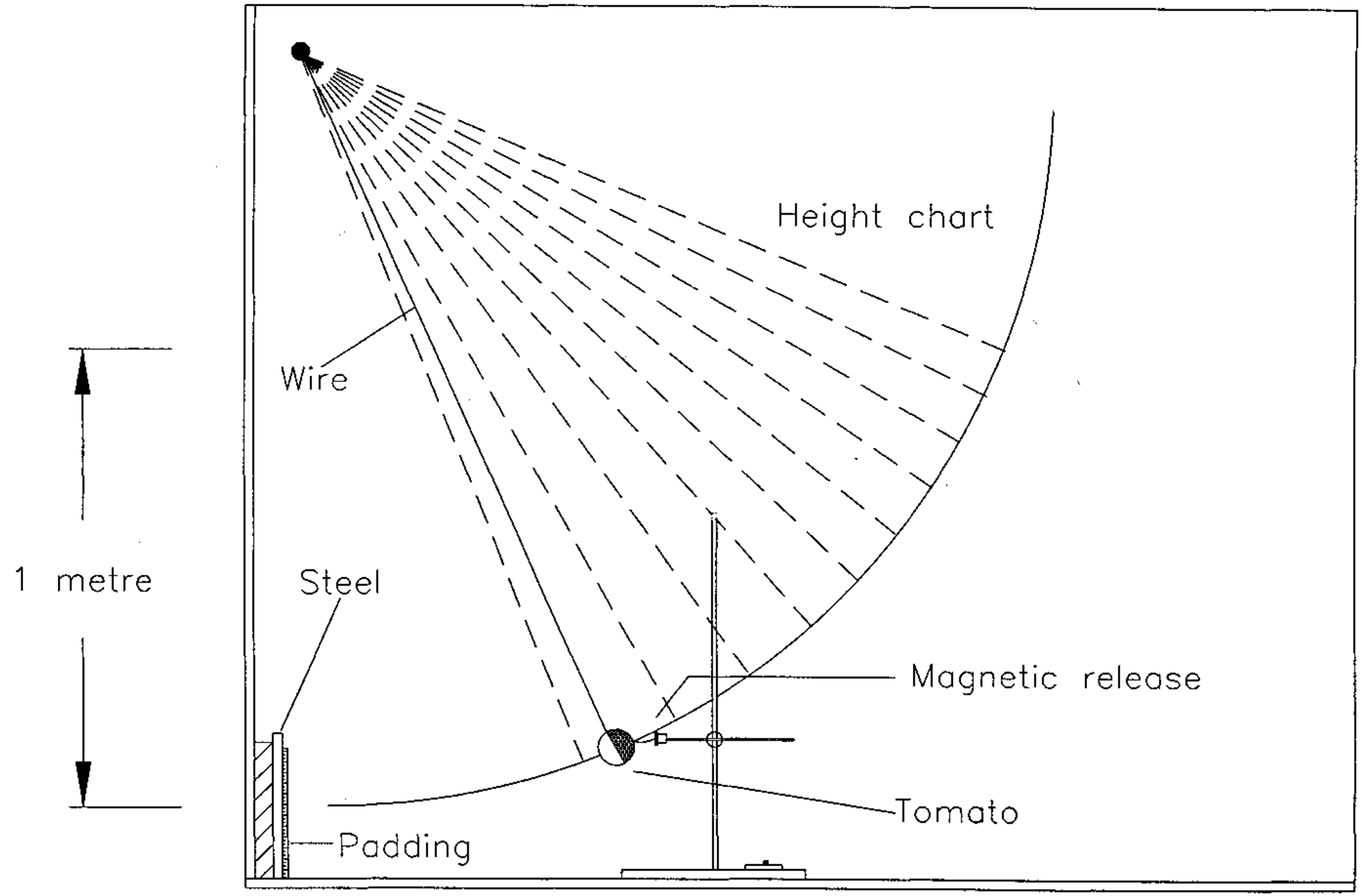
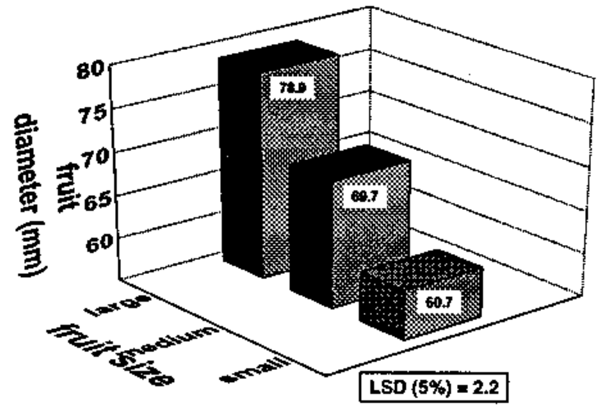
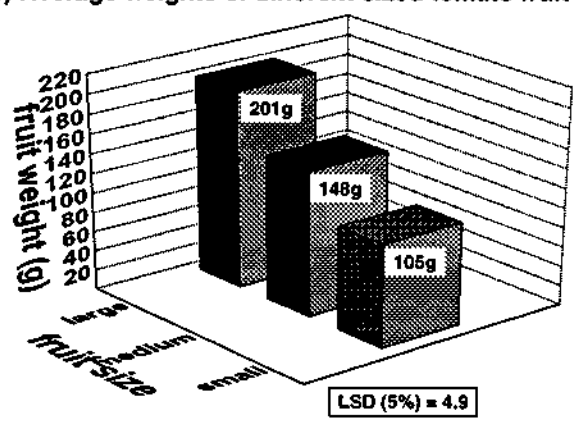


Fig. 3 : Tomato fruit specifications

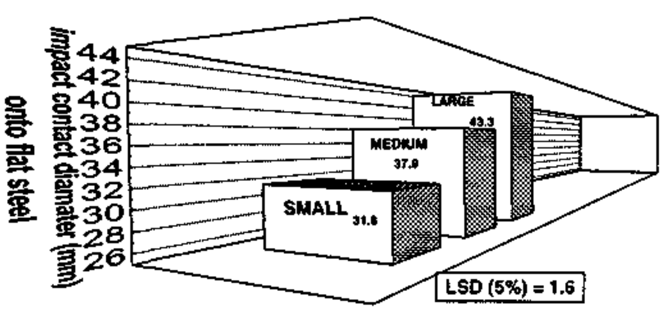
a) Average equator diameters of different sized tomato fruit



b) Average weights of different sized tomato fruit



c) Average diameters of contact areas on coloured tomatoes impacted against flat steel



B. *Correlation of drop heights to impact acceleration readings*

THE INSTRUMENTED SPHERE 100 (or IS100)

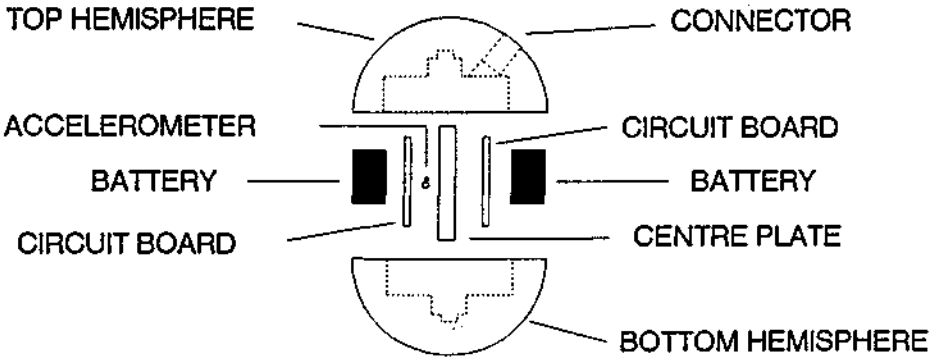
The IS100 impact recording device (also known colloquially as an `electronic pseudo-fruit') consists of a battery powered computer, and a piezo-electric accelerometer enclosed in a spherical shell of 70 mm diameter (Fig. 4). The accelerometer senses impacts along 3 axes.

Impacts registered by the sphere during its handling with produce are sent to a processor chip where they are logged, timed and passed to a memory chip. After the IS is operated, accumulated data are loaded into a computer for analysis. IS based software controls sampling rates, checks and stores data, and sends data to the computer. Computer based software provides data analysis and graphical display.

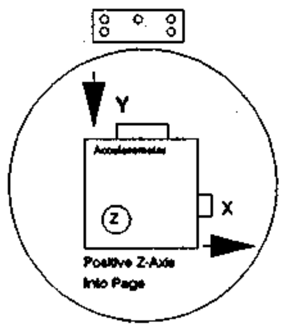
The sphere gives detailed information about numbers of impacts and their (peak) acceleration, measured in G. The higher the value of G, the larger and potentially more damaging the impact.

Using the IS on the impact rig (Fig. 2) enables correlation of drop height to impact acceleration (G), and data can be generated for various flat surfaces on which the sphere strikes.

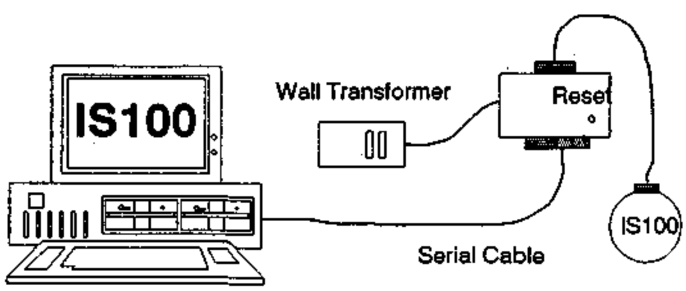
Fig. 4: Components of the IS100 instrumented sphere technology



A. IS100 Components



B. Accelerometer orientation within IS100



C. IS100 Configuration

C. *Field assessments using the instrumented sphere*

ASSESSMENT METHODS

Assessment involved repetitively passing the IS, together with tomatoes, through the normal handling process. The procedure was video-filmed and by co-ordinating the intrinsic timing mechanism in the IS with the camera's stopwatch, it was possible on replay of the footage to determine how a particular impact had occurred.

The IS was programmed with a 40G threshold during data accumulation which means that small impacts with accelerations less than 40G were not recorded, or included in the findings. Impacts of less than 40G are unlikely to cause damage to tomatoes under normal handling circumstances. Exceptions could include small impacts against sharp surfaces which are capable of piercing tomatoes. However, good handling equipment should be free of such protuberances.

INTERPRETATION OF INSTRUMENTED SPHERE DATA

Average impact acceleration figures presented in the results section are based on replicated runs (at least 10) through a particular site. Most sites are defined by a single principal impact but occasionally a `rebound' impact is associated with the principal impact. Note that for clarity of interpretation, the tabular summaries of data include descriptions of the physical sites on equipment where specific impacts occur. However, sometimes the description of the site and its associated impact are synonymous.

The figure presented in the tables as `maximum impact acceleration' is the largest impact out of the ten (sometimes more) runs through a site.

The frequency figure is based on total runs through a site, and serves to describe the consistency of impact occurrence at that site. Where the frequency is less than 100% it can be assumed that factors such as tomato loading, tomato positioning and minor variations in route, combined to ensure that impact did not occur on every run. Where the frequency is not an exact multiple of 10, the presented figure is based on more than 10 runs through the site.

RESULTS AND DISCUSSION

A. Tomato injury and drop height

The following discussion examines some fruit characteristics that may influence the manifestation and severity of injury following an impact from different drop heights. A comprehensive investigation was not attempted. Instead, the experiments were conducted with the aim of providing some background information on injury severity that growers / packers could use to assist in the interpretation of sphere data. However, only the variety `Tempest' has been considered. Observations made during IS assessments at Bundaberg suggested that the response of `Floridade' to impact stress was possibly different. Bruising on `Floridade' appeared to develop more quickly and was more readily apparent at the surface as soft, dark, water-soaked tissue.

For `Tempest', Fig. 5 plots injury levels versus drop height onto flat steel. Severity of internal injury levels progressively increased with increasing drop height. Drops of 80cm caused an average injury rating of approximately 4, the equivalent of `internal bruising' (see injury rating scale, Table 1 in the materials & methods section). McColloch (1962) and Sargent *et al.* (1989) also report an increase in incidence and severity of bruising with increasing drop height.

In comparison, Fig. 6 shows that the severity of internal injury is reduced by placing padding over the steel impact surface. Drops of 80cm onto padding caused an approximate severity rating of only 2.5. The lower r^2 for padding as compared with steel, reflects the padding's function in lowering the correlation between injury level and drop height. As well as reducing impact acceleration, padding increases the velocity change associated with impact, energy is dissipated and resulting injury levels are lower. The effectiveness of padding in reducing tomato damage caused by drops has been reported earlier (McColloch, 1962).

For medium-sized green tomatoes, mechanical injury was evident with drop heights of just 10cm onto steel (Fig. 7). The percentage of damaged fruit progressively increased with increasing drop height and following drops from heights of 80cm, 95% of impacts caused internal injury. Padding effectively reduced the percentage of injured fruit by approximately 30% but was more effective for larger drop heights (Fig. 7). In comparison to bare steel, injuries onto padding started with drops of 20cm (Fig. 7). At 80cm, 63% of drops onto padding caused injury compared with 95% of drops onto steel.

Internal bruising (i.e. rating 4 & greater) on medium, green fruit started at a drop height onto flat steel of 30cm, with 3% of the crop affected (Fig. 8). In comparison, 83% of the crop was internally bruised after 80cm drops (Fig. 8). Sargent *et al.* (1989) tested varieties other than `Tempest' and obtained much higher rates of internal bruising (20-30% for a 20cm drop).

A comparison of injury on green and coloured tomatoes for drops onto steel, shows that up to heights of approximately 40cm, the extent of internal injury development on both maturities was similar (Figs. 5 & 9). However, beyond 40cm, severity increased on green fruit. Conversely, other researchers working with different varieties report increased sensitivity to bruising on riper tomatoes (Sargent *et al.*, 1992; McColloch, 1962). In the present study, splitting of green and coloured `Tempest' fruit started at drops of around 60cm onto steel (data not presented).

Splitting of green `Tempest' tomatoes was affected by core temperature at time of impact (Fig. 10). Fruit with core temperatures of 10°C showed 23% splitting compared with only 3% of fruit at 30°C. Higher temperatures are believed to increase the plasticity of cell wall materials thereby making tissues less prone to failure.

Nevertheless, green fruit temperatures in the range 10°C to 30°C did not have a significant effect on manifestation of internal injury characteristics (Fig. 11). It is possible that temperatures outside of this range could affect internal injury, however, the range covers handling temperatures generally regarded as `too cold' to `too warm' (AGFACTS Department of Agriculture, NSW). One of the Bundaberg field managers suggested that bruising was worse for fruit with core temperatures over 35°C. He had also observed (without recorded or quantified data) that temperatures under 35°C did not effect susceptibility to handling injury. However, these observations were made for varieties other than `Tempest'.

MacLeod *et al.* (1976b) found no relationship between susceptibility to bruising and pulp temperatures in the range 5° to 30°C. However, fruit which were impact bruised at 5°C had more cracks in radial wall tissue.

Size of fruit (see Fig. 3 for fruit specifications) had no effect on the levels of internal injury development for coloured tomatoes (Fig. 12). Halsey (1955 & 1966) also found that bruising was not related to fruit size. Nevertheless, Fig. 12 again illustrates the importance of greater drop heights in causing increased severity of internal injury.

Although fruit size did not appear to affect internal injury, size did influence development of external surface splitting following large drops (Fig. 13). Large fruit size is known to be an anatomical characteristic of cracking sensitive cultivars of tomato (Peet, 1992). For drops of 40cm onto steel, there were no significant differences between the percentages of small, medium and large-sized fruit that had split (Fig. 13). However, for 80cm, only 7% of small fruit developed splits compared with 42% of large-sized, green fruit. Fig. 14 outlines the results of a comparable trial based on coloured tomatoes. As with green fruit, the trend suggests some increase in splitting vulnerability as fruit size increases. Compared to green fruit, more mature and more plastic coloured fruit are perhaps slightly less prone to splitting. For 90cm drops onto steel, 27% of coloured fruit developed surface splits compared with 42% of the green crop (Fig. 14).

The drop tests outlined thus far describe impacts against the side or equator of turgid fruit in optimum, marketable condition. Most impacts of this type caused radial splitting that was predominantly located through the stem scar and shoulder. Fig. 15 compares rates of splitting for impacts against the equator and shoulder for both turgid, and desiccated fruit. Fruit were desiccated following 5 days at 20°C and low humidity (visually they still appeared marketable). For impacts against the equator, desiccated fruit were significantly less likely to split (Fig. 15). However, impacts on the shoulder (around the scar) were more severe in their effects on splitting than those at the equator. Around the scar, the smaller radius of the shoulder probably reduces the ability of the structure to deform plastically. For shoulder impacts, the difference in splitting between turgid and desiccated fruit is not significant. Sargent *et al.* (1989) found that after shipping, bruises were primarily on the shoulder.

In summary, `Tempest' tomatoes appear to be most vulnerable to mechanical injury when they are large, hydrated, green fruit with low core temperatures. However, this variety was surprisingly resilient and when subjected to drop heights that could be considered extreme for any type of produce, responded with low levels of injury development. Often the laboratory drop heights required to induce injury on `Tempest' were in excess of those that would normally be observed in good packing sheds. Split fruit were not observed at any handling stage in the Bowen packing sheds.

Fig. 5 : Effect on internal injury severity of different drop heights onto steel for green tomatoes

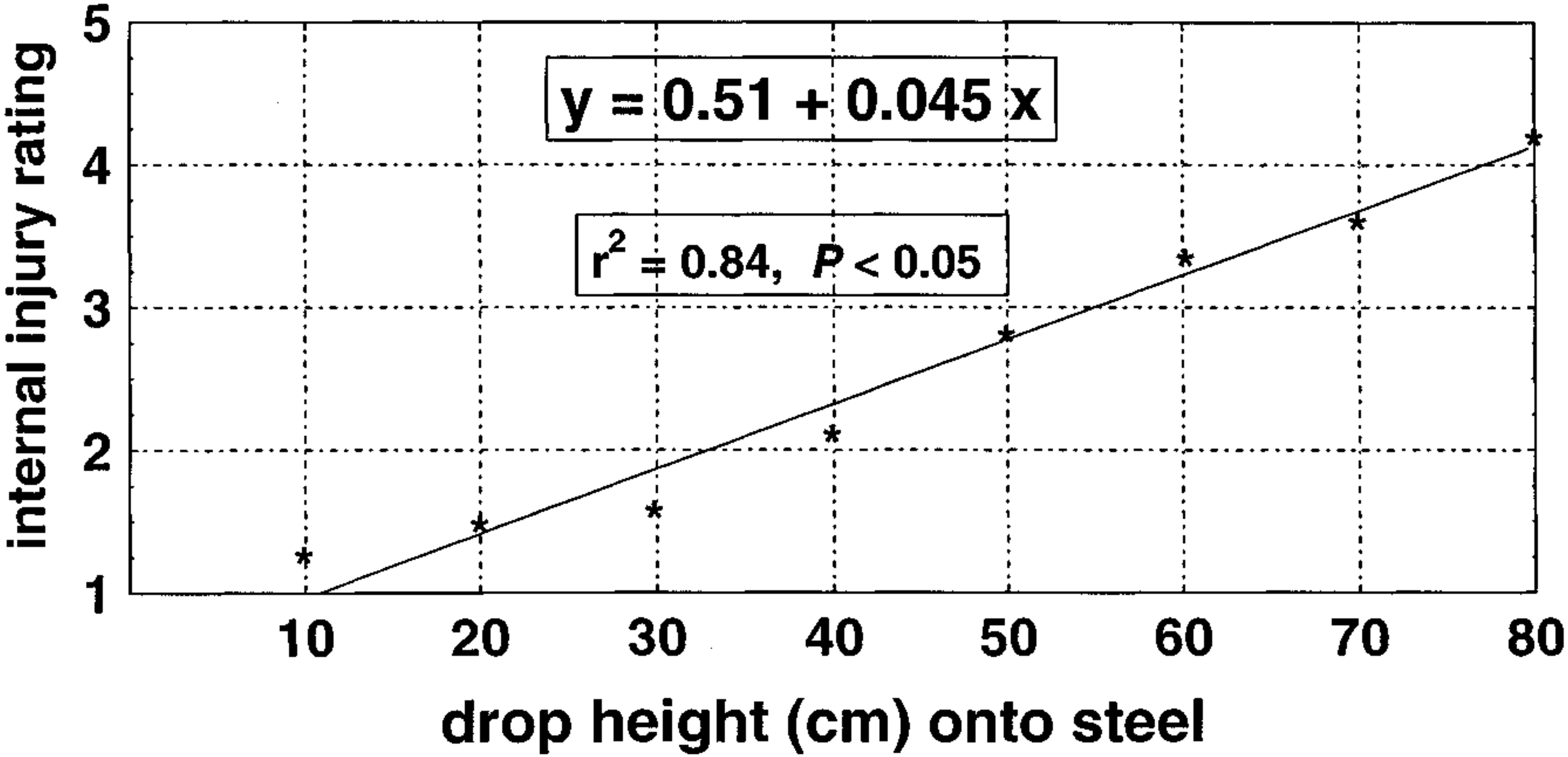


Fig. 6 : Effect on internal injury severity of different drop heights onto padding (over steel) for green tomatoes

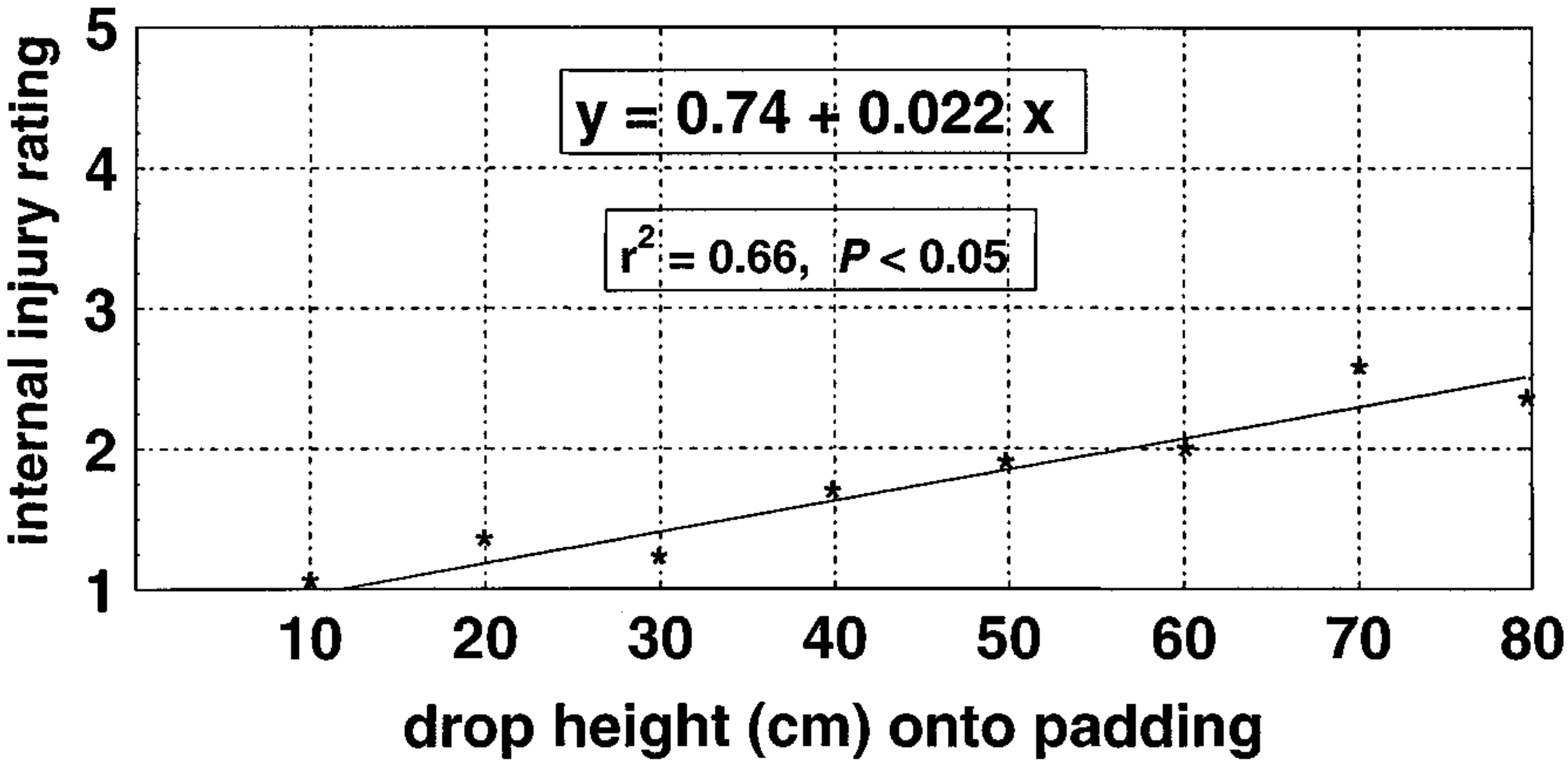
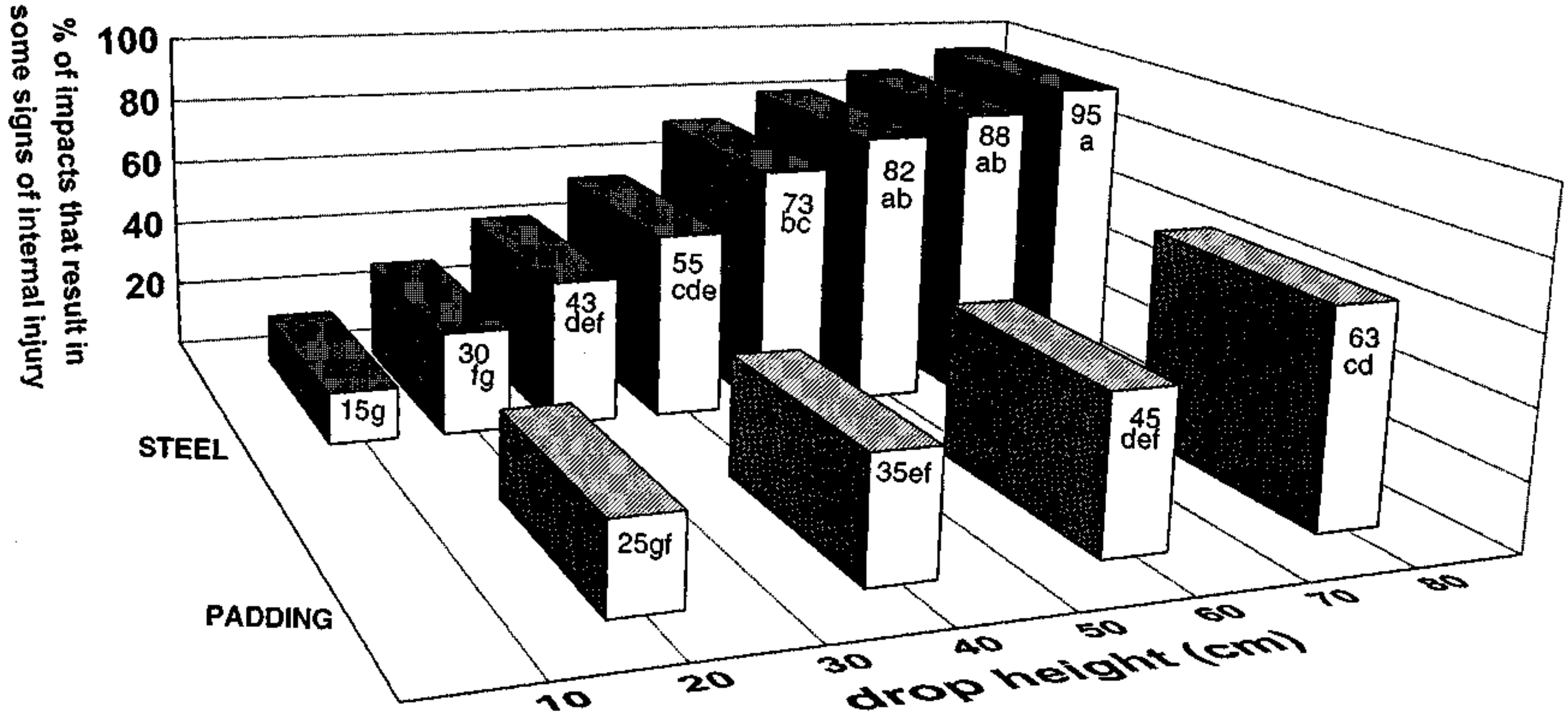


Fig. 7 : Percentage of impacts that result in some signs of internal injury on green tomatoes following drops onto steel & padded steel



Percentage figures followed by a different letter are significantly different, Chi-square test, *P*=0.05

Fig. 8 : Effect on the percentage of bruised green crop after different drop heights onto steel

Percentage figures followed by a different letter are significantly different,

Chi-square test, *P*=0.05

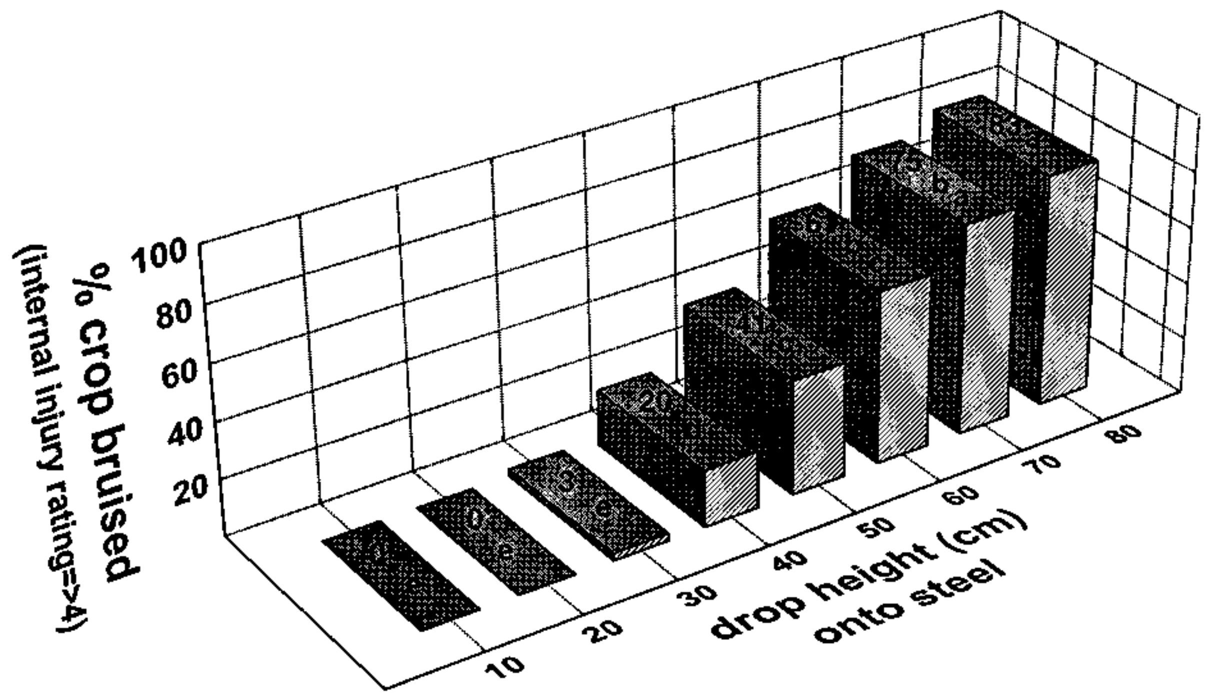


Fig. 9 : Effect on internal injury severity of different drop heights onto steel for coloured tomatoes

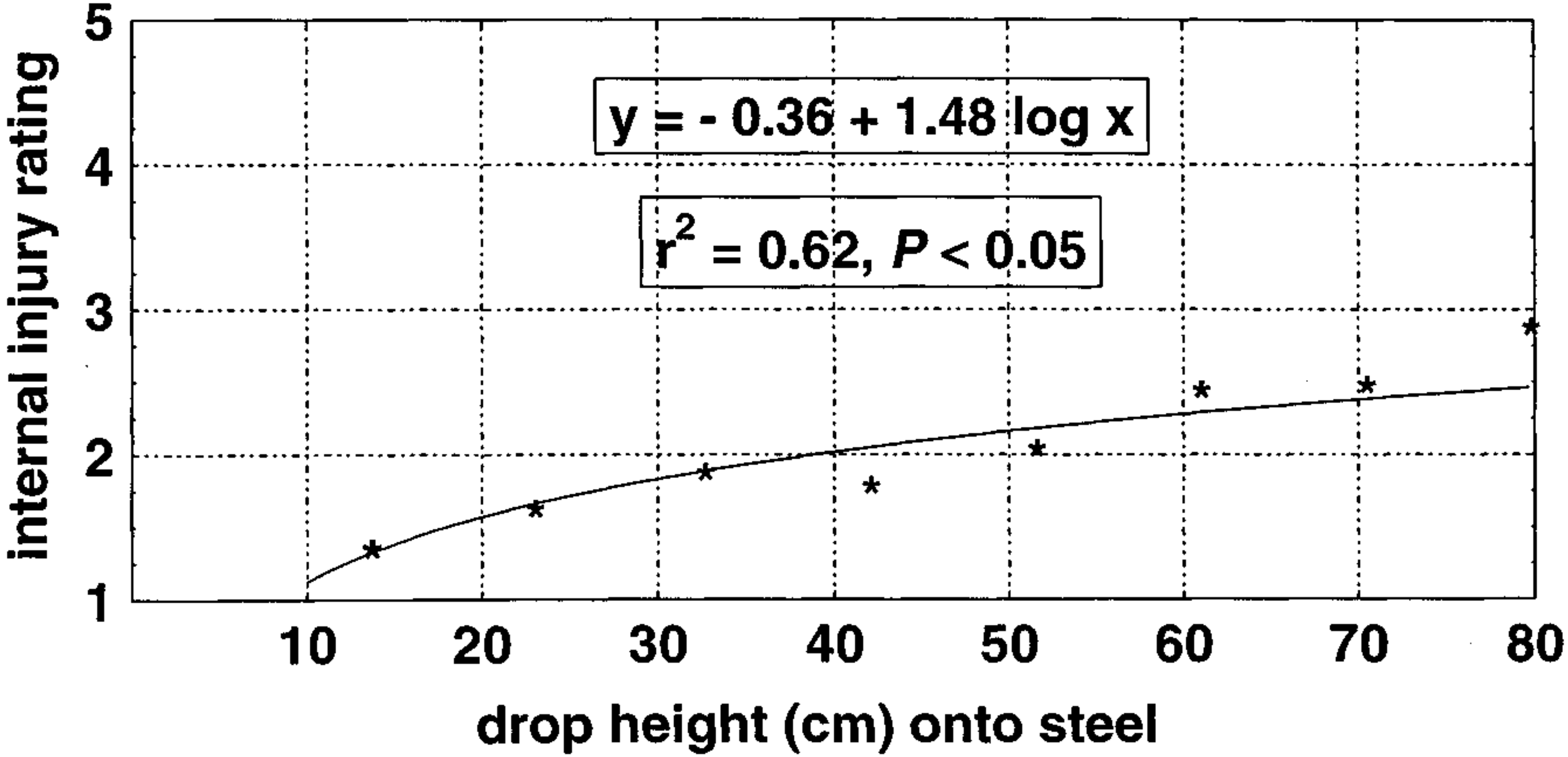


Fig. 10 : Effect of fruit core temperature at time of impact on percentage splitting of green tomatoes dropped from 90cm onto flat steel

Percentage figures followed by a different letter are significantly different, Chi-square test, $P = 0.05$

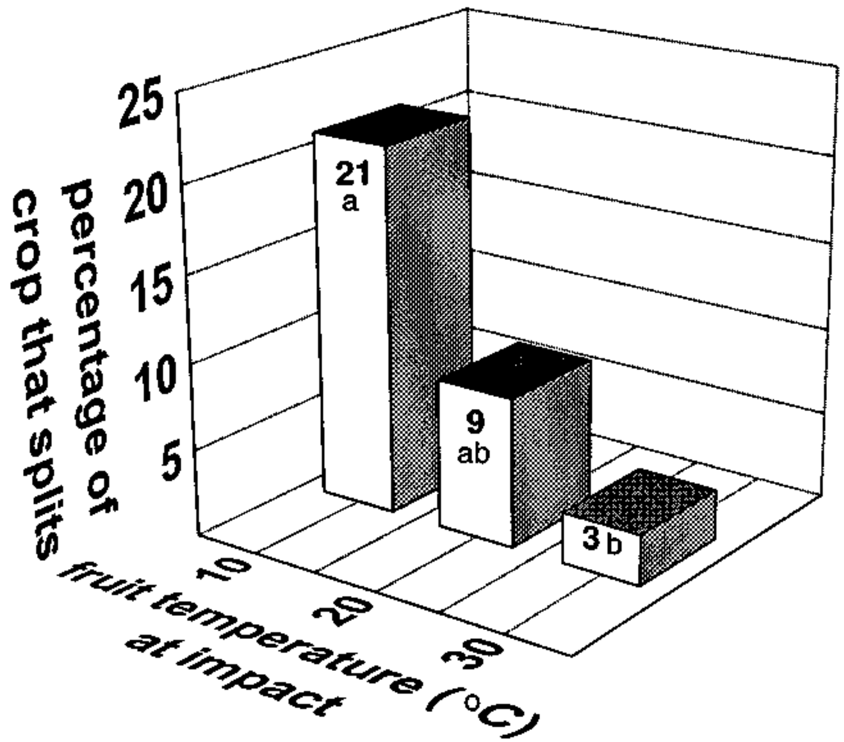
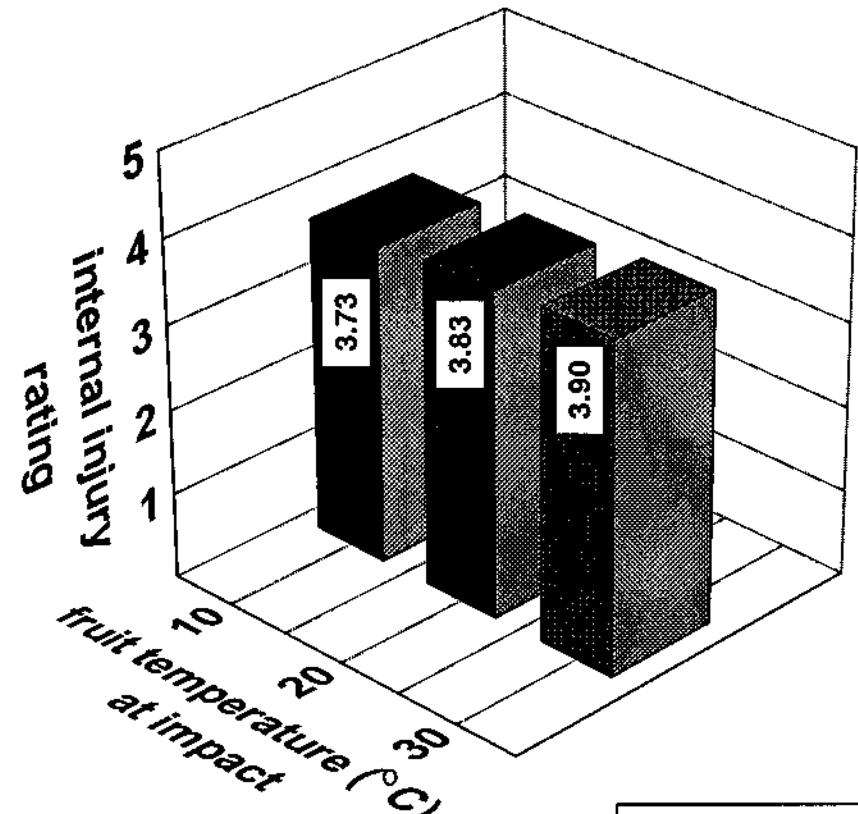
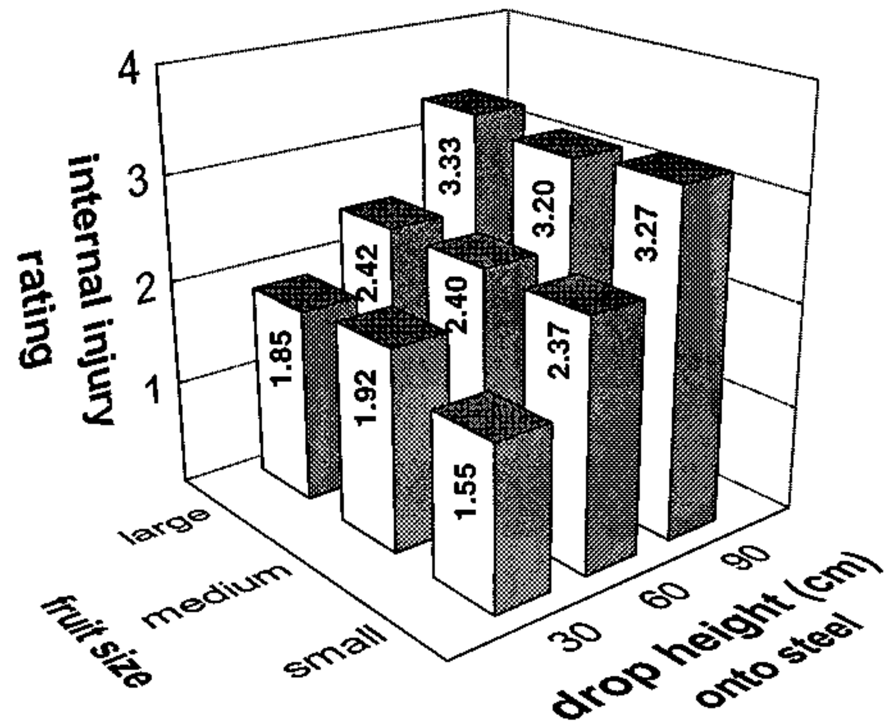


Fig. 11 : Effect of fruit core temperature at time of impact on internal injury severity of green tomatoes dropped from 90cm onto flat steel



LSD(5%)= 0.42 | NS

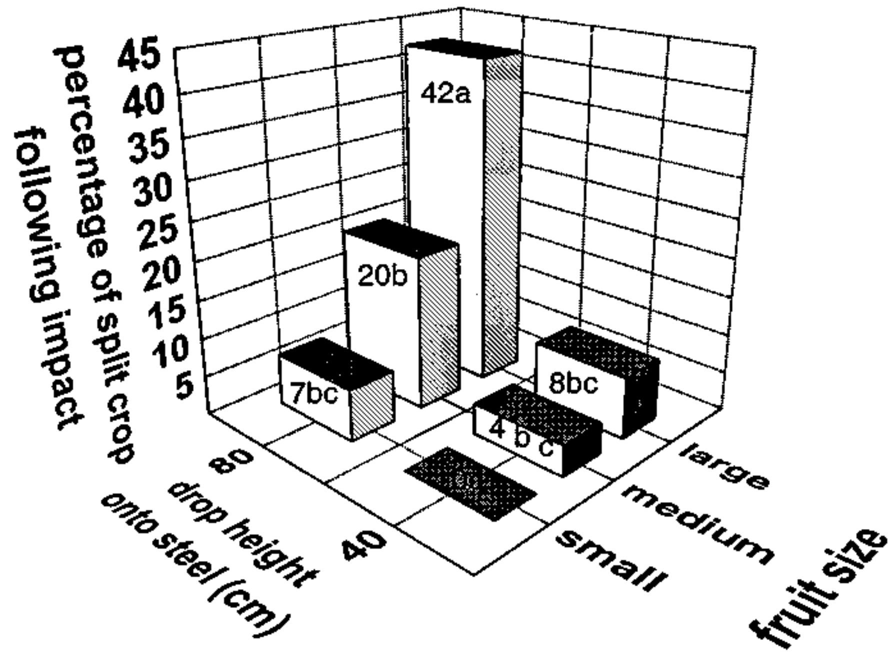
Fig. 12 : Effect of fruit size & drop height onto steel on internal injury severity of coloured tomatoes



LSD (5%)= 0.45

Fig. 13 : Effect of fruit size & drop height onto steel on splitting of green tomatoes

mean weights: small 98g, medium 166g, large 230g



Percentage figures followed by a different letter are significantly different, Chi-square test, *P*=0.05

Fig. 14 : Effect of fruit size & drop height onto steel on splitting of coloured tomatoes

Percentage figures followed by a different letter are significantly different

Chi-square test, P=0.05

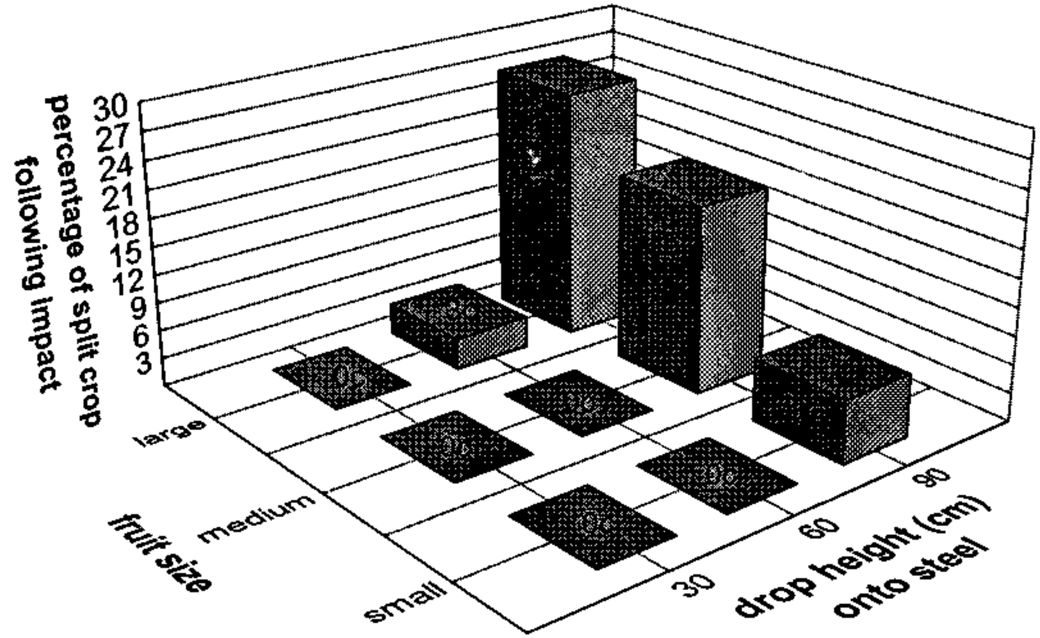
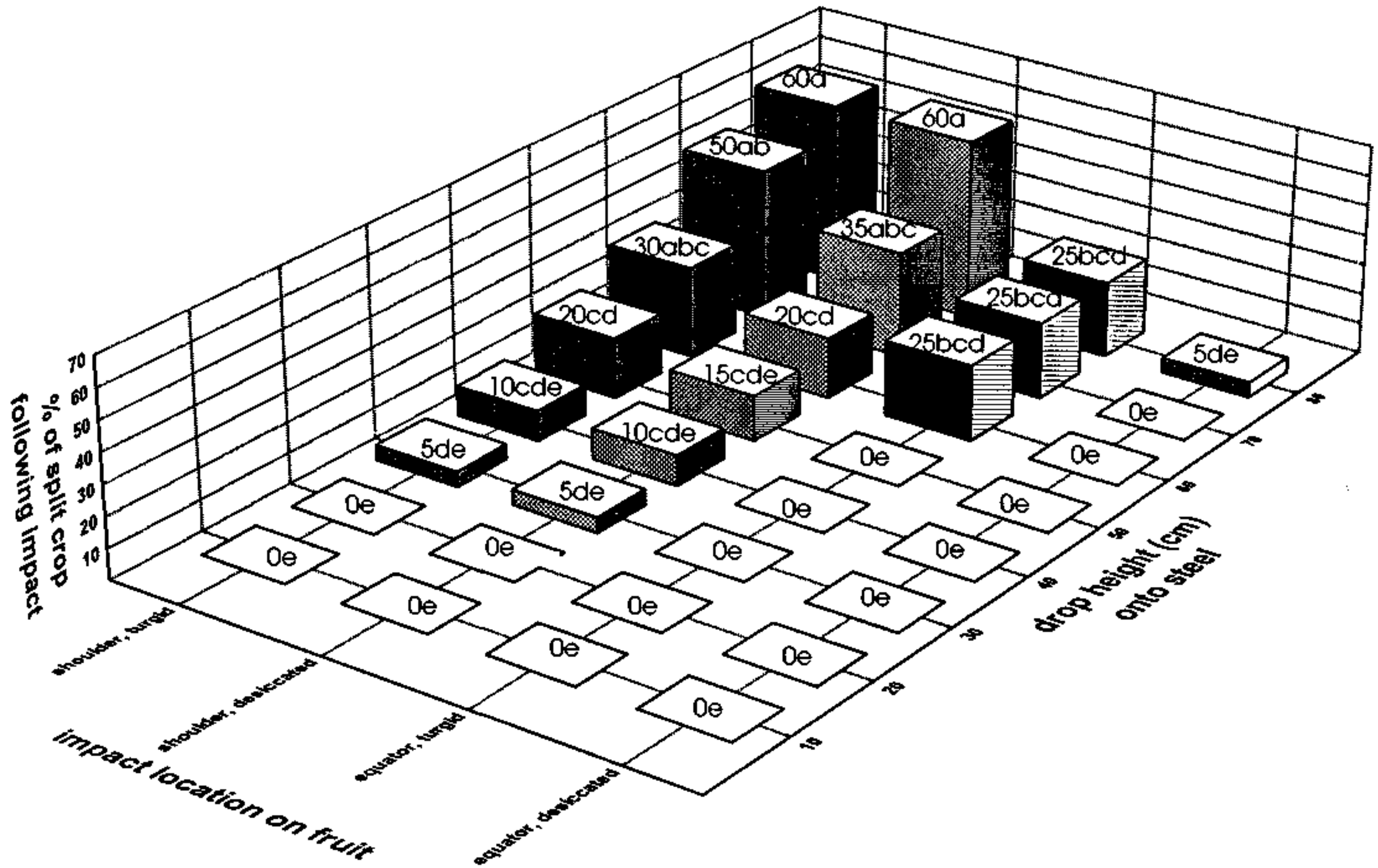


Fig. 15 : Effect of drop height onto steel, fruit hydration and impact location on percentage splitting of green crop



Percentages followed by a different letter are significantly different, Chi-square test, P=0.05

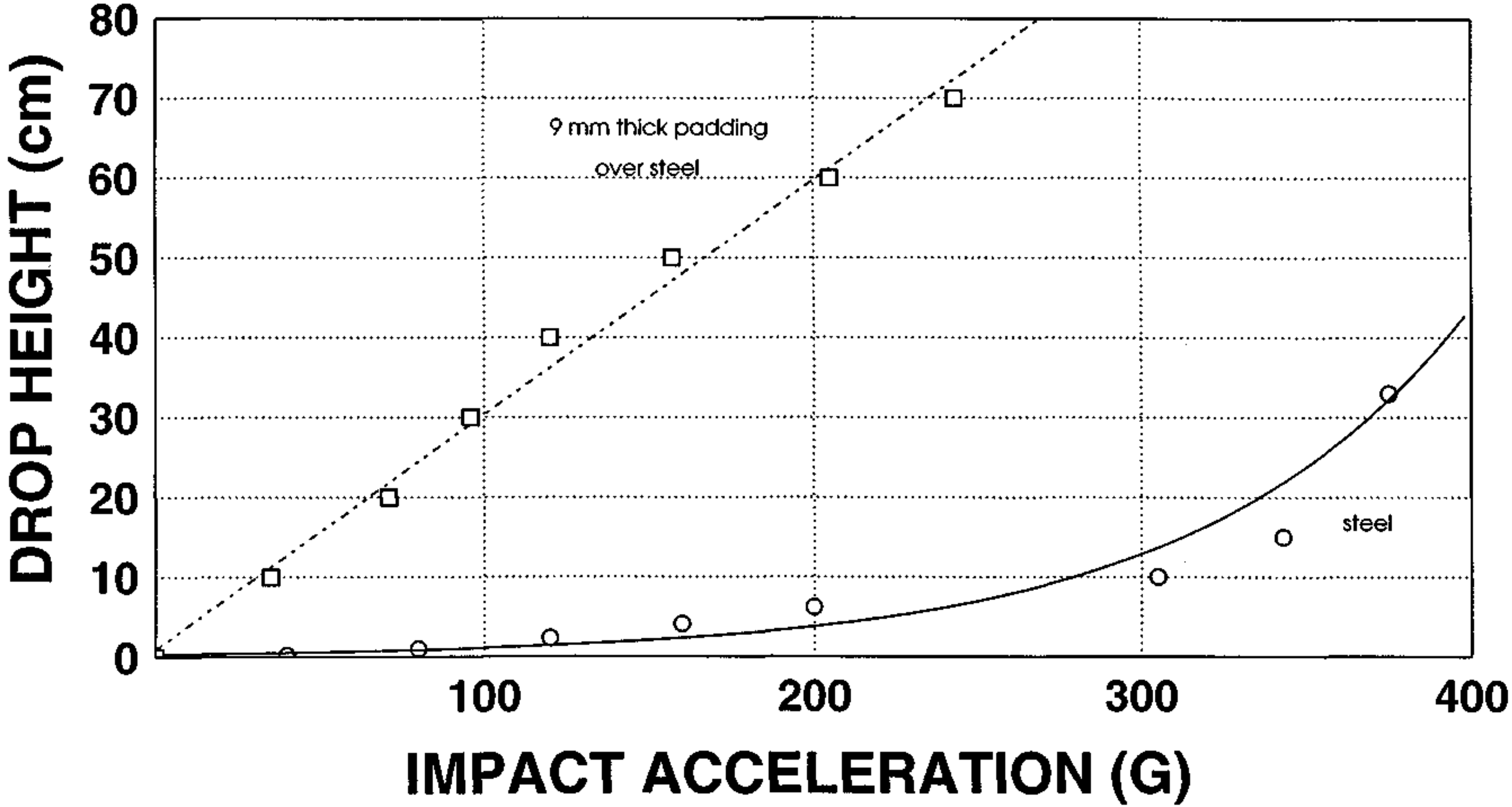
B. Correlation of drop heights to impact acceleration readings

Using the pendulum impact rig (Fig. 2), the sphere was dropped from heights in the range 0- 80cm. Drop heights onto a flat steel plate and flat steel covered with 9mm thick padding were correlated to impact acceleration (G) readings (Fig. 16).

Impact accelerations increased with increasing drop height. A 10cm drop onto the bare steel surface which is supported to prevent movement, resulted in a 305G impact (Fig.16). In comparison, the padding material (see Materials & Methods for specifications) effectively cushioned impact so that a 10cm drop produced only 35G (Fig. 16). Readings of around 350G are the maximum that can be measured both accurately and safely by the instrumented sphere's electronics.

Drops of 60cm onto the 9mm padding and 6cm onto the bare steel resulted in impact accelerations that were approximately equivalent (200G). Clearly the potential benefits to be gained by using padding to lower impact size should not be under-estimated given its relatively cheap cost, easy application and ease of maintenance.

Fig. 16 : Surface response curves for drop height versus impact acceleration



C. Field assessments using the instrumented sphere

PICKING

Techniques for hand picking into plastic buckets were assessed on two occasions. Packing shed operators popularly believe that pickers cause damage to fruit. However, impacts during picking are not necessarily large and their size is dependent on technique and care taken by the individual picker (Table 2).

The sphere was also passed through a prototype machine that removes fruit from the vine. However, before any meaningful information could be obtained, a large impact caused serious damage to the sphere. It was later established that the accelerometer had been separated from the internal circuitry. Nevertheless, IS technology will be an important tool in further development of mechanical picking devices for tomatoes.

MECHANISED HARVESTERS

At Bundaberg, three models of harvesting equipment were investigated with the sphere. It should be noted that unlike harvesters for some other horticultural crops, the machines currently used in the Queensland tomato industry do not remove fruit from the vine. Hand picking still takes place and the `harvester machine' simply acts as a repository for collecting and transferring fruit in the paddock.

For each harvester, impact sites (greater than 40G) are labelled numerically on a plan which also describes equipment type/function (see Figures 17, 18 & 19). To facilitate the identification of impact sites, they have been additionally described in the tables that follow the plans (Tables 3,6 & 8). The second table associated with each harvester precisely describes impact data for each site in terms of average size, frequency and maximum size.

The importance of high fruit loading to buffer movement and reduce impact is demonstrated by comparison of impact acceleration readings taken on harvester `A' with and without fruit.

Table 2: Summary of impact data recorded by an instrumented sphere during tomato picking into plastic buckets

PICKING DESCRIPTION	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
Throw into empty bucket (Picker = casual labour)			
	135	100	198
Throw into bucket with 1-2 layers of fruit (Picker = casual labour)			
	67	100	93
Bucket on angle between knees & tomato/IS passed in individually* (Picker = packing shed manager)			
	63	40	77
***As the number of fruit increased in the bucket, impact was less likely to occur. Impacts generally occurred initially in near empty buckets with exposed bases. Note : this was an observed trend & not one substantiated statistically.**			
Handfuls of fruit (+ IS) dropped into bucket placed vertically on the ground (Picker = packing shed manager)**			
	53	approx 20	63
****Based on a small sample of drops, the degree of fill appeared unrelated to occurrence of impact. Note: this was an observed trend & not one substantiated statistically.**			

Fig.17: Impact sites on harvester model 'A'

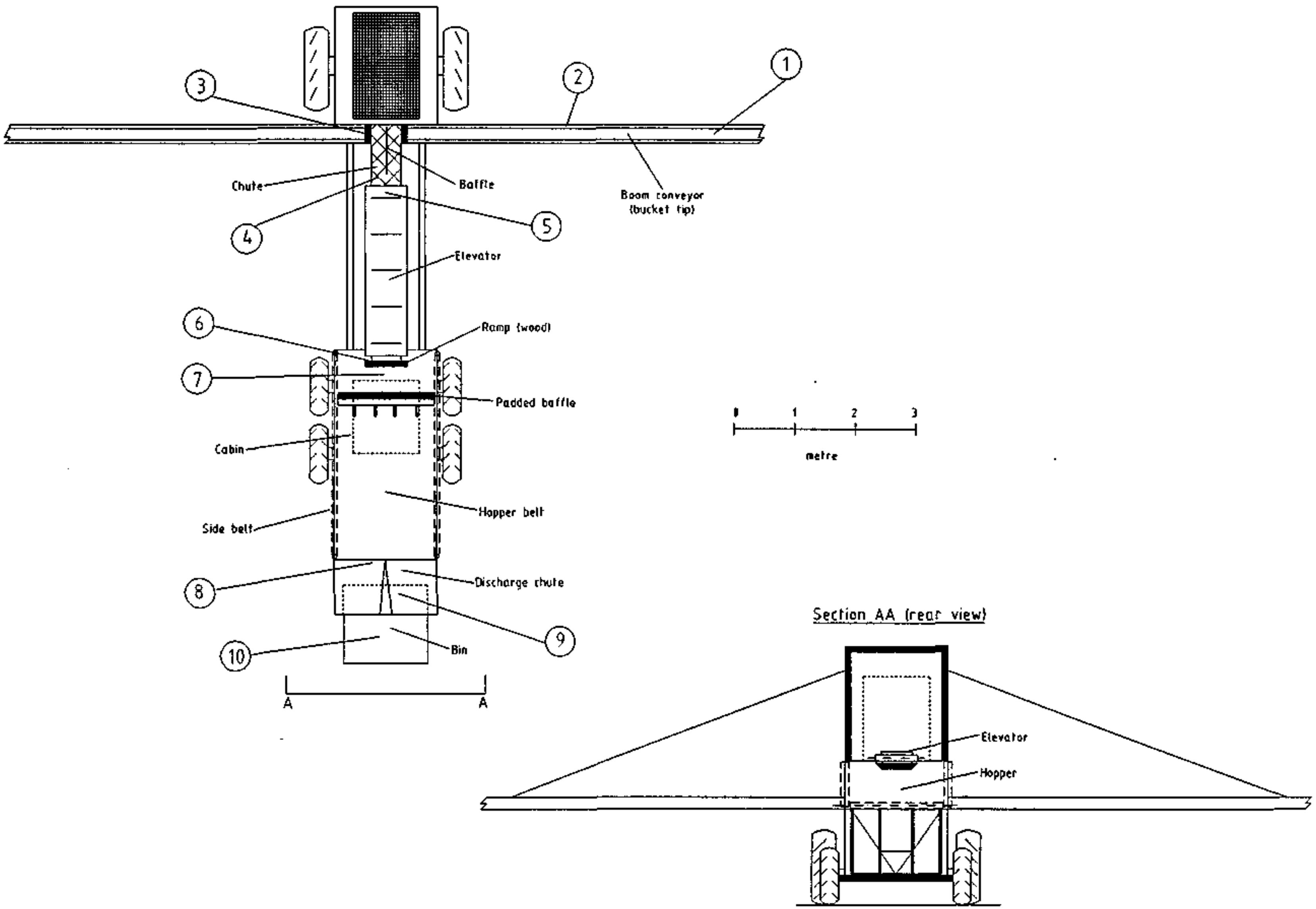


Table 3: Description of impact sites on harvester model `A'

SITE	IMPACT SITE DESCRIPTION
1	bucket tip onto conveyor
2	rebound against edge of conveyor wall
3	off conveyor onto ramp
4	onto chute
5	off chute onto elevator
6	off elevator onto ramp
7(a)	off ramp into hopper (2-5 layers of fruit)
7(b)	off ramp into hopper (Full hopper)
8	off hopper belt onto discharge chute
9	along discharge chute
10(a)	off discharge chute into empty bucket 15 cm below chute tip (no fruit)
10(b)	off discharge chute into wooden bin using padding in bin (with fruit)

Table 4: Summary of impact data recorded by an instrumented sphere on harvester model `A' *(No fruit)*

SITE*	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	98	90	159
2	52	30	57
3	148	60	282
4	119	40	236
5	90	70	193
8	121	100	136
9	125	92	199
10(a)	74	100	98

*Impacts on Site 6 and 7 are independent of fruit loading on harvester.

Table 5: Summary of impact data recorded by an instrumented sphere on harvester model `A' (*With fruit*)

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	49	33	49
2	81	17	81
3	68	83	77
4	57	50	68
5	53	40	55
6	145	100	181
7(a)	71	100	104
7(b)	48	10	48
8	127	50	195
9	95	25	114
10(b)	85	63	121

Fig.18: Impact sites on harvester model 'B' (10 elevator)

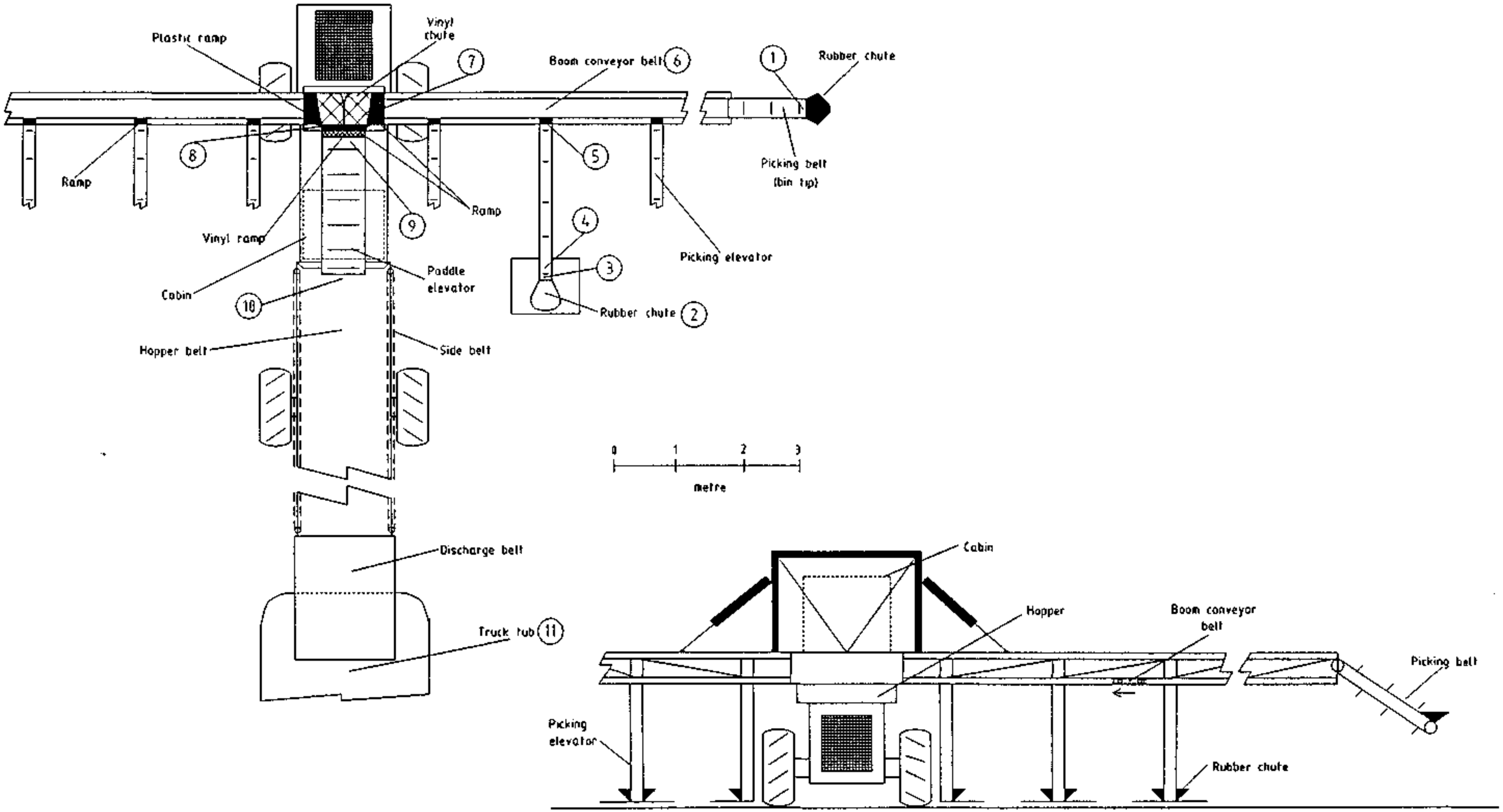


Table 6: Description of impact sites on harvester model `B' (10 elevator)

SITE	IMPACT SITE DESCRIPTION
1	bucket tip onto picking belt (3 fruit layers in bucket)
2	picking onto rubber chute
3	onto picking elevator
4	along picking elevator
5	off picking elevator onto ramp
6	off ramp onto boom conveyor belt
7	off belt onto plastic ramp edge
8	onto ramp after vinyl chute
9	out of chute onto paddle elevator
10(a)*	off paddle elevator into hopper (with fruit)
10(b)	off paddle elevator into empty hopper or single fruit layer
11(a)	off discharge belt into empty truck tub
11(b)	rebound inside empty truck tub
11(c)*	off discharge belt into truck tub (with fruit)

*Range of fruit depths inside hopper and truck tubs.

Table 7: Summary of impact data recorded by an instrumented sphere on harvester model `B' (10 elevator)

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	148	100	223
2	89	38	114
3	69	71	116
4	63	50	106
5	159	100	220
6	64	82	111
7	75	70	88
8	52	10	52
9	95	80	153
10(a)	70	89	93
10(b)	86	100	108
11(a)	301	100	412
11(b)	116	91	224
11(c)	53	58	68

PROBLEM SITES:

Site 5: Large average impact acceleration. Virtually all fruit picked travels over this site so cushioning material should be used on each ramp to minimise potentially damaging impacts.

Site 11(a): Very high average impact acceleration. Effects of large drop height from discharge belt into tub can be minimised by using a mat inside tub to cushion initial fruit drop.

Fig.19: Impact sites on harvester model 'C' (5 elevator)

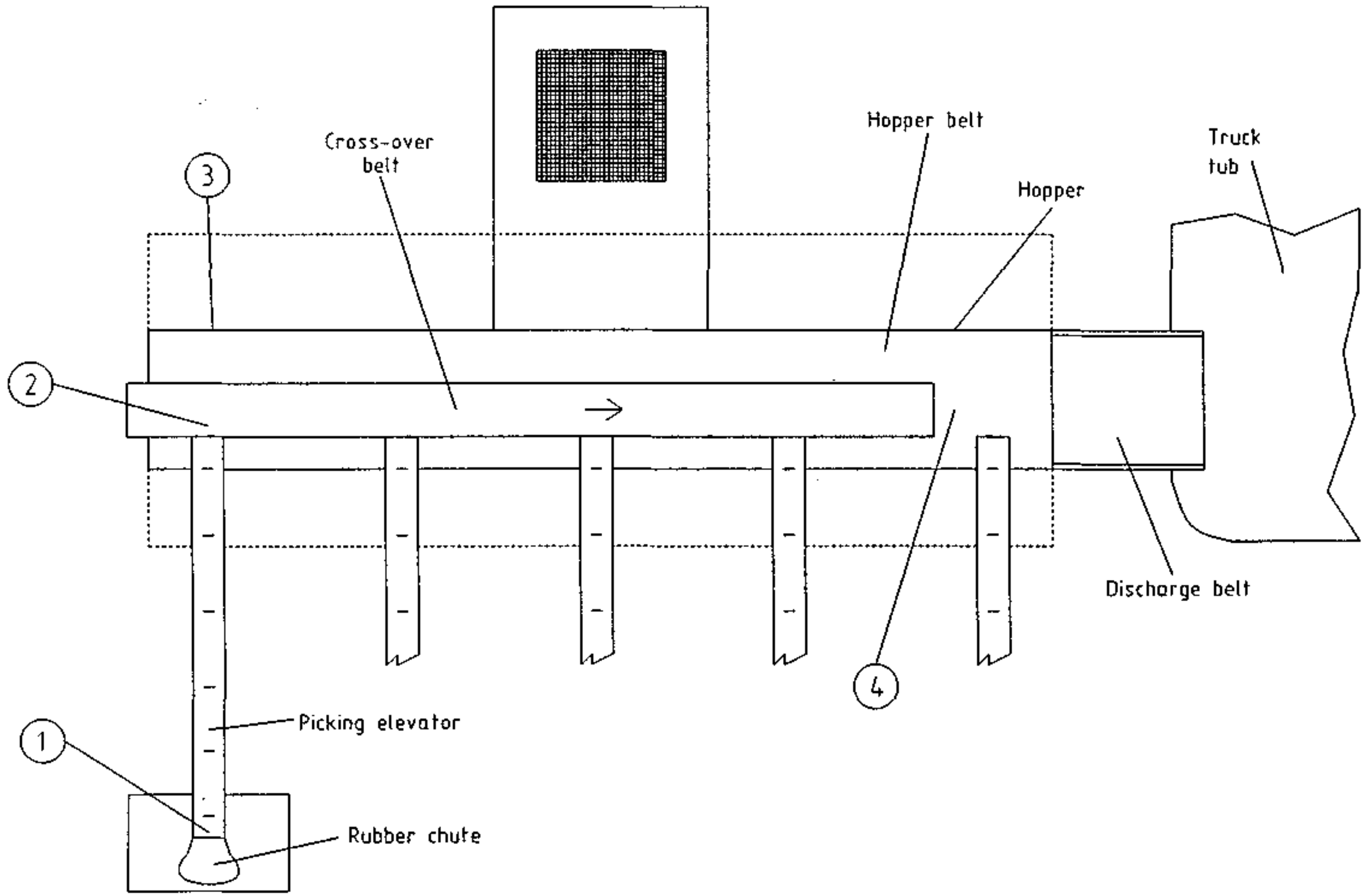


Table 8: Description of impact sites on harvester model `C' (5 elevator)

SITE	IMPACT SITE DESCRIPTION
1	onto picking elevator
2	off picking elevator onto cross-over belt
3	onto cross-over belt side wall
4(a)*	off cross-over belt into hopper (with fruit)
4(b)	off cross-over belt into empty hopper

* Range of fruit depths inside hopper.

Table 9: Summary of impact data recorded by an instrumented sphere on harvester model `C' (5 elevator)

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	61	24	78
2	73	53	123
3	118	13	169
4(a)	73	91	95
4(b)	97	100	157

PACKING SHEDS

In the Bowen district the instrumented sphere was used to assess ten packing sheds, each of which contained a separate line for both green and red fruit. At Bundaberg, packing facilities were investigated in five sheds.

The results are presented in Figures 20 to 46, and in Tables 10 to 61. However, to ensure privacy of findings for the workers and companies who own and operate the packing equipment, results have been labelled with an alphabetic code. Neither the allocated code, nor order of presentation, in any way reflect the capacity to handle fruit correctly (or incorrectly) in specific sheds. As part of the technology transfer activities associated with this project, packing shed operators have been provided with results for their shed. This document will provide them with some means of rating their own operation's performance against that of others.

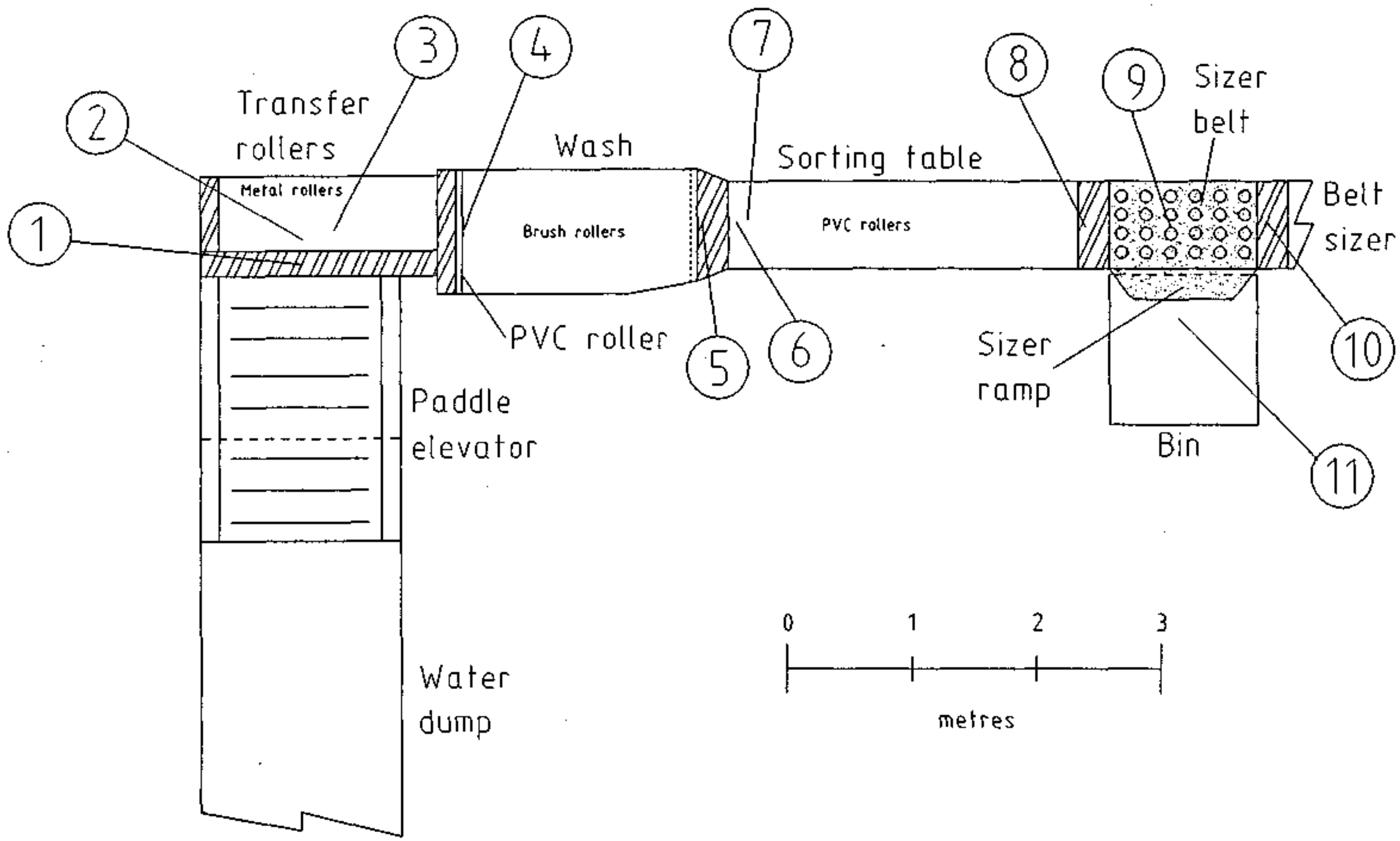
Overall, the sphere's characteristics proved to be well suited to handling studies of tomatoes. It accurately represented movement of the crop through mechanical equipment and its size, which approximates a medium tomato, enabled assessment of all handling line processes. In addition, the impact acceleration range which can be accurately registered by the sphere was the appropriate range for impacts occurring during tomato harvesting, sizing, grading and packing.

The instrumented sphere data presented in this section of the report enables a relative comparison of the damage potential of different sites.

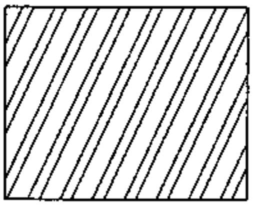
For each shed, impact sites (greater than 40G) are labelled numerically on a floor plan which also describes equipment type/function (see Fig. 20 as an example). To facilitate the identification of impact sites by shed operators, sites have been additionally described in the tables that immediately follow the floor plans (e.g. Table 10). The second table associated with each handling line precisely describes summarised impact data for each site in terms of average size, frequency and maximum size.

Summaries of all the shed data follow the figures and tables presented for individual sheds.

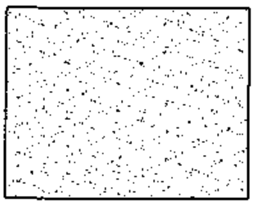
Fig.20: Shed 'MMM' green line



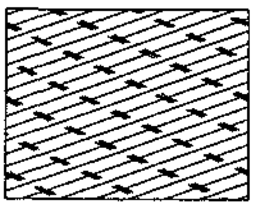
Key to tomato packing line diagrams



Solid ramps - steel/plastic/wood
(including vinyl covered solid ramps)



Cushioning (various thicknesses)/Vinyl flaps



Vinyl (or covered with) sizer ramps and chutes

Elevation changes (along PVC rollers)
Hidden belts etc.

Retarding curtains (Rubber, vinyl etc.)

Singulator rollers/cups

Table 10: Description of impact sites on the `MMM' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto ramp
2	onto metal transfer rollers
3	rebound on metal transfer rollers associated with 2
4	off ramp onto PVC roller (which leads onto brush rollers)
5	off brush rollers onto ramp
6	onto PVC rollers of sorting table from ramp
7	rebound on PVC sorting rollers associated with 6
8	off PVC sorting rollers onto ramp
9	out of sizer belt onto sizer ramp
10	off sizer belt onto ramp
11	drop into bin

Table 11: Summary of impact data recorded by an instrumented sphere on the `MMM' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	60	50	74
2	136	100	185
3	64	90	98
4	78	80	103
5	61	60	79
6	133	100	189
7	69	100	87
8	55	60	60
9	65	40	83
10	68	100	85
11	82	80	127

Fig.21: Shed 'MMM' red line

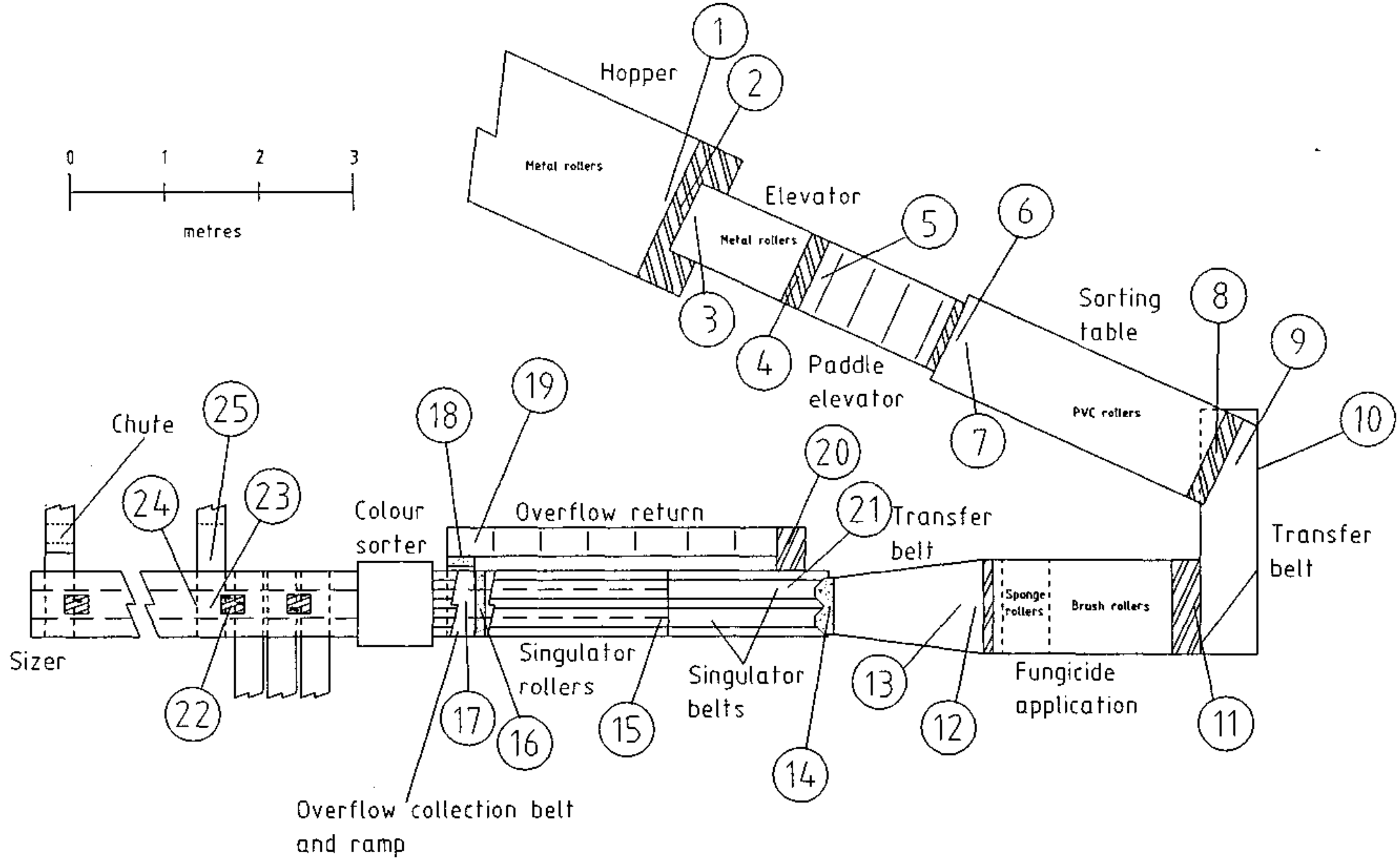


Table 12: Description of impact sites on the `MMM' red line

SITE	IMPACT SITE DESCRIPTION
1	off tomatoes onto leading edge of hopper rollers
2	off hopper rollers onto top edge of ramp
3	onto elevator from ramp
4	off elevator onto ramp
5	onto paddle elevator from ramp
6	off paddle elevator onto sorting table
7	rebound following drop onto sorting table
8	off PVC rollers of sorting table onto ramp
9	off ramp onto transfer belt
10	against side wall opposite ramp
11	off transfer belt onto ramp
12	off ramp onto transfer belt
13	rebound on belt associated with 12
14	onto ramp before singulator belts
15	off singulator belts onto singulator rollers
16	onto overflow ramp
17	off ramp onto overflow belt
18	off overflow belt onto side housing of paddle elevator
19	settling impact on paddle elevator
20	off return paddle elevator onto ramp
21	overflow return to singulator belt
22	off sizer rollers onto leading edge of sizer ramp
23	off ramp onto top area of chute
24	against wall opposite sizer ramp
25	along chute

Table 13: Summary of impact data recorded by an instrumented sphere on the `MMM' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	111	50	138
2	163	100	312
3	160	60	330
4	100	100	125
5	66	30	85
6	153	100	207
7	80	80	111
8	100	100	117
9	75	80	109
10	209	10	209
11	76	100	104
12	114	100	145
13	63	50	75
14	55	60	59
15	58	40	68
16	105	80	129
17	106	80	258
18	127	100	161
19	74	90	99
20	146	100	164
21	52	60	66
22	121	20	157
23	72	30	129
24	62	60	85
25	85	90	149

Fig.22: Shed 'TTT' tomato packing line

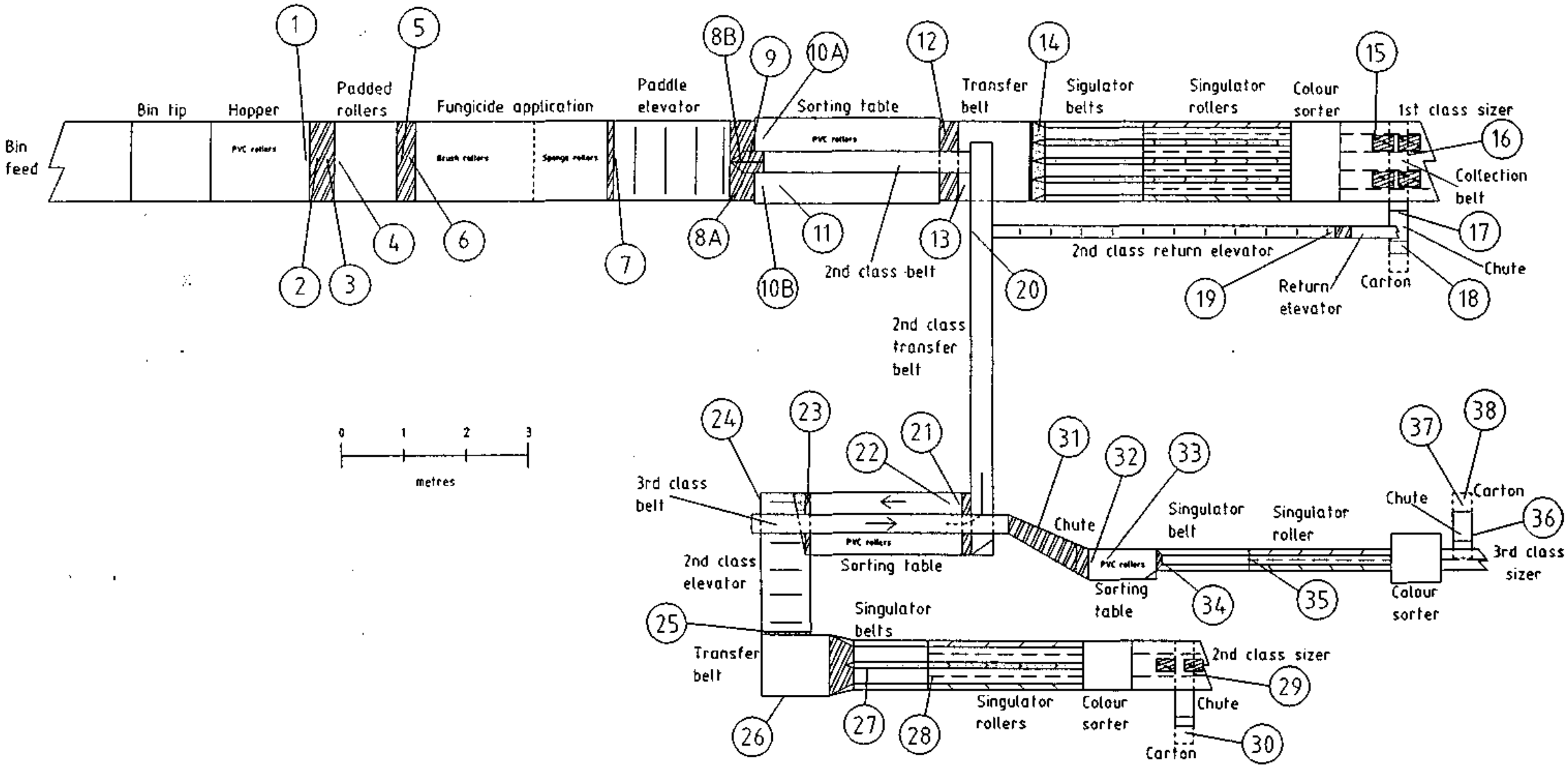


Table 14: Description of impact sites on the `TTT' line

SITE	IMPACT SITE DESCRIPTION
BIN TIP	2 runs, IS on top of fruit, NO IMPACTS
1	onto leading edge of hopper rollers
2	onto ramp
3	bounce along ramp
4	off ramp onto padded rollers/fruit
5	off padded rollers onto ramp
6	bounce along ramp
7	off sponge rollers onto elevator
8A	off elevator directly onto ramp
8B	off elevator onto ramp angle (approx. 25% of fruit hit this angle)
9	onto angle side/ramp
10A	off angle/ramp onto rollers
10B	off ramp onto rollers
11	settling impact along rollers
12	off sorting table onto ramp
13	off ramp onto transfer belt
14	off transfer belt onto vinyl ramp
15	off sizer rollers onto top edge of sizer ramp (first class)
16	against side wall of collection belt (first class)
17	off collection belt onto chute (first class)
18	along chute (sidewall, bounce etc.) (first class)
19	off seconds return belt onto return elevator
20	off second class return elevator against wall along transfer belt
21	off second class transfer belt onto sorting table
22	settling impact along PVC rollers
23	off second class sorting table onto ramp (top edge)
24	onto wall opposite sorting table
25	off seconds elevator onto ramp
26	against wall opposite elavator
27	off transfer belt onto angle
28	onto singulator rollers
29	off sizer against chute wall
30	into near empty carton
31	against side wall of chute (third class line)
32	onto PVC rollers (third class line)
33	along PVC rollers (third class line)
34	off PVC rollers onto ramp (third class line)
35	off singulator belt onto singulator rollers (third class line)
36	off sizer rollers onto chute wall (third class line)
37	into near empty carton (third class line)
38	bounce inside carton

Table 15: Summary of impact data recorded by an instrumented sphere on the `TTT' line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	83	50	122
2	142	90	184
3	83	50	134
4	88	50	122
5	125	100	173
6	56	40	68
7	71	20	78
8A	58	100	62
8B	212	100	259
9	84	80	106
10A	125	100	154
10B	206	100	265
11	60	60	70
12	93	100	113
13	64	20	75
14	47	60	58
15	85	20	86
16	54	50	75
17	62	20	80
18	48	60	56
19	95	90	133
20	81	60	98
21	109	90	143
22	52	40	55
23	87	100	107
24	132	50	202
25	56	70	66
26	90	60	119
27	45	30	49
28	56	30	66
29	74	90	137
30	97	90	126
31	58	50	74
32	117	100	165
33	71	100	110 (3.3 impacts/run)
34	57	30	63
35	86	60	105
36	56	70	65
37	106	100	152
38	63	40	71

Fig.23: Shed 'GGG' green line

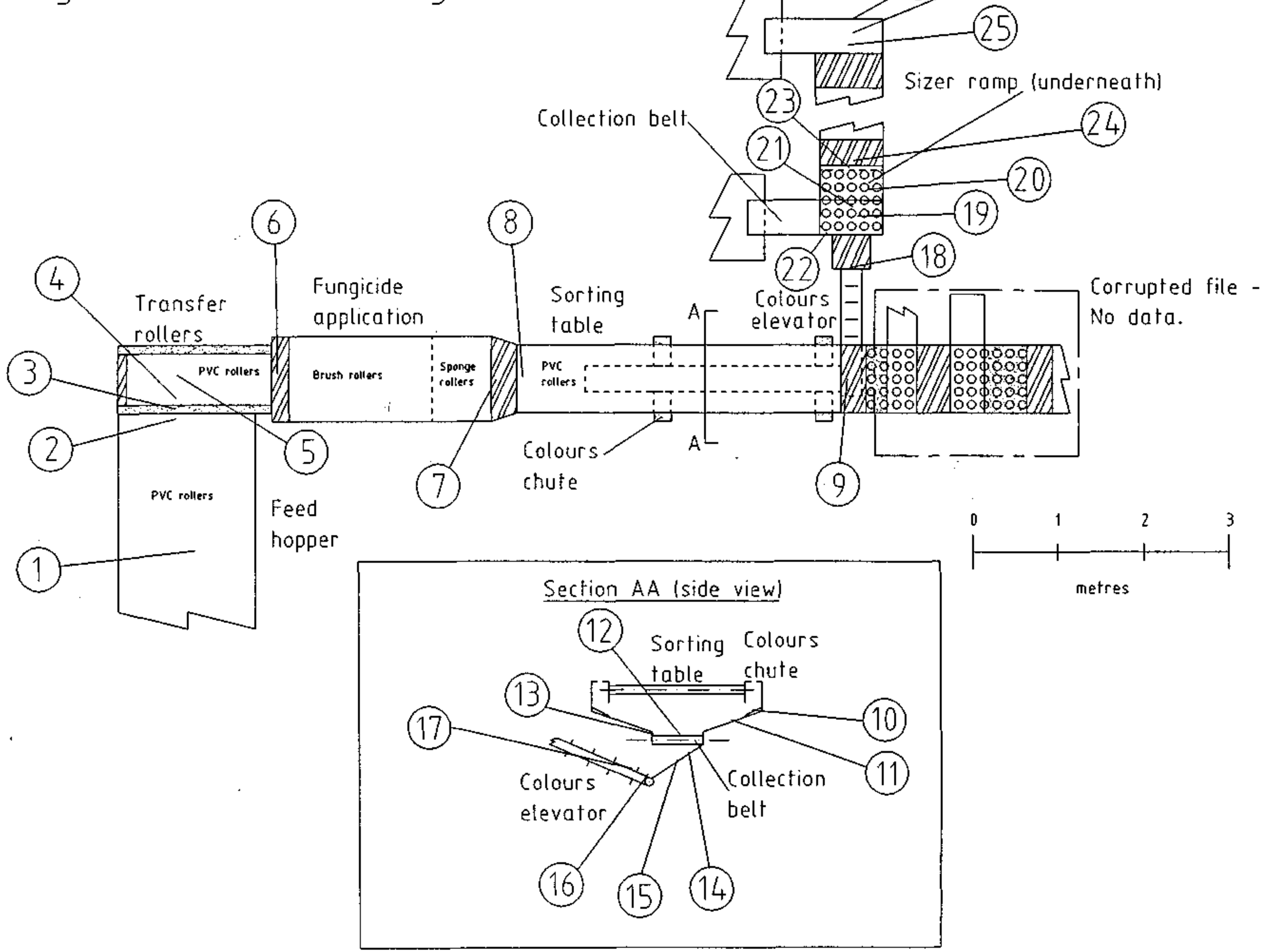


Table 16: Description of impact sites on the `GGG' green line

SITE	IMPACT SITE DESCRIPTION
1A	BUCKET THROW (onto empty hopper rollers). IS on top of full bucket of fruit, 1 rep.
1B	BUCKET THROW (onto empty hopper rollers). IS on top of full bucket of fruit, 1 rep.
1C	BUCKET THROW (onto empty hopper rollers). IS on top of full bucket of fruit, 1 rep.
1D	BUCKET THROW (onto empty hopper rollers). IS on bottom of full bucket, 1 rep.
1E	BUCKET THROW (onto empty hopper rollers). IS on bottom of full bucket, 1 rep.
2	against leading edge of hopper's PVC rollers
3	off hopper rollers onto ramp
4	from hopper, onto PVC transfer rollers
5	rebound on transfer rollers following 4
6	off PVC transfer rollers onto ramp
7	off sponge rollers onto ramp
8	onto PVC rollers of sorting table from ramp
9	off sorting table onto ramp
10	initial impact through colours chute
11	rebound on ramp
12	onto collection belt
13	along metal edge of collection belt housing, usually under opposite ramp
14	off collection belt onto ramp
15	against wall along ramp, opposite collection belt
16	off ramp onto paddle elevator
17	second impact associated with transfer onto paddle elevator
18	off paddle elevator onto ramp
19	drop through sizer belt directly onto collection belt
20	drop through sizer belt onto sizer ramp below
21	onto collection belt following 20
22	against wall along collection belt, opposite sizer ramp
23	against metal roller under leading edge of sizer belt
24	off sizer belt onto sizer ramp
25	off ramp onto end collection belt
26	opposite final ramp, along wall of collection belt housing
27	rebound on collection belt associated with 26

Table 17: Summary of impact data recorded by an instrumented sphere on the `GGG' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1A	69	8 impacts in total, with the largest against side wall of feed hopper opposite throw point	145
1B	NO IMPACTS		
1C	55	total of 6 impacts	70
1D	78	total of 2 impacts	93
1E	74	total of 3 impacts	110
2	71	40	77
3	58	40	77
4	123	100	217
5	61	50	74
6	146	100	161
7	139	100	163
8	89	70	128
9	57	50	73
10	104	100	144
11	73	70	144
12	66	70	80
13	179	100	238
14	67	90	97
15	98	100	127
16	113	100	184
17	82	90	135
18	data not available, corrupted file		
19	107	90	146
20	147	100	180
21	64	50	69
22	137	20	164
23	63	60	71
24	113	100	151
25	51	60	57
26	115	70	127
27	57	60	61

Fig.24: Shed 'GGG' red line

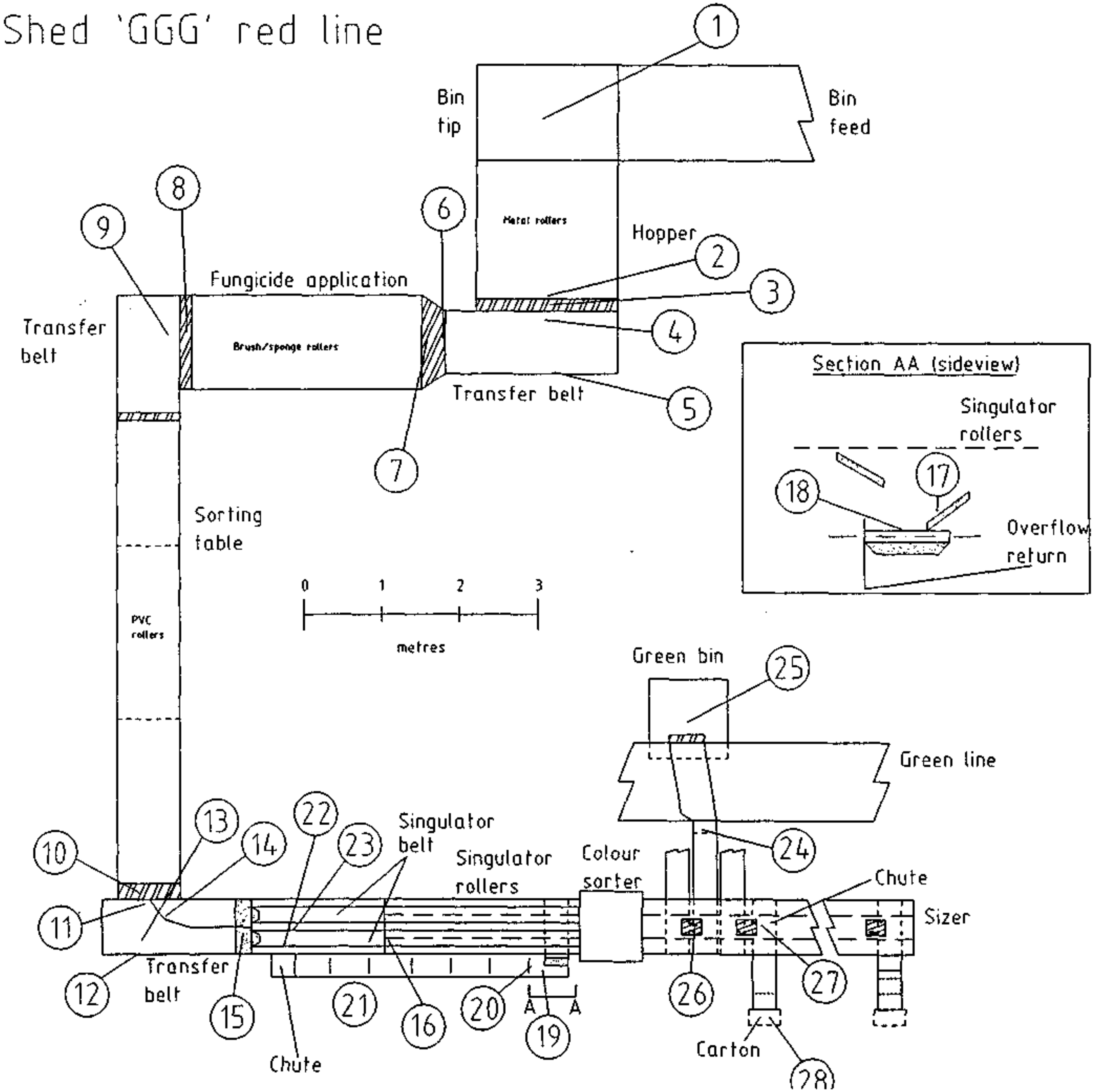


Table 18: Description of impact sites on the 'GGG' red line

SITE	IMPACT SITE DESCRIPTION
1	BIN TIP, 1 rep.. IS on top under single layer of fruit
2	onto leading edge of hopper's metal rollers
3	off hopper onto ramp
4	off ramp onto transfer belt
5	against side wall of belt housing, opposite ramp
6	off transfer belt onto ramp
7	along ramp
8	off brush/sponge rollers onto ramp
9	onto transfer belt from ramp
10	off PVC rollers of sorting table onto ramp
11	off ramp onto transfer belt
12	against side housing of belt, opposite ramp
13	rebound on belt associated with 12
14	against middle divider
15	off transfer belt onto ramp (before singulator belt)
16	off singulator belt onto singulator rollers
17	through overflow return onto ramp
18	off ramp onto transfer belt (in overflow)
19	off overflow belt onto overflow paddle elevator
20	second impact associated with transfer to paddle elevator
21	off paddle elevator overflow onto chute
22	onto singulator belt from overflow chute
23	against wall along singulator belt, opposite overflow chute
24	green bin outlet, off ramp onto chute
25	into full bin of fruit (no padding)
26	off sizer onto ramp
27	off sizer ramp onto chute
28A	into carton with fruit
28B	into empty carton

Table 19: Summary of impact data recorded by an instrumented sphere on the `GGG' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	initial tilt didn't cause impact but on opening of the bin gate-lid, one impact (90G) occurred		
2	107	60	147
3	114	100	153
4	64	40	97
5	81	10	81
6	152	100	181
7	57	80	60
8	110	100	118
9	107	100	133
10	81	100	100
11	98	100	138
12	115	30	149
13	56	30	72
14	68	100	86
15	91	90	99
16	119	20	135
17	82	100	177
18	78	60	163
19	153	100	223
20	64	90	92
21	73	100	89
22	57	40	90
23	139	60	205
24	70	60	82
25	61	100	69
26	97	60	167
27	82	90	155
28A	65	30	69
28B	128	100	157

Fig.25: Shed 'SSS' green line

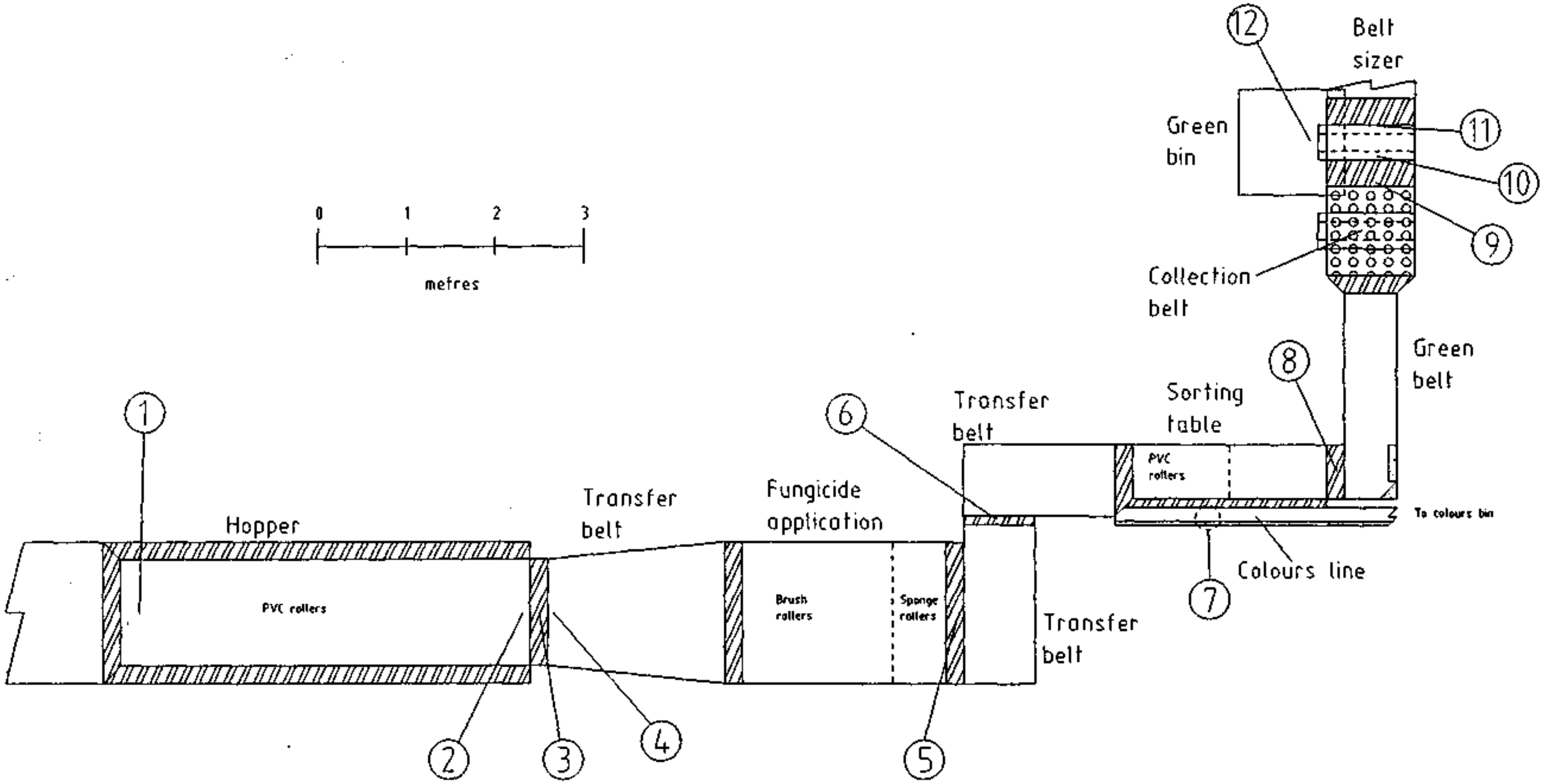


Table 20: Description of impact sites on the `SSS' green line

SITE	IMPACT SITE DESCRIPTION
1A	BUCKET TIP onto hopper's PVC rollers sparsely covered with fruit. IS positioned on top of fruit in bucket (3 reps)
1B	BUCKET TIP onto hopper's PVC rollers sparsely covered with fruit. IS positioned in the middle of the bucket (3 reps)
1C	BUCKET TIP onto hopper's PVC rollers sparsely covered with fruit. IS positioned on bottom of bucket (3 reps)
2	drop onto leading edge of hopper rollers
3	off hopper rollers onto ramp
4	off ramp onto transfer belt
5	onto ramp from sponge rollers
6	off transfer belt onto ramp
7A	field colour take off, commonly used technique with primary impact usually onto padded back- wall
7B	field colour take off, recommended technique with primary impact usually onto belt
8	off PVC rollers onto ramp
9	off sizer belt onto ramp
10	off sizer ramp onto collection belt (where tomatoes roll onto the belt, i.e. **not** where they drop through the sizer belt onto the collection belt)
11	against bottom edge of opposite ramp, following 10
12	into bin (various fills)

Table 21: Summary of impact data recorded by an instrumented sphere on the `SSS' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1A	206	100	253
	Each primary impact at 1A was also associated with 3 to 4 secondary impacts which overall averaged 89G		
1B	45	33	45
1C	59	33	59
2	68	70	127
3	78	70	94
4	119	10	119
5	67	60	86
6	71	60	86
7A	74	90 (primary impact only)	121
7B	68	90 (primary impact only)	144
8	96	100	105
9	57	80	71
10	211	100	281
	Note: a rubber curtain across the sizer ramp would help to reduce impact size on the belt		
11	79	80	119
12	74	30	107

Fig.26: Shed 'SSS' red line

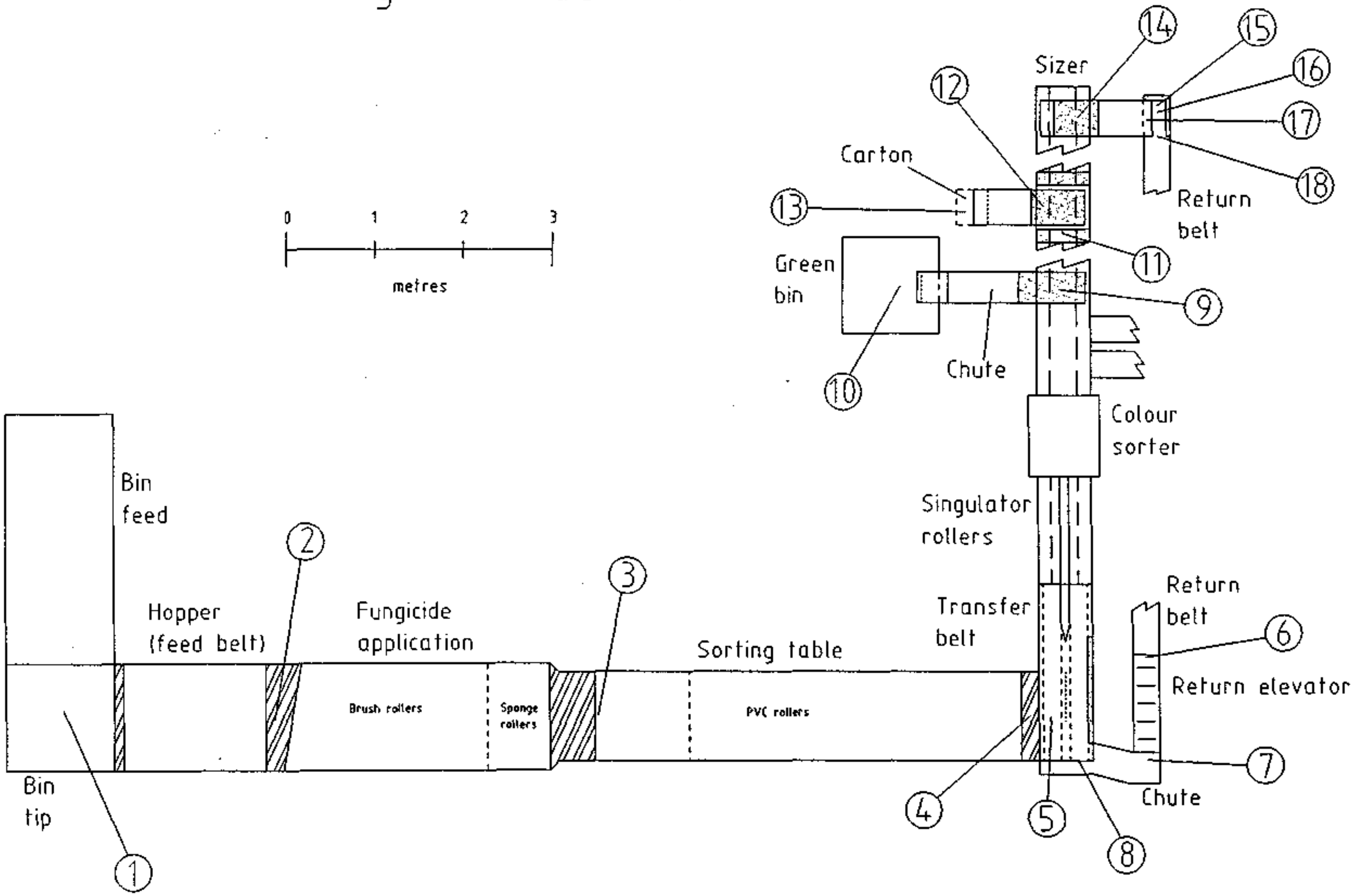


Table 22: Description of impact sites on the `SSS' red line

SITE	IMPACT SITE DESCRIPTION
1	bin tip, IS on top layers of fruit (3 reps)
2	off feed belt onto ramp
3	off ramp onto PVC rollers of sorting table
4	onto ramp from PVC rollers of sorting table
5	off ramp onto transfer belt
6	onto paddle elevator, off return belt
7	off return elevator onto top part of chute
8	onto junction between edge of return chute & transfer belt
9	on bin outlet, off sizer onto padded upper part of ramp
10A	drop into bin onto thick foam
10B	drop into bin onto fruit
11	off sizer onto top of padded hump
12	onto dished base of ramp leading to chute
13A	off chute into empty carton
13B	off chute into carton full of fruit
14	on overflow, out of sizer onto ramp below
15	on overflow, off chute onto return belt
16	rebound on return belt following 15
17	against wall (along return belt) under overhang of chute
18	settling impact on return belt following 17

Table 23: Summary of impact data recorded by an instrumented sphere on the `SSS' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	On 2 of the 3 tips, no impacts were recorded. However, the third tip caused 3 impacts (146G, 56G & 51G). All 3 impacts were unsighted but the largest is believed to have occurred against the bin's gate/lid		
2	113	70	218
3	77	70	103
4	175	100	207
5	74	100	104
6	85	100	125
7	49	90	51
8	116	90	228
9	50	50	59
10A	NO IMPACTS		
10B	55	80	59
	(Note: one impact of 168G was recorded against the side of the bin)		
11	64	20	85
12	108	100	169
13A	107	approx 10	107
13B	61	approx 10	61
14	78	80	92
15	227	100	268
16	60	30	67
17	151	90	223
18	61	60	84

Fig.27: Shed 'JJJ' packing line - section 1

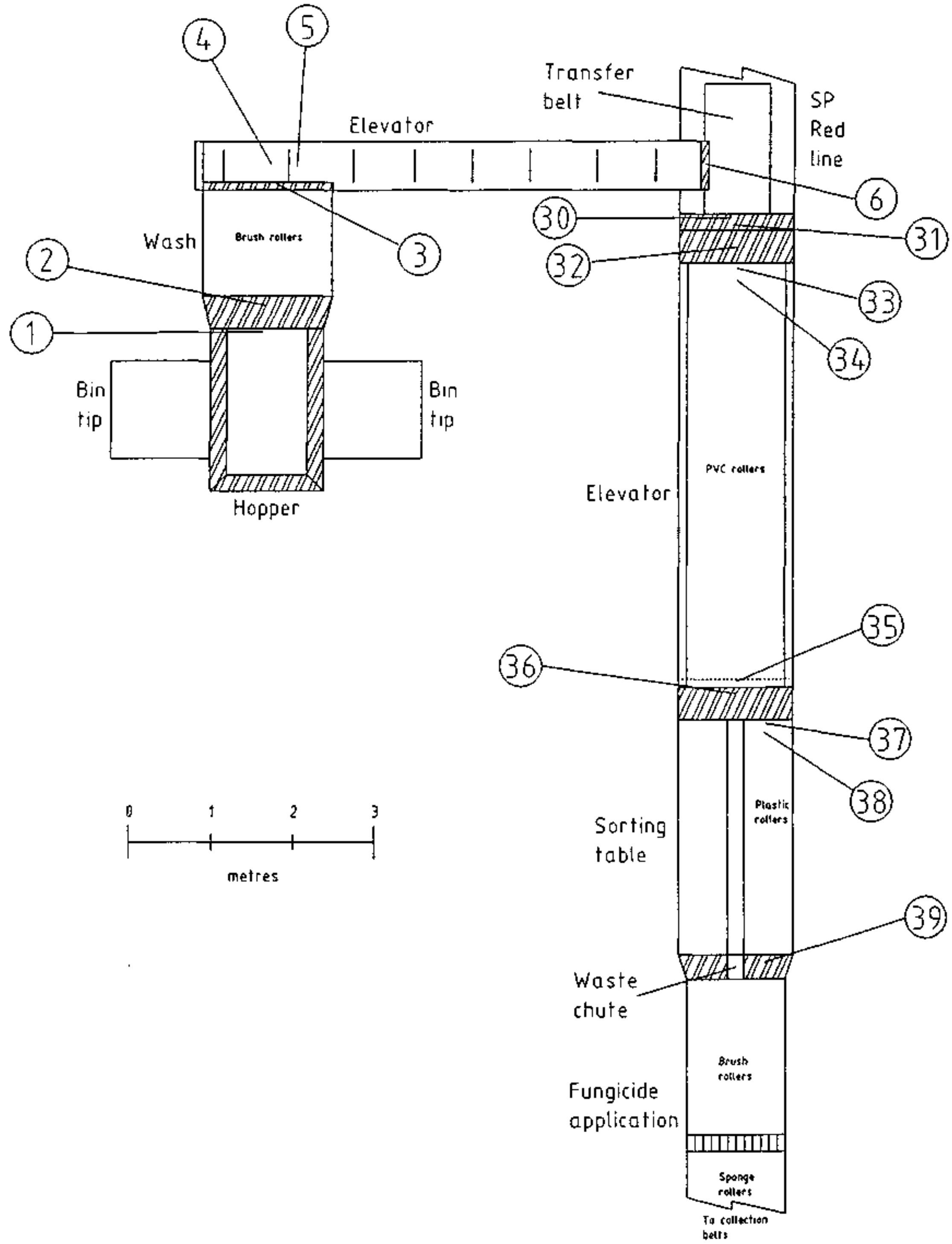


Fig.28: Shed 'JJJ' packing line - section 2

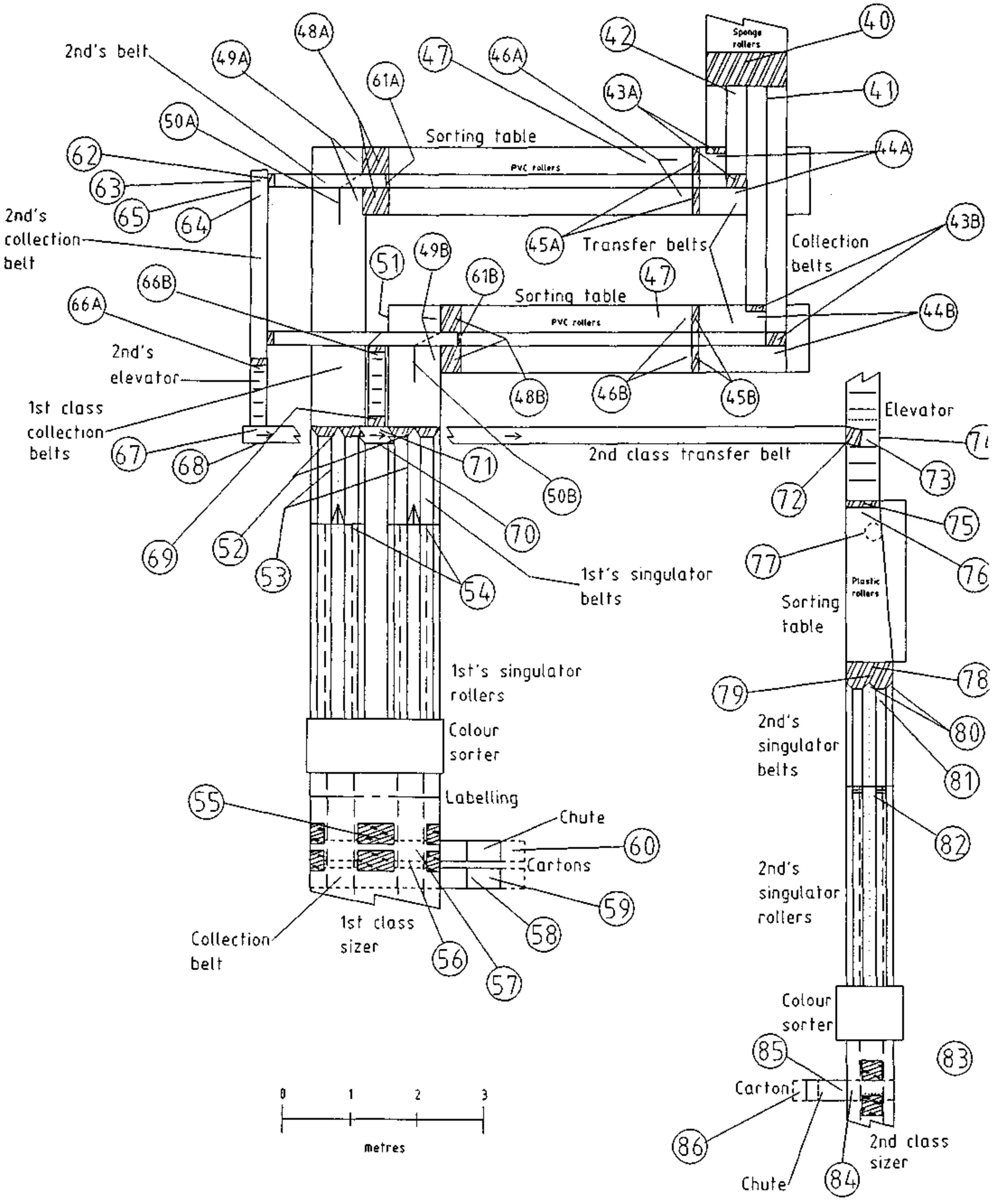


Fig.29: Shed 'JJJ' packing line - section 3

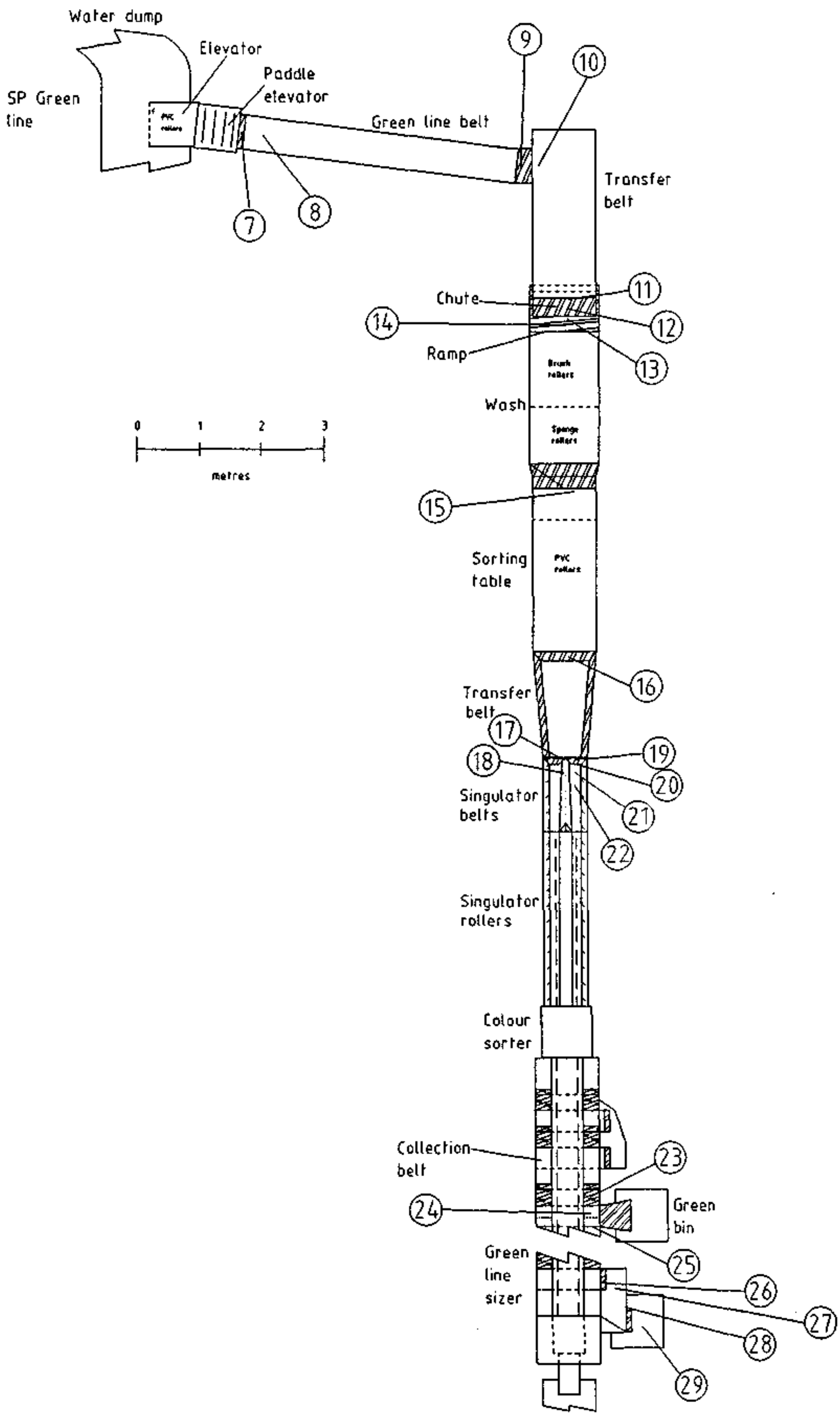


Table 24: Description of impact sites on the `JJJ' red line

SITE	IMPACT SITE DESCRIPTION
1	onto leading edge of hopper
2	off hopper onto ramp
3	off rollèrs onto ramp
4	off ramp onto elevator
5	rebound along elevator following 4
6	off elevator onto ramp
SITES 7 to 29	**GREEN LINE see Tables 3 & 4**
30	main line, off transfer belt onto small ramp
31	bounce along small ramp
32	onto large ramp
33	off ramp onto rollers of elevator
34	settling impact along elevator rollers
35	onto leading edge of elevator rollers
36	off elevator rollers onto ramp
37	off ramp onto rollers of sorting table
38	rebound on rollers following 37
39	off sorting table onto ramp
40	off sponge rollers onto ramp
41	off ramp onto divider between belt lanes
42	onto belt
43A	off collection belts onto ramps, site A
43B	off collection belts onto ramps, site B
44A	off ramps onto transfer belts
44B	off ramps onto transfer belts
45A	off transfer belts onto ramps
45B	off transfer belts onto ramps
46A	onto sorting table from ramps
46B	onto sorting table from ramps
47	secondary impact along sorting table following 46
48A	onto ramp off sorting table
48B	onto ramp off sorting table
49A	off ramp onto collection belt
49B	off ramp onto collection belt
50A	against divider opposite ramp
50B	against divider opposite ramp
51	against wall opposite ramp
52	off collection belts onto dividers/ramps
53	against walls along singulator belts
54	off singulator belt onto singulator rollers
55	first class sizer, onto sizer ramp
56	off sizer ramp onto side wall
57	along collection belt

Table 24 : CONTINUED

SITE	IMPACT SITE DESCRIPTION
58	off collection belt onto chute
59	along chute
60	off chute into carton (range of fill)
61A	second class line, off sorting rollers onto ramp
61B	off sorting rollers onto ramp
62	off seconds belt onto ramp
63	off ramp onto seconds collection belt
64	settling on collection belt
65	against wall opposite ramp
66A	off seconds collection belt onto ramp/elevator
66B	off seconds collection belt onto ramp/elevator
67	off elevator onto transfer belt
68	against wall opposite elevator outlet
69	off elevator onto ramp
70	against side wall, opposite elevator outlet
71	onto transfer belt for second class fruit
72	off seconds transfer belt onto ramp
73	off transfer belt onto elevator
74	against wall opposite ramp
75	off elevator onto ramp
76	off ramp onto sorting table
77	settling impact along sorting table
78	off sorting table onto ramp
79	bounce along ramp
80	off ramp onto angle divider/wall
81	onto singulator belt
82	onto divider angle between singulator rollers
83	off sizer rollers onto ramp
84	along chute (+/- side wall)
85	second impact along chute (+/- side wall)
86	off chute into carton

Table 25: Summary of impact data recorded by an instrumented sphere on the `JJJ' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	116	40	149
2	85	90	115
3	107	100	122
4	170	90	233
5	67	20	77
6	169	100	222
SITES 7 to 29		**see Tables 26 & 27**	
30	148	100	163
31	55	60	63
32	67	90	90
33	168	90	239
34	73	60	86
35	70	50	89
36	102	100	167
37	138	90	250
38	75	80	100
39	119	100	197
40	96	50	140
41	130	40	171
42	108	100	151
43A	121	100	181
43B	74	40	140
44A	57	20	64
44B	75	25	91
45A	83	100	101
45B	62	90	128
46A	83	100	148
46B	88	90	132
47	63	50	79
48A	47	20	52
48B	75	100	107
49A	118	50	181
49B	103	50	152
50A	104	70	236
50B	97	70	178
51	123	20	144
52	89	100	120
53	73	60	111
54	59	50	70
55	124	10	124
56	127	50	178
57	60	60	87

Table 25 : CONTINUED

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION
58	66	90	92
59	60	60	76
60	97	50	166
61A	78	10	78
61B	79	90	106
62	53	90	59
63	142	90	186
64	68	40	89
65	90	40	108
66A	67	100	86
66B	71	70	112
67	75	80	103
68	129	70	163
69	129	100	149
70	124	50	182
71	87	60	131
72	59	80	81
73	83	70	162
74	176	70	249
75	130	100	166
76	229	100	267
77	81	100	161
78	61	80	78
79	52	30	66
80	82	40	111
81	55	20	64
82	100	20	141
83	101	40	112
84	93	100	257
85	191	30	245
86	93	50	170

Table 26 : Description of impact sites on the `JJJ' green line

SITE	IMPACT SITE DESCRIPTION
7	green line, off paddle elevator onto belt/ramp
8	green line, bounce along belt
9	green line, off belt onto ramp
10	green line, off ramp onto transfer belt
11	green line, off transfer belt onto chute
12	green line, bounce along chute
13	green line, off chute onto ramp
14	green line, along ramp
15	green line, off ramp onto PVC rollers of sorting table
16	green line, off PVC rollers onto ramp
17	green line, off transfer belt onto divider
18	green line, along divider
19	green line, off transfer belt onto ramp
20	green line, along ramp
21	green line, off ramp onto singulator belt
22	green line, along singulator belt
23	green line, off sizer rollers onto sizer ramp
24	green line, off ramp onto collection belt
25	green line, against side wall opposite ramp
26	green line, off collection belt onto ramp
27	green line, off transfer ramp onto transfer belt
28	green line, against wall
29	green line, into bin

Table 27: Summary of impact data recorded by an instrumented sphere on the `JJJ' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION
7	87	100	171
8	62	70	72
9	97	100	112
10	103	100	110
11	171	100	274
12	59	80	75
13	150	100	247
14	56	70	68
15	72	100	121
16	60	90	67
17	101	30	127
18	95	30	135
19	112	80	135
20	65	30	76
21	63	20	67
22	99	10	99
23	102	60	155
24	94	70	184
25	139	40	228
26	60	60	84
27	58	70	72
28	70	30	74
29	45	10	45

Fig.30: Shed 'HHH' green line

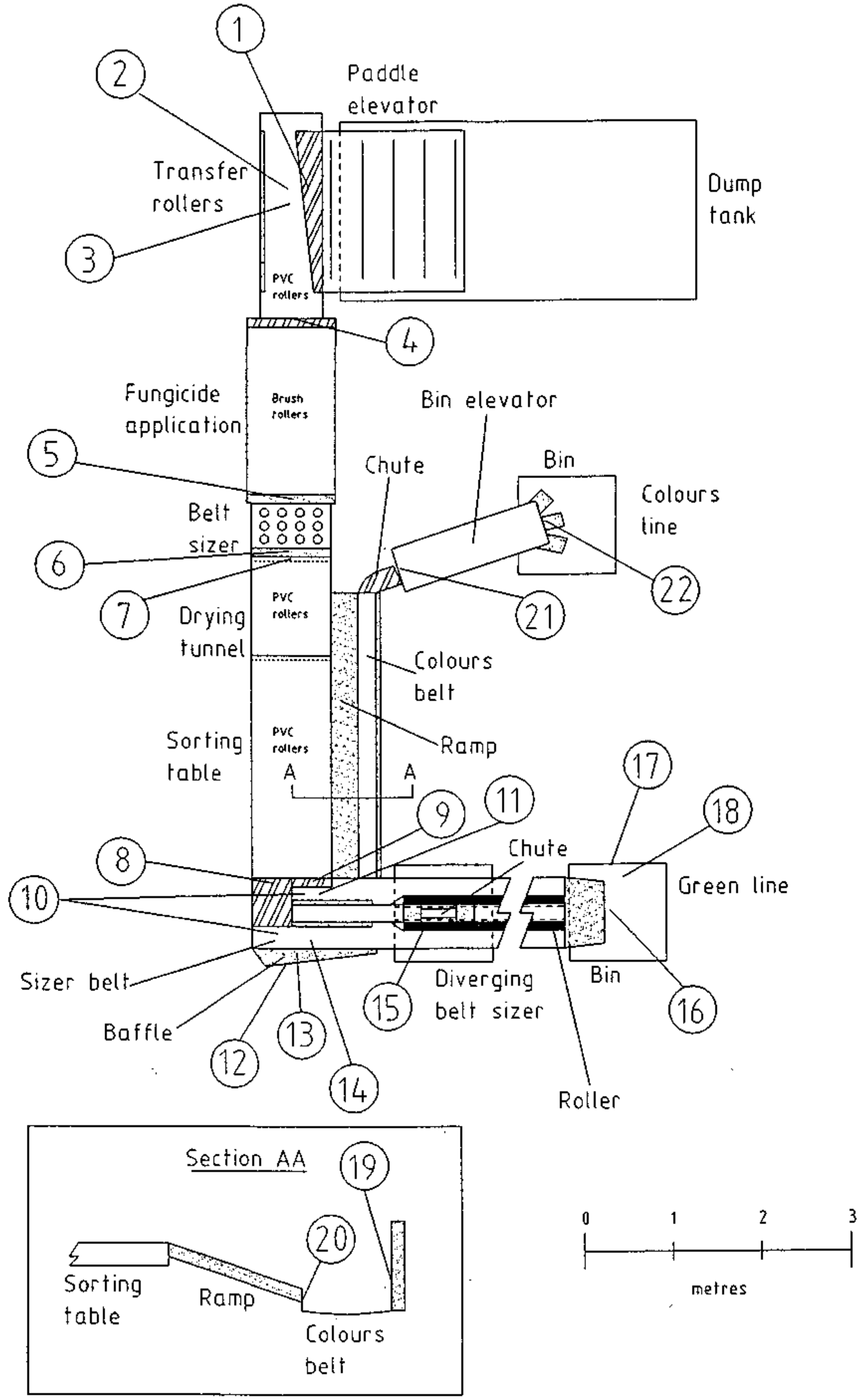


Table 28: Description of impact sites on the `HHH' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto ramp
2	onto transfer rollers
3	bounce along transfer rollers
4	off transfer rollers onto top edge of ramp
5	off brush rollers onto ramp
6	off belt sizer onto ramp
7	onto drying tunnel rollers
8	off sorting table onto large ramp
9	off sorting table onto small ramp
10	onto sizer belt
11	bounce onto sizer belt off padded wall (small ramp)
12	onto baffle side wall
13	rebound back onto baffle
14	off baffle onto sizer belt
15	onto sizer roller
16	drop into bin (1/4 to 3/4 full)
17	against bin wall
18	secondary impact inside bin
19	onto padded wall opposite sorting table (colours line)
20	rebound onto wall along colours belt
21	onto bin elevator
22	off bin elevator onto padded baffle (inside bin)

Table 29: Summary of impact data recorded by an instrumented sphere on the `HHH' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	66	100	94
2	128	100	154
3	52	56	60
4	57	90	62
5	58	100	87
6	88	90	103
7	59	44	68
8	58	75	67
9	49	75	51
10	147	100	190
11	86	100	102
12	62	50	72
13	120	50	132
14	57	50	74
15	47	38	55
16	54	50	79
17	161	50	276
18	59	38	70
19	64	64	160
20	177	50	264
21	52	50	53
22	67	100	70

Fig.31: Shed 'HHH' red line

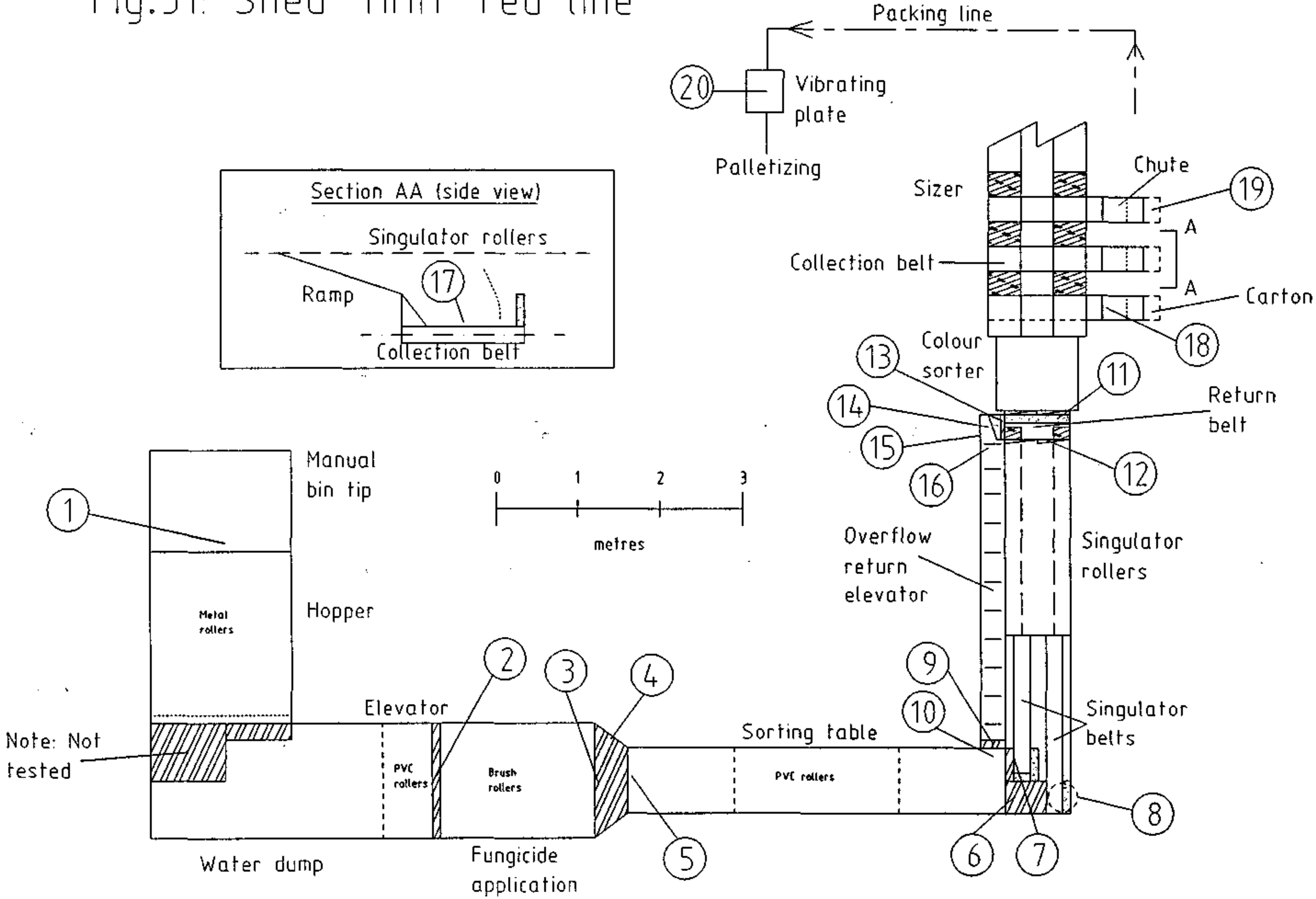


Table 30: Description of impact sites on the `HHH' red line

SITE	IMPACT SITE DESCRIPTION
1	bin tip (1 rep), IS placed 2 fruit layers deep below the surface at the bin's front
2	off elevator, across ramp
3	off brush rollers onto ramp
4	against wall on ramp
5	off ramp onto PVC rollers of sorting table
6	onto largest ramp after sorting table
7	onto base of ramp/singulator belt
8	off largest ramp onto singulator belt or wall opposite ramp
9	off paddle elevator of overflow return onto ramp
10	off overflow return onto PVC rollers of sorting table
11	off sizer at overflow return, onto ramp
12	at overflow return, off ramp onto belt (or wall along belt opposite ramp)
13	onto ramp from belt
14	off ramp onto paddle elevator
15	opposite ramp, against wall along elevator
16	settling onto elevator & paddles, after impact against wall opposite ramp
17	at sizer, off ramp onto collection belt
18	off collection belt onto chute
19A	into carton containing fruit
19B	into empty carton
20A	mechanical carton vibration to settle fruit, IS in top layer of fruit (2 reps/runs)
20B	mechanical carton vibration to settle fruit, IS on bottom of carton (1 run), carton vibrated in recommended manner i.e. carton held firm with only fruit moving
20C	mechanical carton vibration to settle fruit, IS on bottom of carton (1 run), carton not vibrated in recommended manner i.e. movement of both carton & fruit.

Table 31: Summary of impact data recorded by an instrumented sphere on the `HHH' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	41	100 (based on 1 rep)	41
2	108	100	124
3	52	50	55
4	69	20	70
5	94	90	140
6	67	90	77
7	97	70	133
8	70	90	129
9	48	50	50
10	109	100	197
11	107	80	167
12	159	100	273
13	78	80	115
14	83	40	113
15	144	100	216
16	87	100	112
17	95	70	135
18	68	100	107
19A	64	60	73
19B	85	100	114
20A	NO IMPACTS		
20B	over approx 3 sec, 19 impacts, size range 40G to 69G, average = 48G		
20C	over approx 3.8 sec, 32 impacts, size range 40G to 101G, average = 60G		

Fig.32: Shed 'FFF' green line

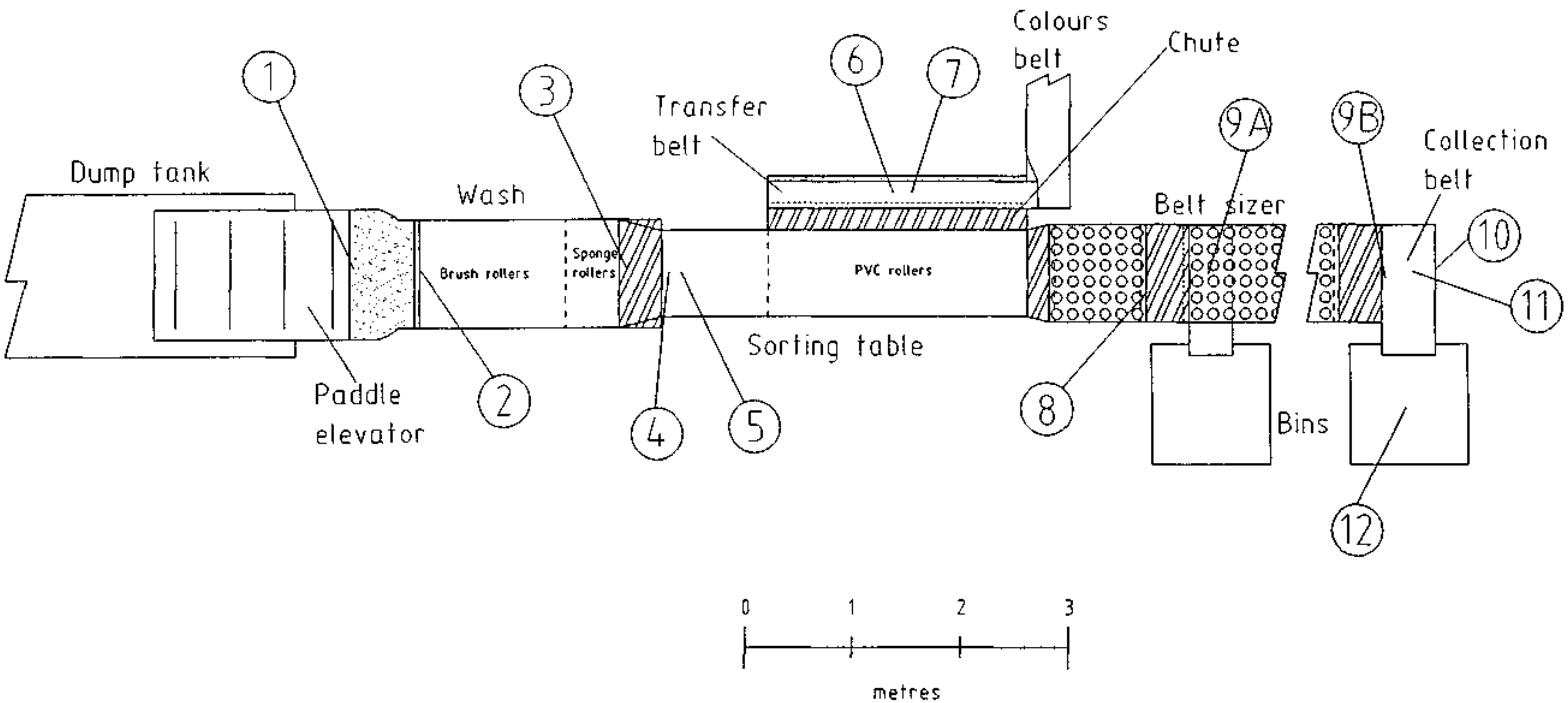


Table 32: Description of impact sites on the `FFF' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto ramp
2	onto rollers following ramp
3	off sponge rollers onto ramp
4	off ramp onto PVC rollers of sorting table
5	rebound along sorting table
6	red fruit throw off
7	rebound associated with 6
8	against metal roller at top of sizer belt incline
9A	out of sizer belt, through to collection belt
9B	off end ramp onto collection belt
10	against wall opposite ramp
11	rebound on belt following 10
12	into bin

Table 33: Summary of impact data recorded by an instrumented sphere on the `FFF' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	58	90	63
2	84	80	135
3	50	20	54
4	71	70	99
5	61	30	64
6	94	80	159
7	74	40	135
8	121	approx 50	159
9A	175	80	234
9B	120	100	141
10	169	80	213
11	66	60	83
12	61	80	71

Fig.33: Shed 'FFF' red line

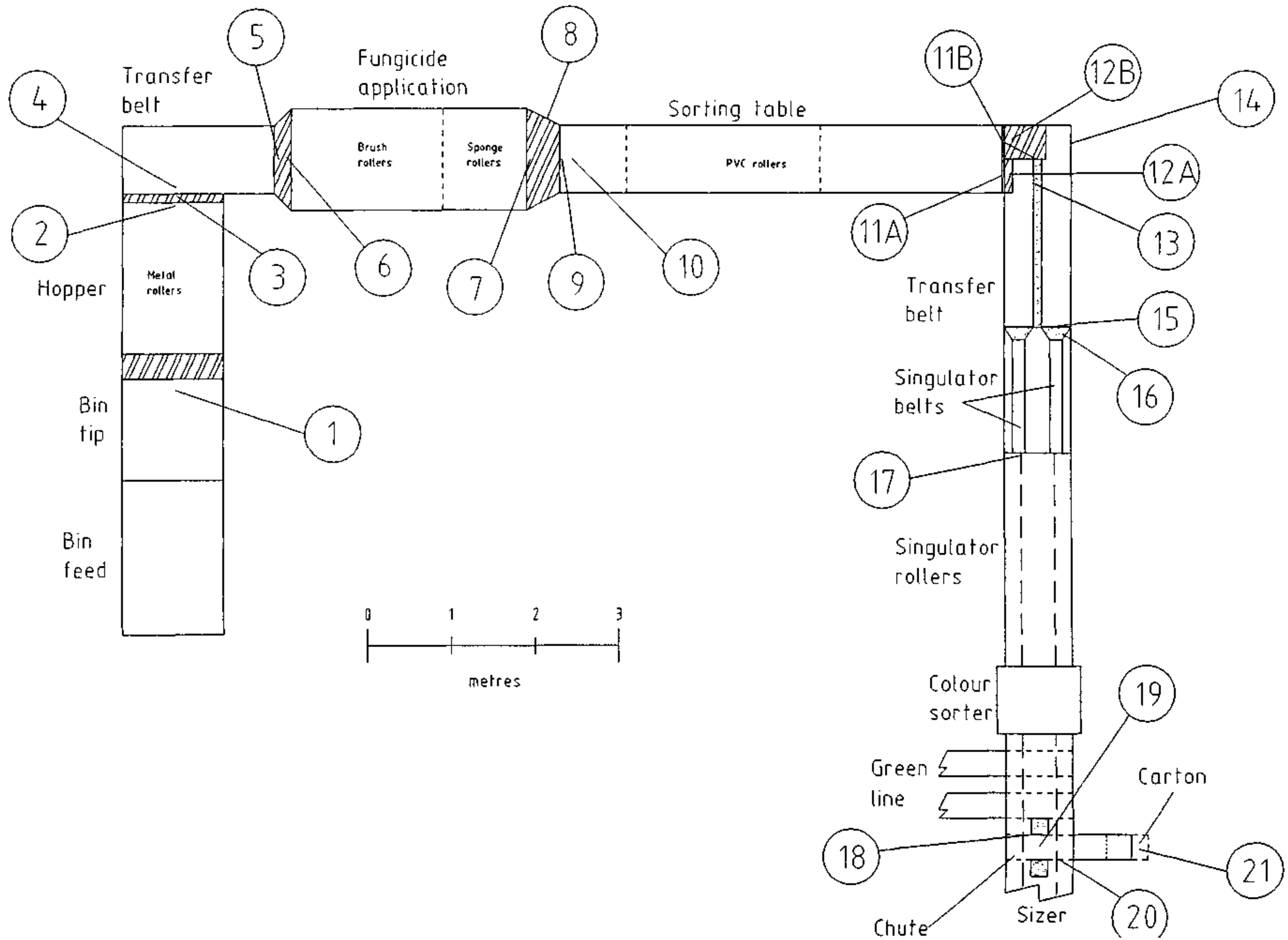


Table 34: Description of impact sites on the `FFF' red line

SITE	IMPACT SITE DESCRIPTION
1A	bin tip (IS on top of fruit) - impact against bin holder, one run
1B	bin tip (IS 2 layers below surface), one run
2	onto metal rollers of hopper before ramp
3	off hopper onto ramp
4	off ramp onto transfer belt
5	off transfer belt onto ramp
6	along ramp
7	off sponge rollers onto ramp
8	against ramp side wall
9	onto sorting table PVC rollers
10	bounce along PVC rollers
11A	onto sorting table edge (metal bar) - small ramp
11B	onto sorting table edge (metal bar) - large ramp
12A	onto small ramp
12B	onto large ramp
13	against lane separator of transfer belt
14	off large ramp against opposite wall
15	off transfer belt onto edge of ramp (metal strip)
16	onto ramp/singulator belt angle
17	onto singulator rollers
18	off sizer ramp onto edge above chute
19	onto chute
20	against chute sidewall
21	into carton (empty to 1/4 full)

Table 35: Summary of impact data recorded by an instrumented sphere on the `FFF' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1A	133	5 impacts/run	207
1B	NO	IMPACTS	
2	105	90	157
3	80	90	125
4	92	70	130
5	124	100	172
6	77	80	141
7	71	100	88
8	54	20	54
9	92	60	124
10	54	30	67
11A	124	100	153
11B	106	100	122
12A	55	30	60
12B	50	60	60
13	129	60	161
14	94	50	146
15	111	100	142
16	74	30	110
17	64	10	64
18	124	20	130
19	101	100	137
20	90	90	115
21	71	90	157

Fig.34: Shed 'RRR' green line

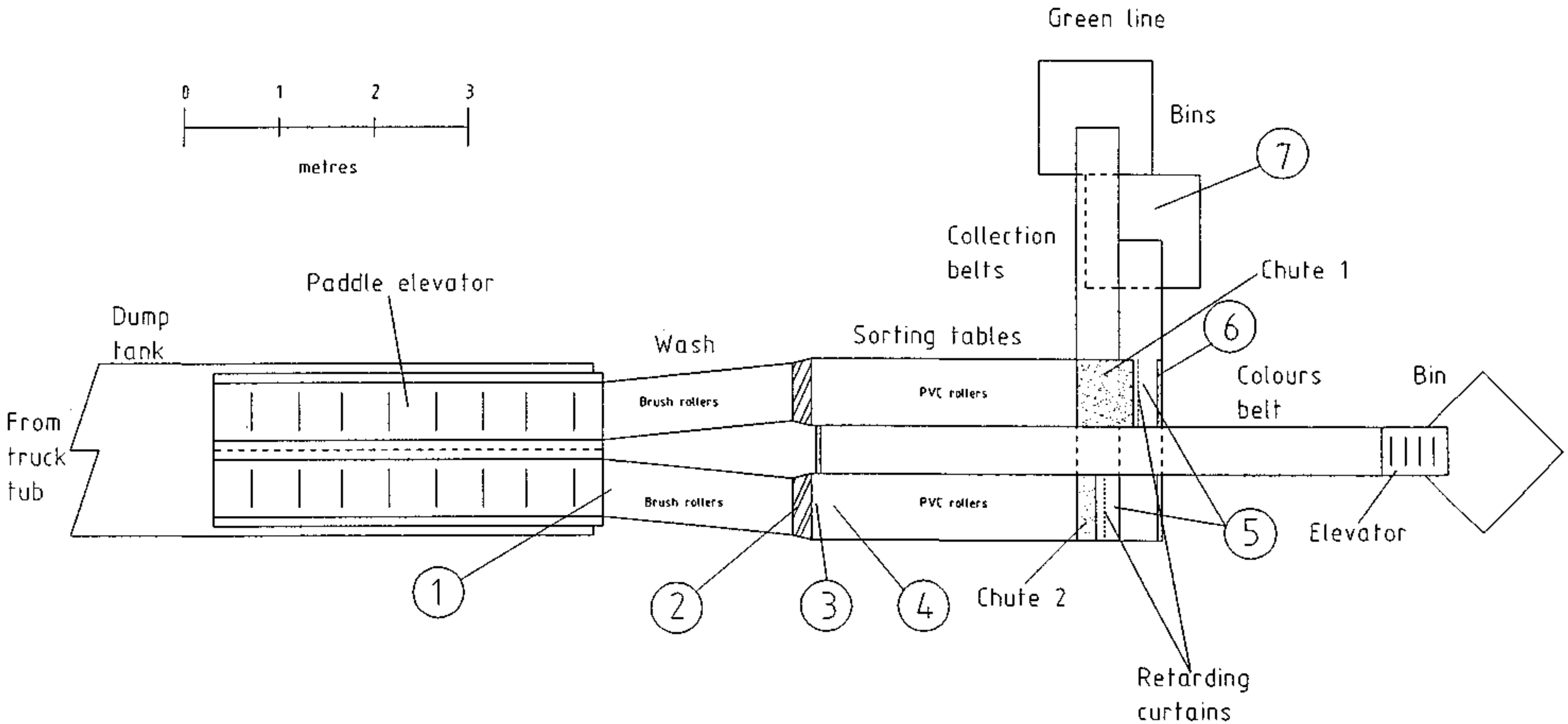


Table 36: Description of impact sites on the `RRR' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto brush rollers
2	from brush rollers onto top of steel ramp
3	onto PVC rollers of sorting table
4	rebound along rollers of sorting table
5	off chutes onto collection belts
6	against wall opposite chute1
7	off collection belt into bin

Table 37: Summary of impact data recorded by an instrumented sphere on the `RRR' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	54	60	71
2	116	100	167
3	74	90	108
4	63	30	74
5	99*	60	346*
6	71	20	89
7	59	70	73

* The reading of 346G is not consistent with other readings at this site. If it is disregarded, the average impact size is 49G, and the largest only 61G. This aberrant reading may be the product of some malfunction in the equipment but this would be unusual. The site should be carefully checked for any detail of design that might be causing the occasional very large impact.

Fig.35: Shed'RRR' red line

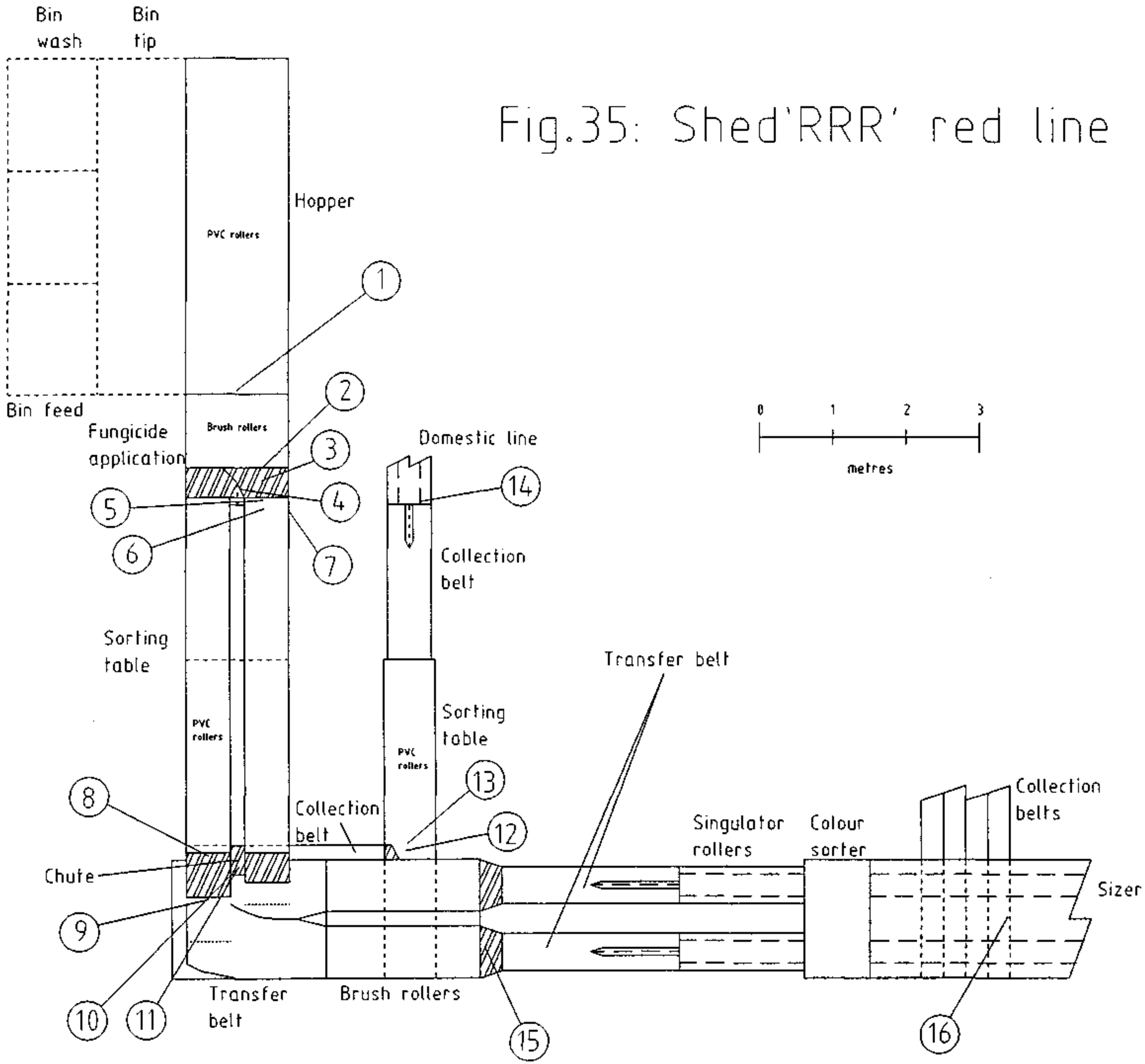


Table 38: Description of impact sites on the `RRR' red line

SITE	IMPACT SITE DESCRIPTION
BIN TIP	NO IMPACTS (2 BINS)
1	onto edge of hopper's PVC rollers
2	off brush rollers onto ramp
3	rebound along ramp
4	on ramp at side-wall junction
5	off ramp onto PVC rollers of the sorting table
6	rebound on sorting table rollers
7	against wall along sorting table (near ramp)
8	off PVC rollers of sorting table onto ramp
9	off ramp onto transfer belt
10	domestic line, impact associated with chute (not seen)
11	secondary impact associated with 10
12	domestic line, from ramp onto PVC rollers of sorting table
13	domestic line, rebound on rollers associated with 12
14	domestic line, off collection belt onto singulator
15	onto ramp from brush rollers
16	against side-wall of collection belt housing, immediately following drop from sizer

Table 39: Summary of impact data recorded by an instrumented sphere on the `RRR' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	58	10	58
2	149	100	177
3	49	40	60
4	69	20	80
5	91	80	119
6	68	40	73
7	118	less than 20	143
8	65	100	86
9	69	100	81
10	93	90	180
11	91	60	130
12	94	100	135
13	73	60	100
14	53	10	53
15	62	60	70
16	56	40	67

Fig.36: Shed 'UUU' tomato packing line

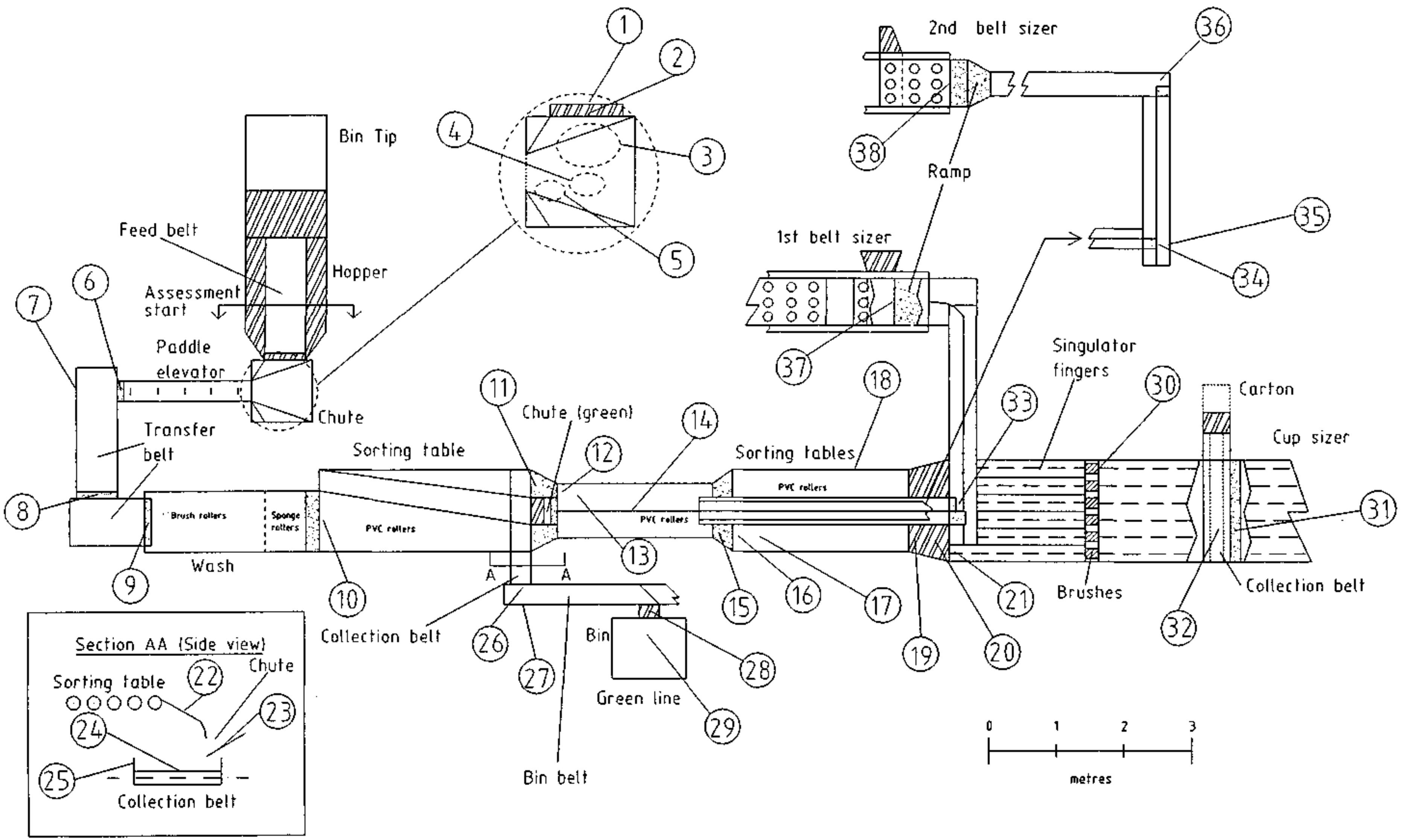


Table 40: Description of impact sites on the `UUU' tomato packing line

SITE	IMPACT SITE DESCRIPTION
1	onto leading edge of feed belt (for IS on top of pile)
2	onto ramp following feed belt
3	onto the chute
4	along chute
5	end of chute near entrance to paddle elevator
6	off paddle elevator onto ramp
7	rebound against opposite wall
8	onto ramp between transfer belts
9	onto ramp leading to brush rollers
10	onto PVC rollers of sorting table
11	off sorting table onto ramp
12	off ramp onto PVC rollers of second sorting table
13	rebound on PVC rollers (associated with 12)
14	against centre divider
15	onto ramp between second and third sorting table
16	onto PVC rollers of third sorting table
17	rebound along PVC rollers (associated with 16)
18	against wall
19	off third sorting table onto ramp
20	bounce on ramp
21	onto singulator fingers
22	green line, off sorting table onto ramp
23	green line, from ramp onto edge of chute
24	green line, onto collection belt below
25	green line, rebound on belt or bounce against wall (depends on loading)
26	green line, off collection belt onto bin belt
27	green line, against wall opposite
28	green line, onto ramp leading to bin
29	green line, onto fruit in bin
30	from singulator fingers onto sizer cups
31	firsts line, off cups onto ramp
32	firsts line, off ramp onto collection belt
33	seconds line, off ramp onto belt (lower system to first belt sizer)
34	seconds line, off ramp onto belt (upper system to second belt sizer)
35	seconds line, against wall opposite 34
36	seconds line, off ramp onto belt (upper system)
37	transition between ramp and entry to holed belt sizer
38	off ramp onto second belt sizer, onto metal roller supporting start of holed belt
	Note: holed sizer belt for seconds was not assessed

Table 41: Summary of impact data recorded by an instrumented sphere on the `UUU' tomato packing line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	145	50	180
2	81	70	158
3	146	80	226
4	84	80	130
5	120	90	185
6	163	90	209
7	105	20	135
8	60	80	65
9	71	90	93
10	73	100	93
11	78	100	100
12	105	100	153
13	74	100	96
14	58	50	72
15	59	80	73
16	57	90	69
17	63	80	67
18	105	30	117
19	136	100	205
20	58	50	78
21	60	20	62
22	50	70	63
23	61	80	90
24	130	100	188
25	91	60	118
26	49	20	52
27	76	40	110
28	43	20	47
29	81	100	113
30	57	100	70
31*	223	100	289
32	86	90	162
33	65	70	90
34	149	100	181
35	110	80	131
36	135	100	157
37	179	70	229
38	201	100	275

* padding worn away in places

Fig.37: Shed 'III' green line

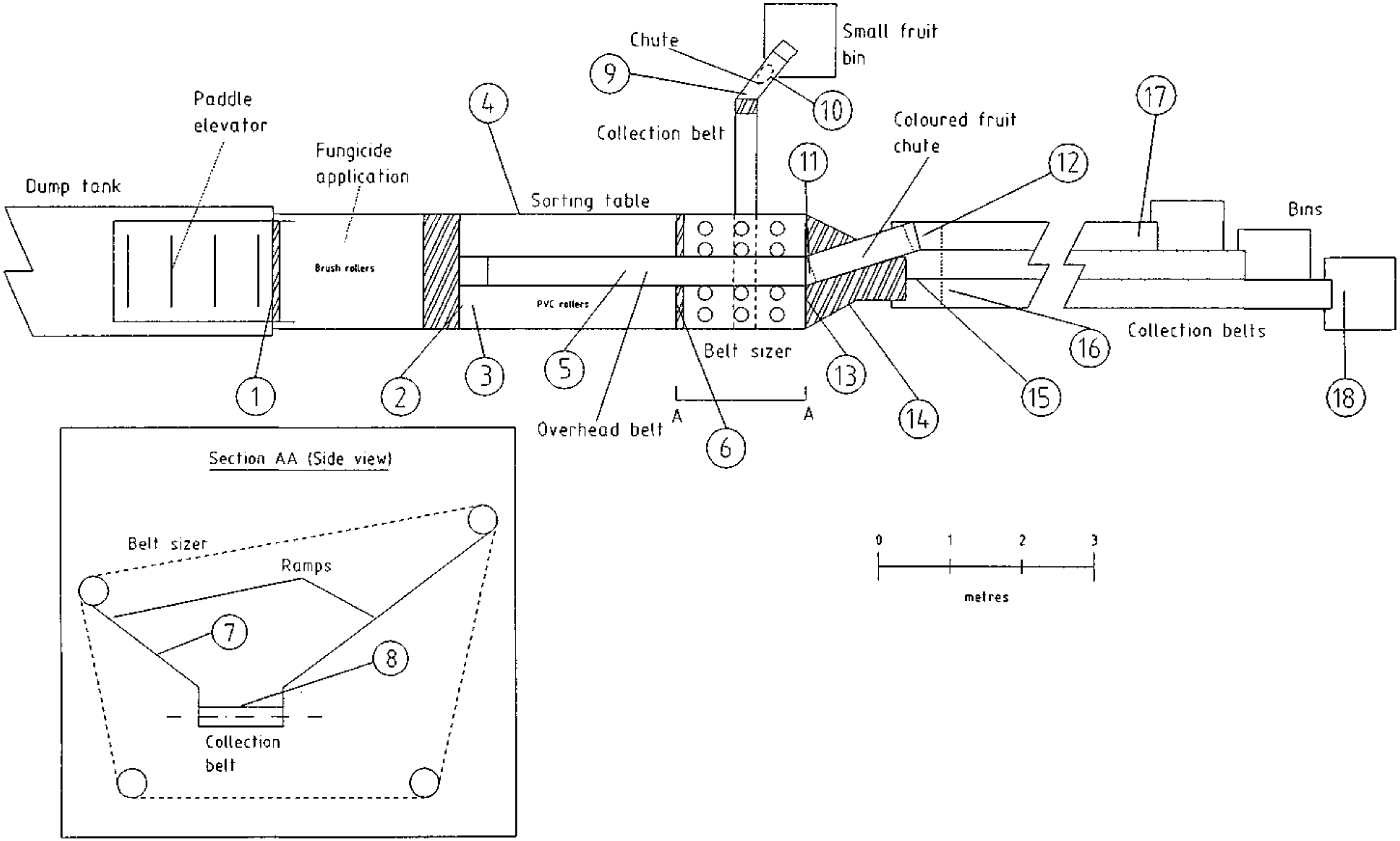


Table 42: Description of impact sites on the `III' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto ramp before brush rollers
2	onto PVC rollers of sorting table
3	rebound on sorting table (associated with 2)
4	against side wall of sorting table
5	transfer by sorters to elevated lane for coloured fruit
6	onto ramp after sorting table
7	small fruit, through sizer belt onto ramp
8	small fruit, from ramp onto collection belt
9	small fruit, off ramp onto chute
10	small fruit, along chute
11	coloured line, off belt onto chute
12	coloured line, off chute onto collection belt
13	bulk of green fruit, off sizer belt onto ramp
14	against wall of ramp
15	onto centre divider
16	onto collection belt
17	along collection belt (includes impacts against side wall)
18	into bin

Table 43: Summary of impact data recorded by an instrumented sphere on the `III' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	157	70	248
2	116	100	161
3	65	50	73
4	132	10	132
5*	98	100	147
6	122	100	142
7	130	100	195
8	89	70	130
9	189	100	248
10	58	30	63
11	53	30	59
12	132	100	155
13	65	100	77
14	75	50	111
15	148	20	203
16	69	50	88
17	87	40	139 (side wall)
18	51	70	58

* placement much better than throw

Fig.38: Shed 'III' red line

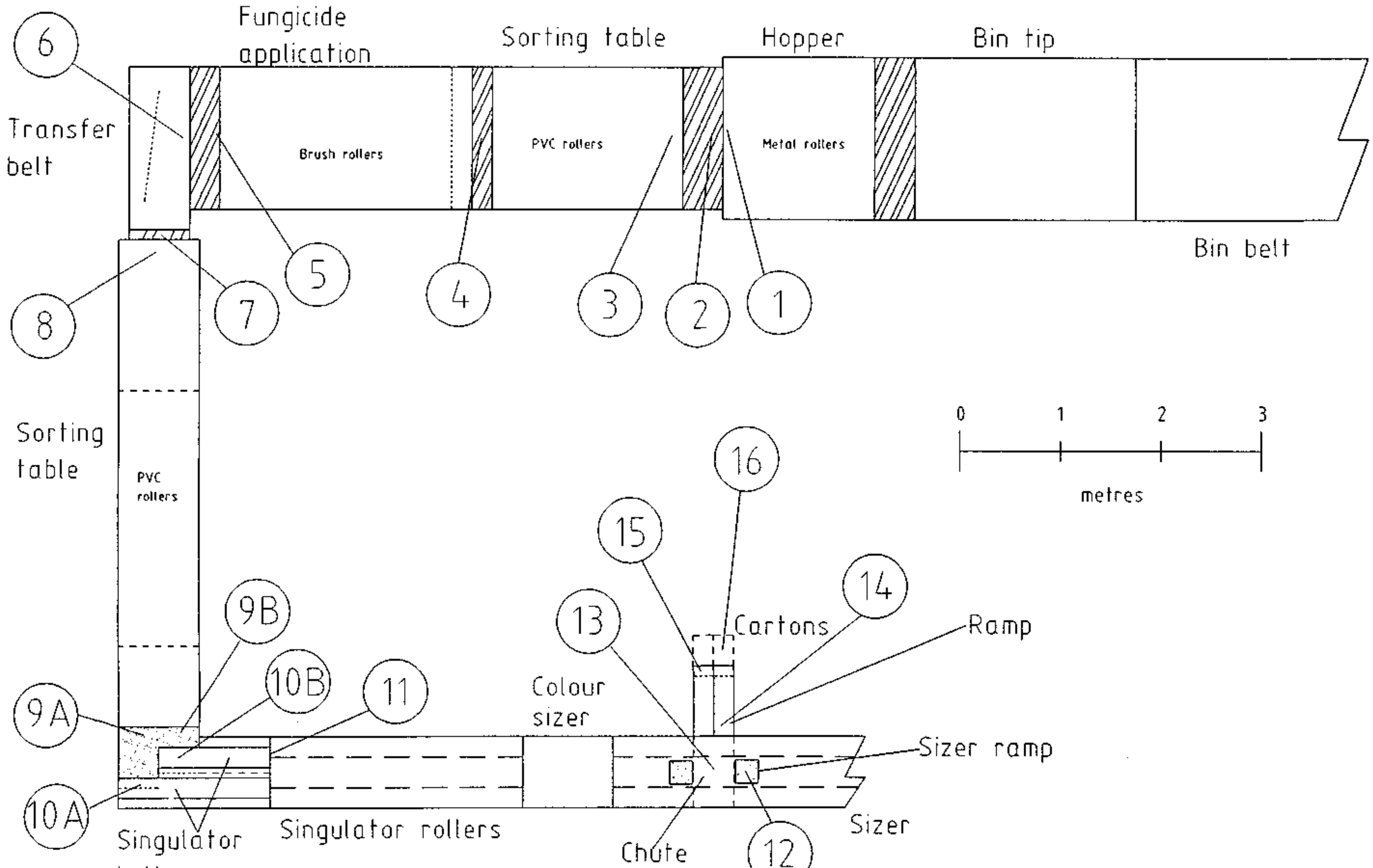


Table 44: Description of impact sites on the `III' red line

SITE	IMPACT SITE DESCRIPTION
NO IMPACT	BIN TIP. The sphere was included in five bins at tipping. For 2 bins the sphere was located on the top of tomatoes, for one bin approx. at one third depth, and for the remaining two bins the sphere was buried in tomatoes to half the bin's depth.
1	impact against metal rollers when the IS drops from upper layer - usually near leading edge of hopper rollers
2	from hopper rollers onto ramp
3	onto PVC rollers of sorting table from ramp
4	off PVC rollers onto ramp
5	off brush rollers onto ramp
6	from ramp to transfer belt
7	onto ramp from transfer belt
8	off ramp onto PVC rollers
9A	onto long ramp from PVC rollers
9B	onto short ramp from PVC rollers
10A	off long ramp onto singulator belt
10B	off short ramp onto singulator belt (size of impact here is heavily dependent on loading)
11	onto singulator rollers
12	drop onto sizer ramp
13	from ramp onto chute
14	along chute
15	end/sides of chute to carton
16	drop into carton with single layer of fruit

Table 45: Summary of impact data recorded by an instrumented sphere on the `III' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	88	70	113
2	111	100	148
3	70	80	93
4	91	100	96
5	70	80	86
6	139	100	184
7	58	60	79
8	53	30	64
9A	51	40	63
9B	60	30	85
10A	73	60	86
10B	137	60	204
11	48	50	61
12	63	100	74
13	86	100	99
14	71	90	109
15	78	70	104
16	47	40	54

Fig.39: Shed 'WWW' tomato packing line

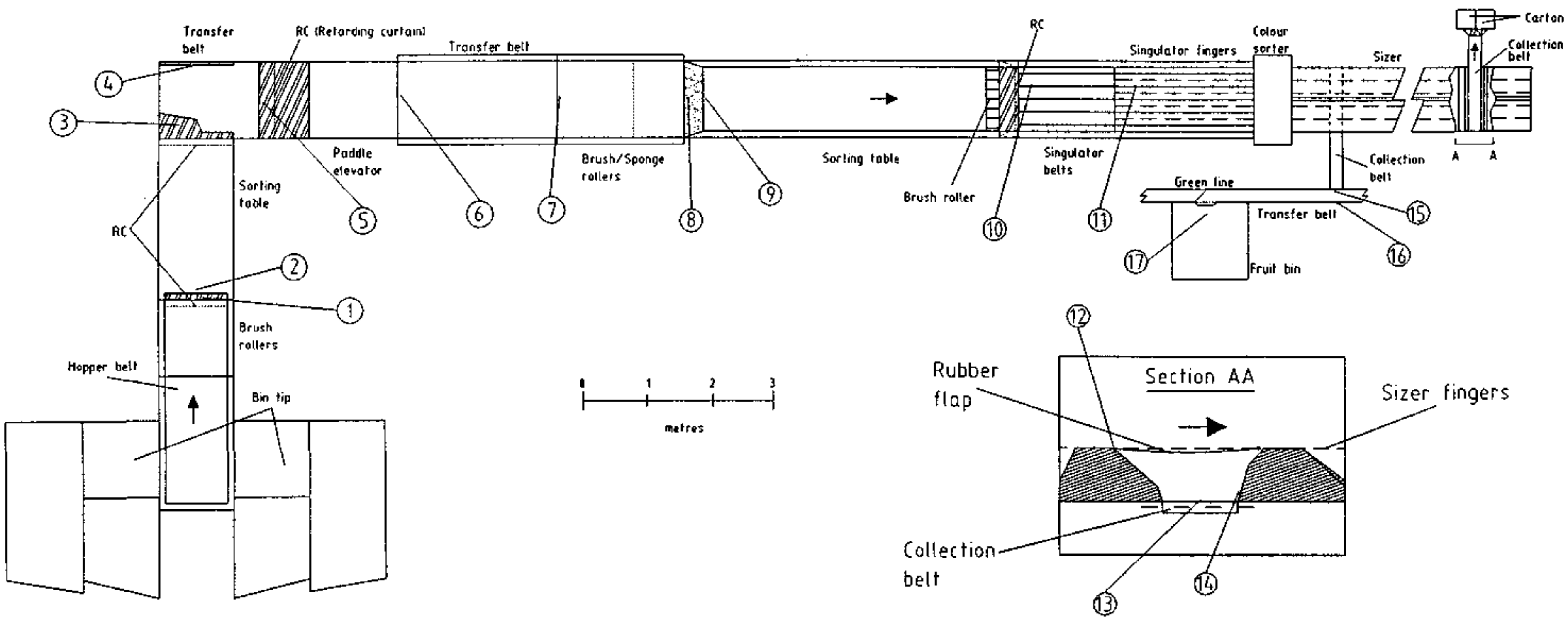


Table 46: Description of impact sites on the `WWW' tomato grading line

SITE	IMPACT SITE DESCRIPTION
1	off hopper belt onto ramp
2	off ramp onto sorting table
3	off sorting table onto ramp
4	onto side wall opposite sorting table
5	off transfer belt onto onto ramp
6	off paddle elevator onto tansfer belt
7	off transfer belt onto brush rollers
8	off sponge rollers onto ramp
9	off ramp onto sorting table
10	off sorting table onto metal dividers between singulator belt
11	onto singulator fingers against singulator wall
12	off sizer fingers onto top edge of housing between sizer lines
13	onto collection belt
14	against wall along collection belt
15	off green line collection belt onto tansfer belt
16	onto wall opposite green line collection belt
17	off green line transfer belt into full bin

Table 47: Summary of impact data recorded by an instrumented sphere on the `WWW ` tomato grading line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	79	91	95
2	73	91	95
3	165	100	266
4	57	30	66
5	111	77	128
6	65	8	65
7	44	9	44
8	52	42	53
9	56	75	67
10	64	38	85
11	57	20	67
12	73	27	91
13	133	100	292
14	94	45	193
15	65	91	90
16	90	64	114
17	70	100	85

Fig.40: Shed 'PPP' green line

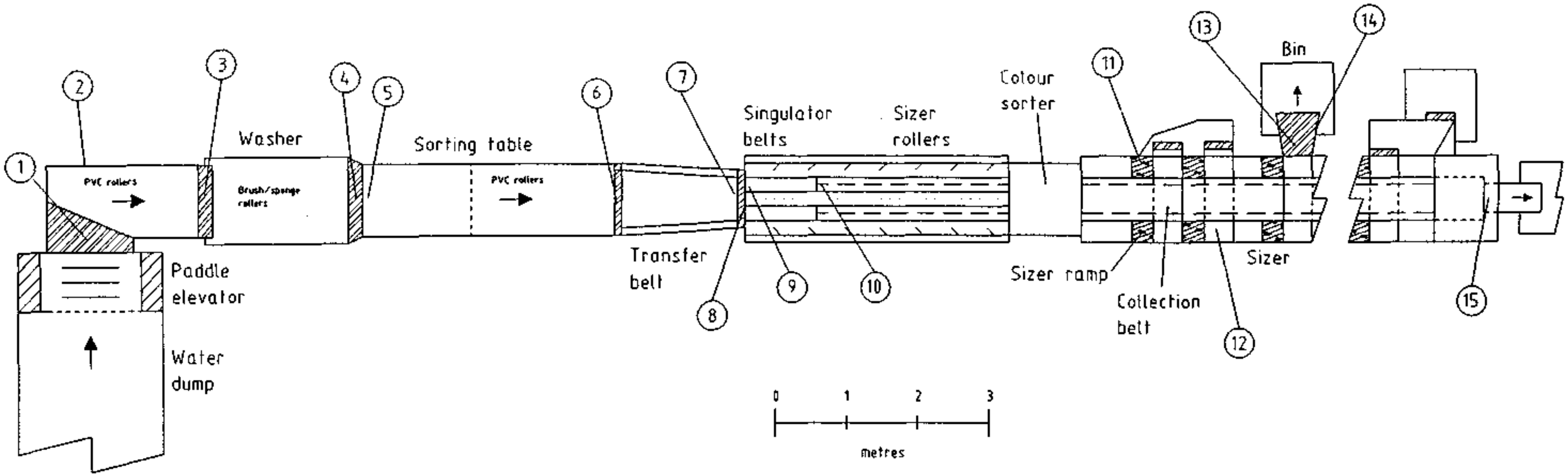


Table 48: Description of impact sites on the `PPP' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto ramp
2	against side wall opposite paddle elevator exit
3	off PVC rollers onto ramp
4	off sponge rollers onto ramp
5	off ramp onto sorting table (PVC) rollers
6	off sorting table onto ramp
7	off transfer belt onto top of ramp
8	onto bottom of ramp
9	off ramp onto singulator belt
10	off singulator belt onto sizer roller
11	onto sizer ramp
12	onto collection belt
13	off collection belt onto top of chute
14	against side wall of chute
15	off sizer onto bin belt
16	into bin, various fills

Table 49: Summary of impact data recorded by an instrumented sphere on the `PPP' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	93	100	140
2	71	80	103
3	69	60	89
4	56	60	74
5	67	90	93
6	59	80	72
7	109	100	117
8	57	100	65
9	62	60	82
10	62	50	75
11	102	20	113
12	155	27	261
13	69	27	113
14	67	93	93
15	59	80	77
16	63	60	81

Fig.41: Shed 'PPP' red line

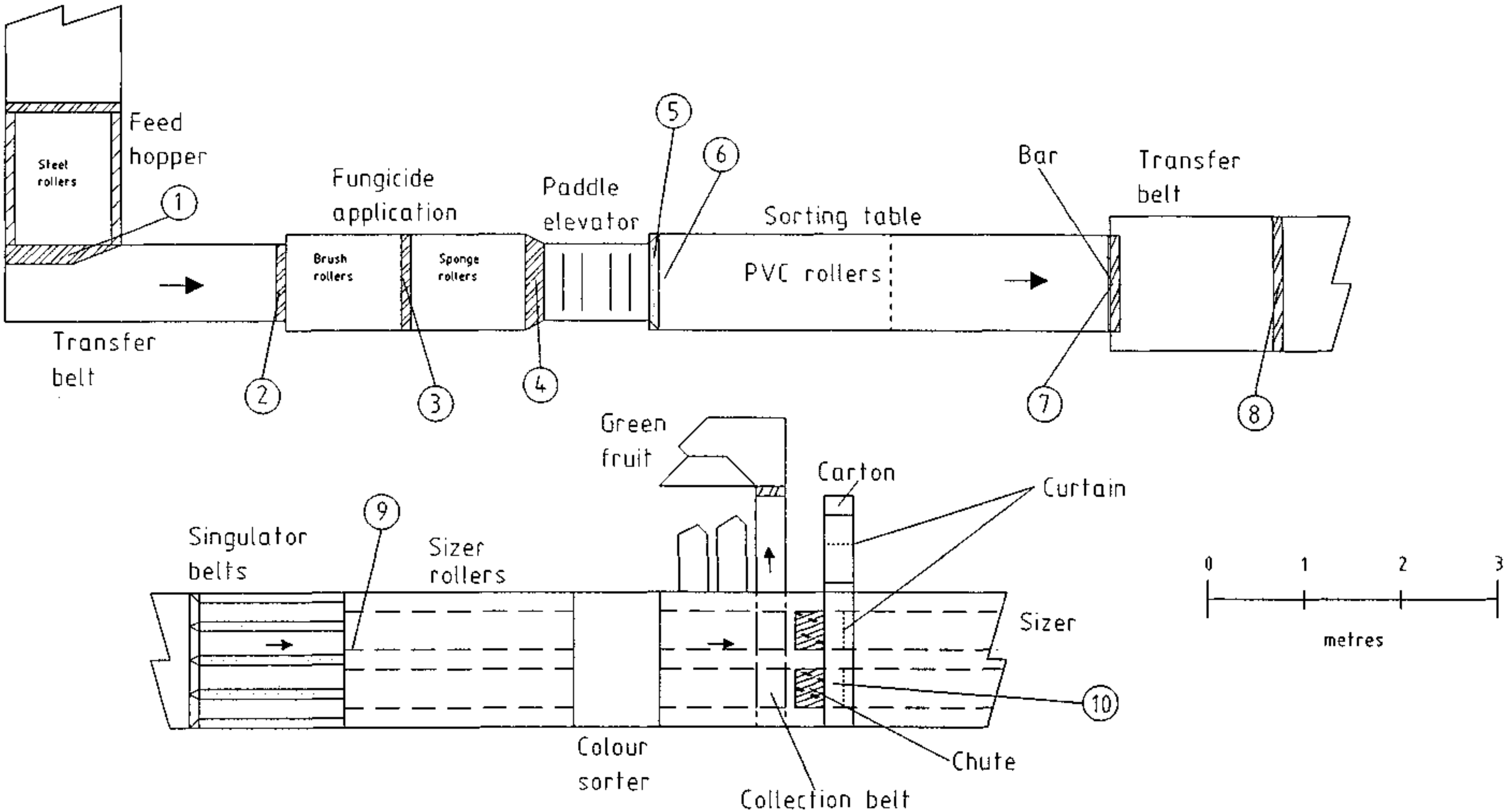


Table 50: Description of impact sites on the `PPP' red line

SITE	IMPACT SITE DESCRIPTION
1	from feed hopper onto steel ramp
2	off transfer belt onto ramp
3	off brush rollers onto ramp
4	off sponge rollers onto ramp
5	off paddle elevator onto ramp
6	off ramp onto sorting table (PVC rollers)
7	off sorting table onto ramp
8	off transfer belt onto ramp
9	off singulator belt onto sizer rollers
10	onto collection belt

Table 51: Summary of impact data recorded by an instrumented sphere on the `PPP' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	111	100	151
2	69	60	82
3	50	20	52
4	48	40	48
5	50	70	54
6	132	100	179
7	120	100	173
8	78	100	98
9	63	60	74
10	69	60	84

Fig.42: Shed 'VVV' tomato grading line

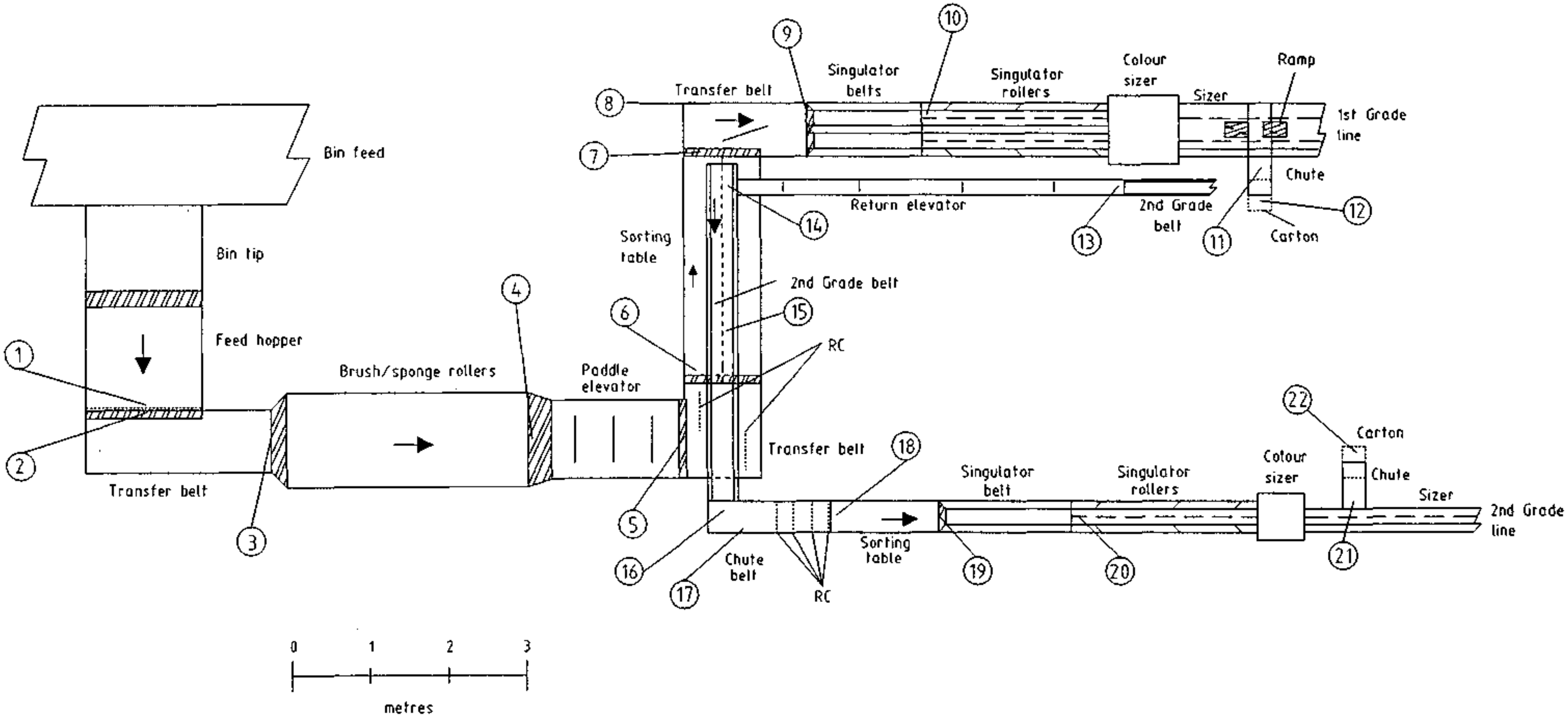


Table 52: Description of impact sites on the `VVV' tomato grading line

SITE	IMPACT SITE DESCRIPTION
1	against leading edge of feed hopper rollers
2	off feed hopper onto ramp
3	off transfer belt onto ramp
4	onto top edge of ramp
5	off paddle elevator onto ramp
6	off ramp onto sorting table
7	off sorting table onto ramp
8	against side wall opposite sorting table
9	off transfer belt onto top edge of ramp (1st Grade line)
10	off singulator belt onto singulator rollers (1st Grade line)
11	off singulator rollers along chute (approx. half way down) (1st Grade line)
12	off chute into 1/4 -full carton (1st Grade line)
13	off 2nd Grade belt onto return elevator
14	off return elevator onto 2nd Grade belt (above sorting table)
15	hand placement by sorter onto 2nd Grade belt (above sorting table)
16	off 2nd Grade belt onto chute belt
17	against wall inside chute
18	off chute belt onto 2nd Grade sorting table
19	off sorting table onto ramp (2nd Grade line)
20	off singulator belt onto singulator rollers (2nd Grade line)
21	off singulator rollers onto top of chute (2nd Grade line)
22	off chute into empty carton (2nd Grade line)

Table 53: Summary of impact data recorded by an instrumented sphere on the `VVV' tomato grading line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	131	90	231
2	129	90	199
3	142	100	165
4	88	100	104
5	215	100	283
6	69	100	101
7	66	91	86
8	63	60	72
9	82	100	113
10	105	45	175
11	68	100	84
12	51	33	56
13	91	80	102
14	124	100	146
15	119	100	190
16	71	90	101
17	71	100	85
18	106	100	228
19	61	90	85
20	73	20	87
21	56	60	70
22	71	60	117

Fig.43: Shed 'QQQ' green line

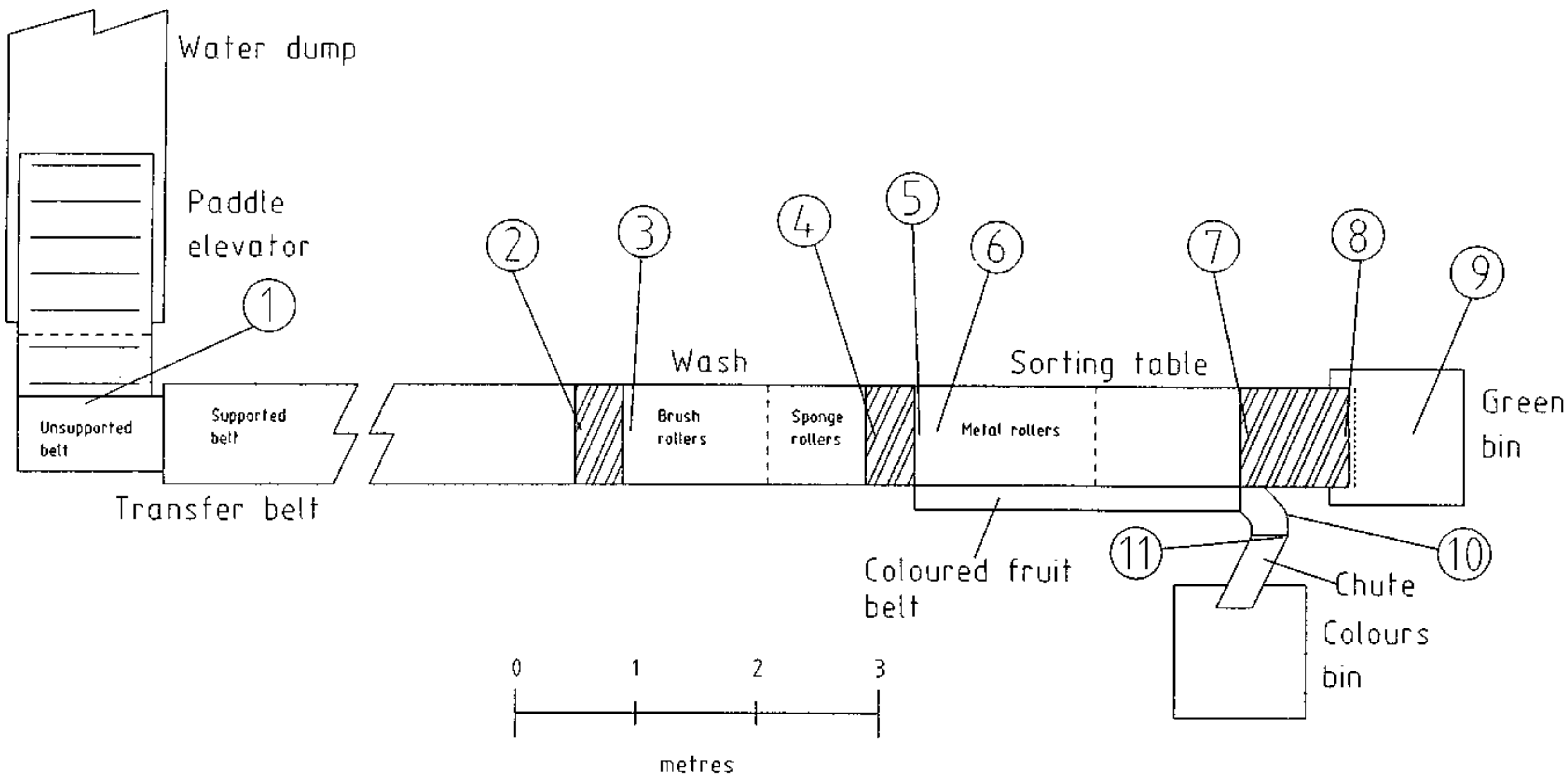


Table 54: Description of impact sites on the `QQQ' green line

SITE	IMPACT SITE DESCRIPTION
1	off paddle elevator onto unsupported belt
2	onto ramp from supported belt
3	off ramp onto brush rollers
4	onto ramp from sponge rollers
5	off ramp onto metal rollers of sorting table
6	rebound on metal rollers (associated with 5)
7	onto ramp from sorting table
8	against rubber curtain and/or end of ramp
9	onto padding in bin
10	coloured fruit line, against wall of chute on corner
11	coloured fruit line, against wall & junction on chute
	Note: on the coloured fruit line, 10 drops into a bin resulted in no recorded impacts

Table 55: Summary of impact data recorded by an instrumented sphere on the `QQQ' green line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1*	52	20	54
2	123	100	154
3	48	40	54
4	48	10	48
5	140	100	255
6	113	70	135
7	139	100	153
8	47	50	55
9	83	100	112
10	86	100	105
11	75	100	83

* Excellent example of how the impact associated with a relatively large drop can be minimised by careful design. In this case the unsupported belt acts very effectively to cushion the impact.

Fig.44: Shed 'QQQ' red line

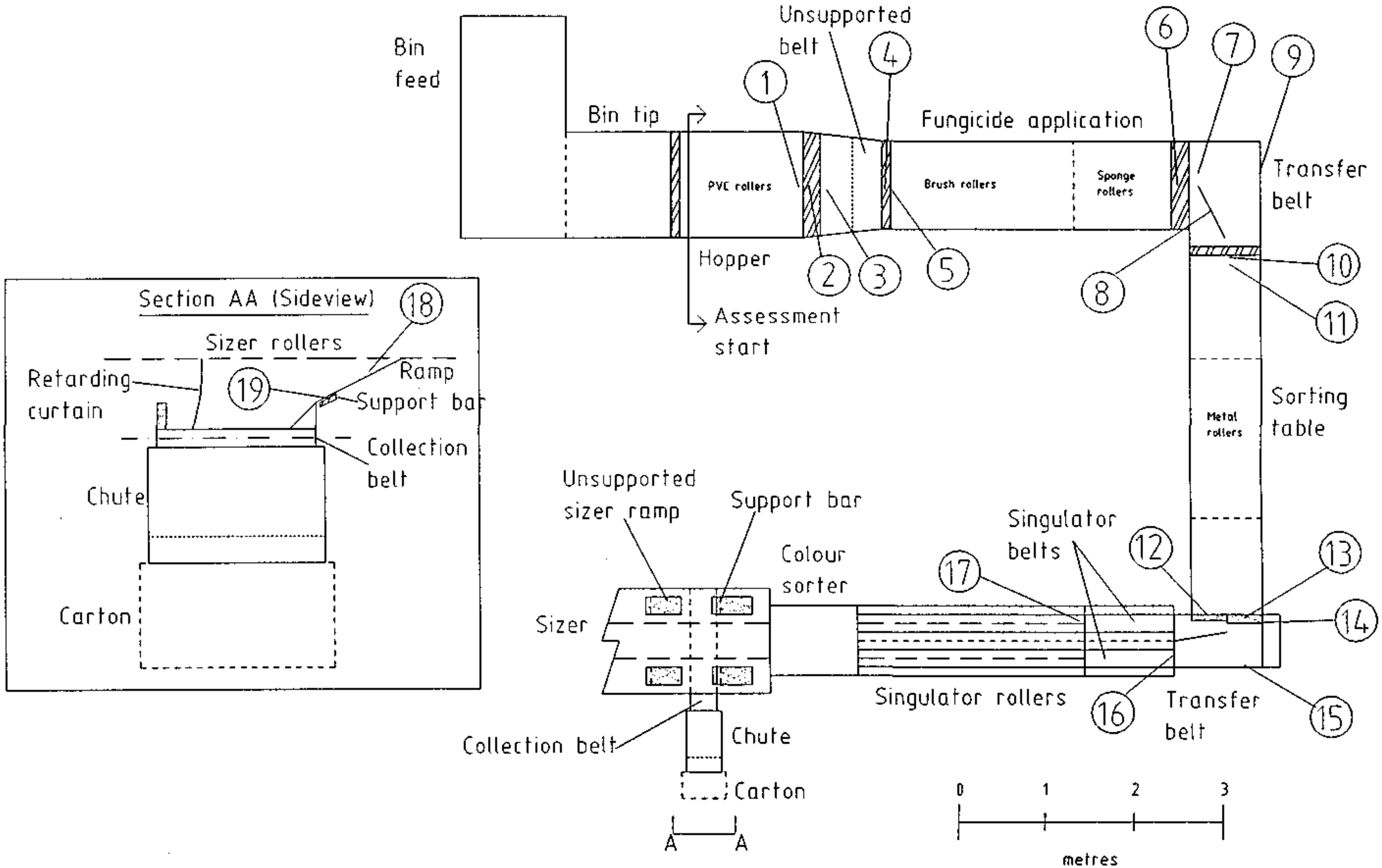


Table 56: Description of impact sites on the `QQQ' red line

SITE	IMPACT SITE DESCRIPTION
1	against edge of PVC rollers on the hopper
2	onto top of ramp
3	onto leading edge of ramp and belt junction
4	onto ramp leading to brush rollers
5	rebound associated with 4
6	off sponge rollers onto start of ramp
7	off ramp onto transfer belt
8	against guide on transfer belt
9	against wall opposite ramp
10	onto metal rollers of sorting table
11	rebound on sorting table associated with 10
12	off sorting table onto narrow ramp
13	off sorting table onto top of wide ramp
14	rebound on wide ramp
15	against wall opposite ramp
16	onto singulator belts (could include impacts against singulator side wall near entrance)
17	off singulator belt onto singulator rollers
18	off sizer rollers onto main body of unsupported ramp
19	onto part of the ramp which is supported underneath by a metal bar

Table 57: Summary of impact data recorded by an instrumented sphere on the `QQQ' red line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	75	80	91
2	77	90	103
3	96	100	159
4	122	100	157
5	49	60	53
6	69	100	76
7	101	90	158
8	118	40	145
9	77	50	92
10	78	90	109
11	77	30	93
12	138	100	195
13	186	100	256
14	59	100	79
15	137	less than 30	157
16	90	100	110
17	57	40	62
18	57	15	67
19	159	20	162

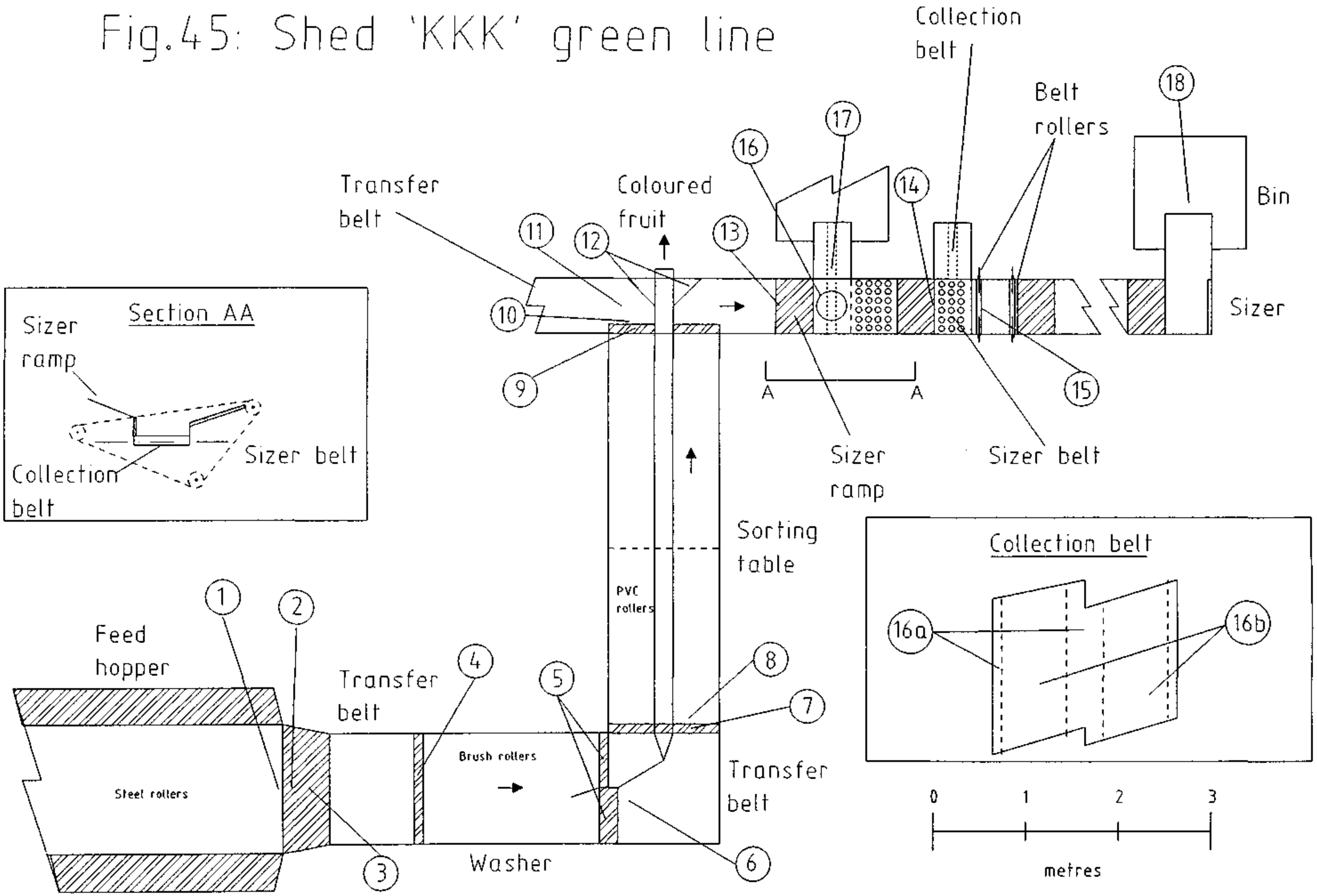


Fig.45: Shed 'KKK' green line

Table 58: Description of impact sites on the `KKK' green line

SITE	IMPACT SITE DESCRIPTION
1	against leading edge of hopper rollers
2	off hopper rollers onto top of ramp
3	rebound along ramp
4	off transfer belt onto ramp
5	off washer onto ramp
6	off ramp onto transfer belt
7	off transfer belt onto ramp
8	off ramp onto sorting table (PVC rollers)
9	off sorting table onto ramp
10	off ramp onto transfer belt
11	bounce along belt
12	against metal guide
13	off transfer belt onto top of sizer ramp
14	roll back against edge of sizer ramp
15	against metal roller under holed sizer belt
16	out of holed sizer belt, randomly onto collection belt below
16a	additional drop test by hand (see Figure insert), centre or edge of collection belt which is unsuspended from below
16b	additional drop test by hand (see Figure insert), strips of the belt with backing board
17	rebound along belt after 16
18	off collection belt into bin (between half & full of tomatoes)

Table 59: Summary of impact data recorded by an instrumented sphere on the `KKK' green fruit handling line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	82	70	111
2	101	100	164
3	90	10	90
4	91	80	152
5	60	70	74
6	52	10	52
7	52	70	61
8	78	80	107
9	54	60	62
10	71	80	93
11	99	30	118
12	65	40	85
13	81	100	97
14	66	60	102
15	66	50	88
16	146	100	293
16a	54	80	-
16b	282	100	-
17	84	24	118
18	54	67	60

Fig.46: Shed 'KKK' red line

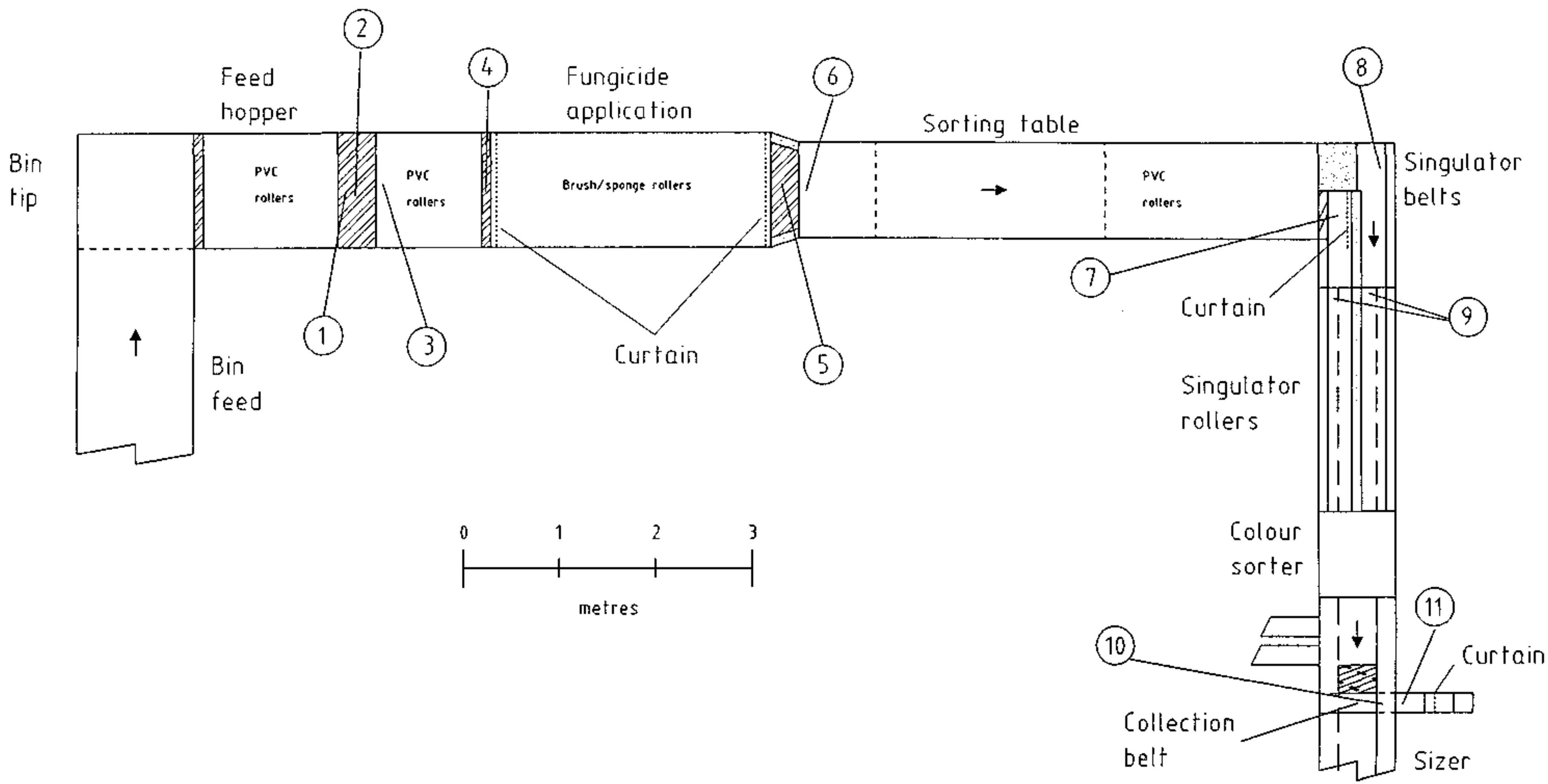


Table 60: Description of impact sites on the `KKK' red line

SITE	MPACT SITE DESCRIPTION
1	off feed hopper onto ramp
2	rebound along ramp
3	off ramp onto PVC rollers
4	off PVC rollers onto ramp
5	off brush/sponge rollers onto ramp
6	off ramp onto PVC rollers of sorting table
7	off ramp (after sorting table) onto belt & angled wall
8	off vinyl/sponge covered ramp (after sorting table) onto belt & angled wall
9	off singulator belt onto singulator rollers
10	along collection belt
11	off collection belt onto metal chute

Table 61: Summary of impact data recorded by an instrumented sphere on the `KKK' red tomato packing line

SITE	AVERAGE IMPACT ACCELERATION (G)	FREQUENCY OF OCCURRENCE (%)	MAXIMUM IMPACT ACCELERATION (G)
1	105	100	172
2	57	50	62
3	96	50	146
4	85	90	114
5	85	100	129
6	54	60	61
7	70	60	91
8	56	70	64
9	68	40	81
10	63	40	76
11	122	100	142

C. Field assessments using the instrumented sphere

SUMMARIES OF SHED DATA

Impacts generally occur in the transition zones between different functional components that make up tomato handling lines. For example, between a series of rollers and a transfer belt. These zones are typified by changes in elevation, speed and direction. General recommendations to reduce impact acceleration appear in section`E'.

Based on all sheds, the most direct route for first class fruit between bin-tip and carton (not inclusive) entailed passage through an average of 25 impact sites (>40G). Impact size between bin-tip and the carton averaged 91G, and the average maximum across all sites was 119G.

The distribution of impact size for first class fruit on a direct route between bin-tip and carton is outlined in Fig. 47. About 50% of impacts had sizes less than 80G. Only about 5% were greater than 160G .

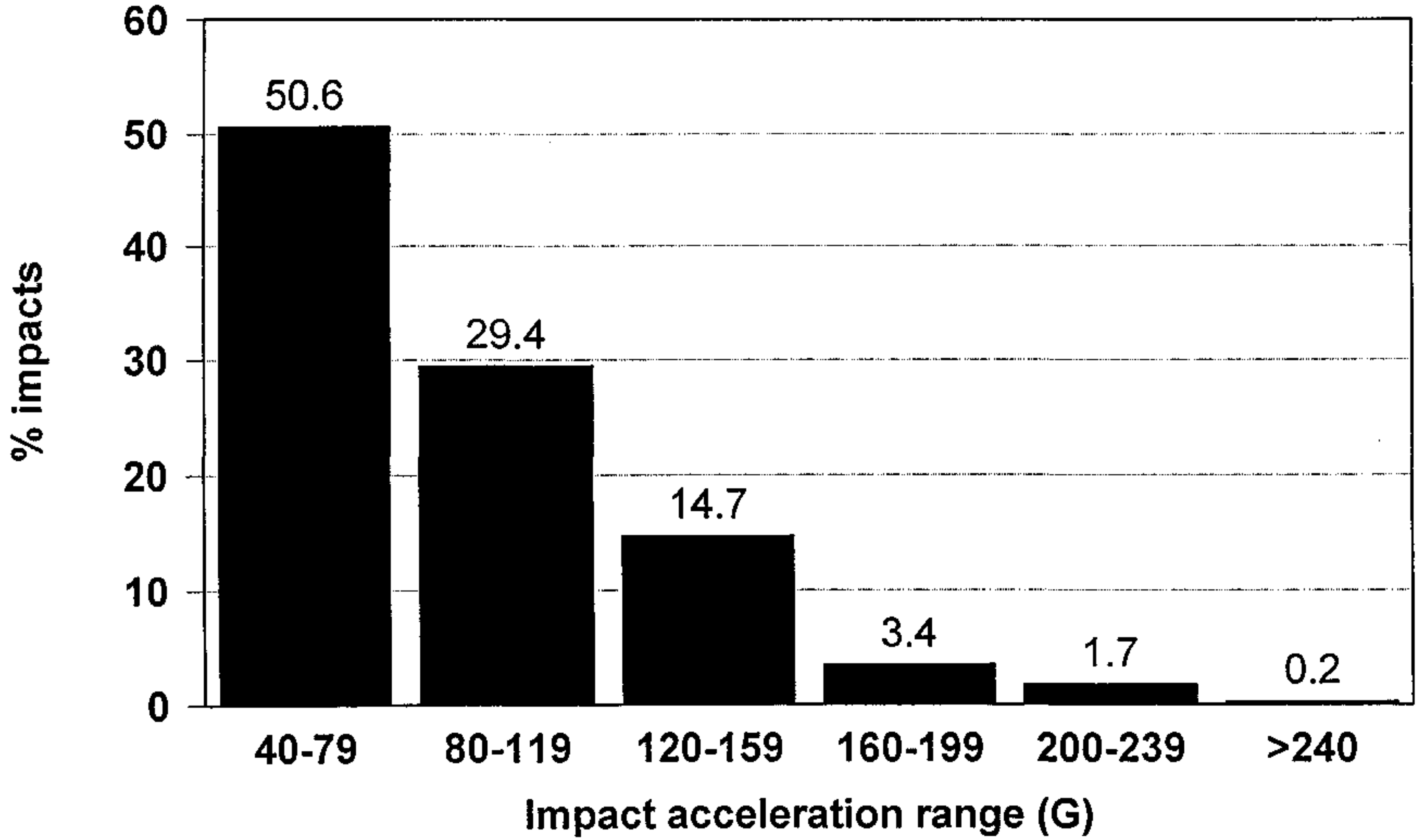
Table 62 lists the most severe impact in each of the packing sheds based on a consideration of frequency and average impact size. The average size is 183G, with a range 132G to 229G. In comparison, Table 63 describes the most severe impact based on the maximum impact acceleration recorded at each site. In this case, the range is 234G to 346G, with an overall average of 277G.

Impacts larger than 350G are at the upper end of the range which can be safely and accurately measured by the sphere. Recommendations to reduce impact acceleration at these worst sites appear in Tables 62 and 63.

Table 64 considers all impacts over 150G recorded in all 15 sheds. The locations (and causes) of these impacts have been categorised to allow some generalisations to be made about origins of large impacts on tomato handling lines. Forty-five percent of large impacts occurred as the IS moved onto ramps. Other important problem areas were transfer onto rollers, contact with unpadded (or under-padded) walls, neglected overflow returns, and drops onto the

Fig.47: Distribution of average impact acceleration for 15 QLD tomato sheds

(based on all packing lines)



Not including bin tip or impacts into carton or bulk bins

SUMMARY

Table 62: Sites in each of the fifteen packing sheds at which the most severe impacts occurred (based on average impact size*)

SHED	SITE No.	SITE DESCRIPTION	AVERAGE IMPACT ACCELERATION (G)	RECOMMENDATIONS TO REDUCE IMPACT ACCELERATION
MMM	2 (red)	off hopper rollers onto edge of ramp	163	add padding to the edge of ramp
TTT	10B	off ramp onto sorting table rollers (PVC)	206	add heavy retarding curtain at end of ramp
GGG	13 (green)	along metal edge of collection belt housing	179	add padding along metal edge of collection belt housing
SSS	15 (Red)	on overflow, off chute onto return belt	227	remove any support from under return belt and add retarding curtain at end of chute
JJJ	76 (red)	off ramp onto sorting table rollers	229	add heavy retarding curtain at end of ramp
HHH	12 (red)	at overflow return, off ramp onto belt/wall	159	add padding along side wall opposite ramps
FFF	9A (green)	out of sizer belt through to collection belt	175	remove any support under collection belt beneath sizer belt
RRR	2 (red)	off brush rollers onto ramp	149	add padding on ramp
UUU	31	firsts line, off sizer cups onto ramp	223	add or replace worn padding on ramp
III	9 (green)	off ramp onto chute	189	add padding along chute and place retarding curtain at end of ramp
WWW	3	off sorting table onto ramp	165	add padding on ramp (retarding curtain at this site is not preventing impact)
PPP	6 (red)	off ramp onto sorting table (PVC) rollers	132	add heavy retarding curtain at end of ramp
VVV	5	off paddle elevator onto ramp	215	add padding on ramp, raise ramp or lower paddle elevator
QQQ	13 (red)	off sorting table onto top of wide ramp	186	add padding on ramp
KKK	16 (green)	out of holed sizer belt, onto collection belt	146	remove any support under collection belt beneath sizer belt

*** Based on high frequency and high average impact acceleration**

SUMMARY

Table 63: Sites in each of the fifteen packing sheds at which the most severe impact occurred (based on maximum impact acceleration*)

SHED	SITE No.	SITE DESCRIPTION	MAXIMUM IMPACT ACCELERATION (G)	RECOMMENDATIONS TO REDUCE IMPACT ACCELERATION
MMM	3 (red)	onto elevator from ramp (metal rollers)	330	add heavy retarding curtain at end of ramp; replace with paddle elevator
TTT	10B#	off ramp onto sorting table rollers (PVC)	265	add heavy retarding curtain at end of ramp
GGG	13 (green)#	along metal edge of collection belt housing	238	add padding along metal edge of collection belt housing
SSS	15 (Red)#	on overflow, off chute onto return belt	268	remove any support from under return belt and add retarding curtain at end of chute
JJJ	11 (green)	off transfer belt onto chute	274	replace steel chute with vinyl sling chute
HHH	12 (red)#	at overflow return, off ramp onto belt/wall	273	add padding along side wall opposite ramps
FFF	9A (green)#	out of sizer belt through to collection belt	234	remove any support under collection belt beneath sizer belt
RRR	5 (green)	off chutes onto collection belt	346	check supports below collection belt
UUU	31#	firsts line, off sizer cups onto ramp	289	add or replace worn padding on ramp
III	1 (green)	off paddle elevator onto ramp before brush rollers	248	add padding on ramp
WWW	13	onto collection belt	292	remove support under collection belt
PPP	12 (green)	onto collection belt	261	check supports below collection belt
VVV	5#	off paddle elevator onto ramp	283	add padding onto ramp, raise ramp or lower paddle elevator
QQQ	13 (red)#	off sorting table onto top of wide ramp	256	add padding onto ramp
KKK	16 (green)#	out of holed sizer belt, onto collection belt	293	remove any support under collection belt beneath sizer belt

*** Independent of impact frequency**

 # Sites with both largest average, and maximum, impact acceleration

SUMMARY

Table 64: Categorisation of impact sites (across all packing lines) with an average impact acceleration greater than 150G

CATEGORY OF IMPACT SITE	FREQUENCY* (%)	AVERAGE IMPACT ACCELERATION (G)	RECOMMENDATIONS TO REDUCE DAMAGE#
onto ramp (from elevator, sorting table etc.)	45	178	add padding on ramp to reduce impact size
onto PVC rollers (from elevator, ramp)	16	185	add retarding curtain before rollers; maintain high loading on rollers
onto collection belt associated with belt sizer	16	210	install new sizer; remove supports from under belt
along overflow return	13	173	retarding curtains and padding added at entrance and exit of return
against walls (along collection belts and opposite ramps)	10	175	add padding along walls to prevent impact

*** Based on 31 sites with average impact accelerations greater than 150G and at least 80% frequency of occurrence**

 # See recommendations in text for further details regarding reduction of impact acceleration

collection belts of older style, belt sizers. Some recommendations are made for impact reduction in Table 64, however, a more detailed account follows in section `E' of this report.

For tomato packing houses in the U.S.A., Sargent *et al.* (1990) found that transfer points with the greatest potential for causing injury were impacts from high drops onto metal plates, drops/rolls to sorting and grading roller conveyors, drops to conveyors supported by metal plates, and drops to brush rollers with excessive rotational velocities.

The majority of ramps incorporated into Queensland tomato packing lines were unpadded and constructed from steel or aluminium. Cushioning of ramps should be a priority for all growers. Drops onto PVC rollers, usually off elevators or ramps, can be alleviated with retarding curtains.

Although tipping of bulk-bins filled with fruit is popularly considered to be damaging, it was found in this study that very few large impacts were associated with this process. Use of fully filled bins, gentle tipping actions and unloading through bin side gates were probably common reasons for avoiding large impacts. However, fruit on the surface of a bin load can be exposed to impacts against the bin lid/tipper if a gentle tipping action is not used.

D. Matching field readings of the instrumented sphere to injury levels

In laboratory tests, damage to tomato variety `Tempest' occurred in response to drop heights and associated impact accelerations that were often larger than those recorded in the field.

`Tempest' fruit is able to tolerate impacts that would generally be considered extreme in most handling situations for fresh produce. However, it is interesting to note that other researchers working with the instrumented sphere and tomatoes also found that laboratory generated injury thresholds were rarely exceeded during commercial handling (Sargent *et al.*, 1990).

Other tomato varieties may be more susceptible to injury than `Tempest', and Bundaberg shed staff alluded to this possibility. In support of this observation, Sargent *et al.* (1989) working with American varieties obtained higher rates of internal bruising with lower drop heights compared to `Tempest'.

How do packing shed managers interpret sphere readings in order to know whether damage is occurring in their shed?

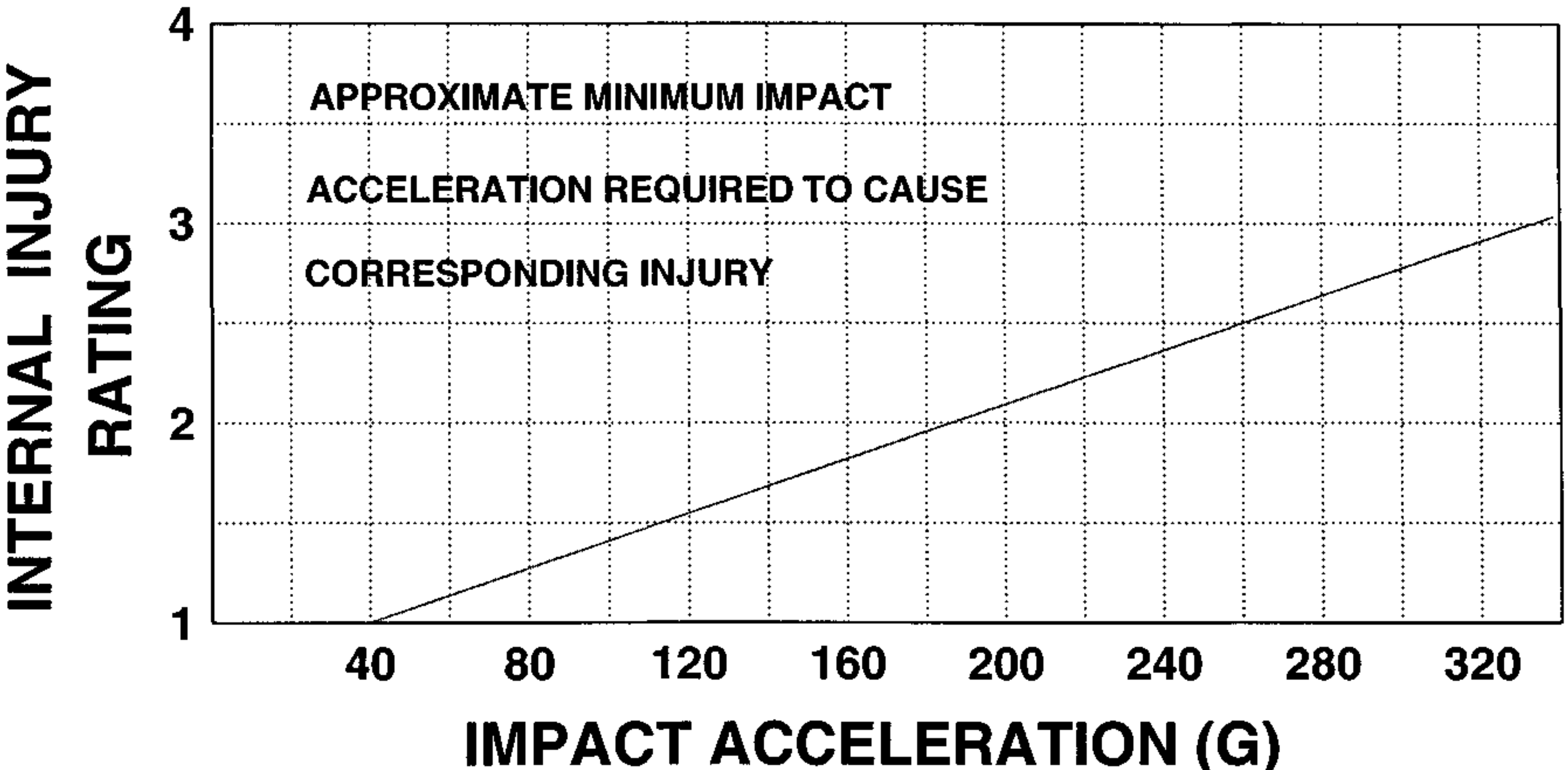
Based on data from Figs. 6 & 16, Fig. 48 is an easy to use guide that provides an approximate correlation between injury to `Tempest' tomatoes and impact acceleration.

Rating 2 injuries as outlined in Table 1, probably start in response to impact accelerations of around 185G. Based on average impact sizes, less than 5% of impacts fall into this category. For `Tempest', worse injuries develop following much larger impacts but as Table 63 suggests, impacts of this size probably occur with relatively low frequency at only 1 or 2 points on most lines.

For more objective interpretation of IS readings, handlers of any tomato variety can be confident that the size of impact accelerations associated with drops, bumps and collisions provide an accurate indication of the relative potential of different sites to cause damage.

Fig. 48 : Predictor plot for internal injury rating of `Tempest' tomatoes

(based on Figures 6 and 16)



E. General recommendations to reduce impact size on handling equipment

Automated handling lines are made up of individual components such as sorting tables, belts & sizers which are usually connected by ramps or chutes. IS assessments have demonstrated that the manner in which these components are linked plays an important role in causing injuries to fresh produce. Generally, fruit movement between components in these *transition zones* is a major source of impact damage. Often, *transition zones* include a change in elevation where produce is free to drop and then impact against ramps, rollers or supported belts.

Several options are available to reduce impact size on packing lines:

Reduce drop heights
Impact acceleration increases with drop height, so clearly drop distances between components should be minimised. Installation of a ramp between two levels is a common solution and can be very effective when correctly planned and constructed. In some circumstances, sling chutes made of vinyl or rubber sheeting can be used as an alternative to solid ramps.

Add cushioning
Hard surfaces that may come into contact with fruit during impact should *always* be padded with a cushioning material. Characteristics of good cushioning material include:

- a high capacity to absorb impact energy
- closed-cell construction for ease of cleaning, and to avoid water absorption, impregnation with dirt and microbial growth
- resistance to chemicals
- high tensile strength & wear resistance
- smooth surface to avoid fruit abrasion

Padding is available in many thicknesses but if excessively thick may cause undesirable bounce. Padding used on packing lines should be between 7mm and 15mm thick.

Remove supports under belts
In many instances, produce passes off a ramp and impacts onto a conveyor belt supported from beneath by wood, steel or belt rollers. To prevent impact damage in this type of transition, any support under a belt should be removed. This ensures that produce drops only onto the flexibile belt, and that energy associated with the impact is absorbed without causing damage.

Maintain high loading
High produce loading (i.e. volume) on handling lines helps to cushion and slow movement where free, down-grade rolling is likely to occur. Where possible, run the line at full capacity and match the speed of different components in the line to ensure a smooth flow of produce. However, observe reasonable limits as excessive loading can hinder operation of equipment.

Assess handling line design
Generally, longer lines incorporate more turns and transitions between components and are likely to cause more impacts than shorter lines. Transition zones that incorporate changes in direction and speed can also cause increases in numbers of collisions between fruit. Some component designs are inherently damaging (e.g. some older-style sizers) and replacement with gentler equipment may be the best option.

Use retarding curtains
Rubber retarding curtains impede movement through drops and are a cheap and effective means of slowing speed through a ramp or chute. They should be heavy enough to slow the movement of crop and can be positioned along ramps, or at the outlet of ramps, particularly before subsequent drops onto plastic or metal rollers.

Educate employees
Sorting, packing and pallet stacking staff should understand how produce injuries occur. It is advisable that they receive special instruction on handling to reduce damage.

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