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## **Quantifying Metal-Detector Sensitivity with Metal Spheres**

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July 2002

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## Technical Note

# Quantifying Metal-Detector Sensitivity with Metal Spheres

Tom Bloodworth (JRC Ispra/IPSC/HS Unit)

*July 2002*

### **Abstract**

This report describes the simple tests performed to evaluate the possibilities for using spherical metal balls as test targets to measure the sensitivity of metal detectors. Tests to determine the maximum height at which metal balls are detected have been made for four types of metal detector. The maximum detection height for each ball is plotted against ball diameter, to produce a characteristic sensitivity curve. Balls of several ferromagnetic steels as well as non-magnetic stainless steel and aluminium were used. Between the different ferromagnetic steels there is no observable difference in the sensitivity characteristics plotted. The non-magnetic stainless steel and aluminium are however significantly different in response.

It is proposed that measurements similar to those made could be used as part of standardized in-air tests to evaluate metal detectors. Further studies are however needed to relate the measurements to the responses from realistic (mine-like) targets and to measure the effects of soils.

## CONTENTS

<b>1</b>	<b>Introduction</b>	<b>3</b>
<b>2</b>	<b>Technical Approach</b>	<b>3</b>
<b>3</b>	<b>Measurement Method</b>	<b>4</b>
<b>4</b>	<b>Metal Detectors</b>	<b>6</b>
4.1	<i>Schiebel AN19/2</i>	6
4.2	<i>Foerster Minex 2FD 4.500</i>	6
4.3	<i>Guartel MD8</i>	6
4.4	<i>Vallon ML1620C (Phase Two tests only)</i>	7
<b>5</b>	<b>Ball Diameters and Materials: Phase One</b>	<b>7</b>
<b>6</b>	<b>Results: Phase One</b>	<b>8</b>
6.1	<i>Schiebel AN19/2</i>	8
6.2	<i>Foerster Minex 2FD 4.500</i>	8
6.3	<i>Guartel MD8</i>	8
6.4	<i>General Observations</i>	8
<b>7</b>	<b>Ball Diameters and Materials: Phase 2</b>	<b>9</b>
<b>8</b>	<b>Results: Phase 2</b>	<b>9</b>
8.1	<i>Schiebel AN19/2</i>	9
8.2	<i>Foerster Minex 2FD 4.500</i>	10
8.3	<i>Guartel MD8</i>	10
8.4	<i>Vallon ML1620C</i>	11
8.5	<i>General Observations</i>	11
<b>9</b>	<b>Conclusions</b>	<b>11</b>
<b>10</b>	<b>Proposed Sensitivity Standards</b>	<b>12</b>
<b>11</b>	<b>References</b>	<b>12</b>

## 1 Introduction

Metal detectors are an essential part of the toolkit of a humanitarian deminer. Metal detection is the main “non-contact” method available to detect mines in most of the areas of the world where humanitarian mine clearance operations are carried out. Despite the fact that metal detectors have been used for finding mines since the Second World War, there is little standardization in the way sensitivity is set.

The work reported here is an investigation into the feasibility of using metal balls as the basis for a universal scale of sensitivity. Detection capability could thus be defined in terms of a metal ball diameter and the maximum distance from a detector at which it can be detected. The goal of producing such a scale is to establish quantitative detection threshold levels and allow assessment and comparison of mine clearing operations performed at different sensitivities, independently of the detector used. In addition, a sensitivity measurement is required for any test and evaluation trial conducted to determine the performance of a metal detector. Many metal detector manufacturers already provide small metal targets for sensitivity checking, but they are all different and not related to any common standard.

A typical entry in a respected landmine guide [1] reads; “*The mine is manufactured from non-metallic material but has enough metal content to be detected by good metal detectors such as the Schiebel AN19/2 or Ebinger 420 PB.*” Both of these detectors have variable sensitivity and the type of soil in which the mine is laid can have a big influence on the sensitivity required to detect it. The lack of any quantitative measure of sensitivity therefore means that the utility of this advice is rather limited. The entry in the guide would be rather more useful if it could say; “*To detect this mine when buried at the intended depth of Dmm in soil type S, requires a sensitivity level L*”. L would be defined as the sensitivity level that can detect a standard metal target of a certain size at a given height. It would be particularly useful if common sizes of steel ball-bearing balls could be used for making the standard targets. It would be relatively easy for deminers to obtain such items in remote areas.

The aim of this work was therefore to discover, using a series of simple tests, whether measuring sensitivity in this way is a practical idea. In particular, some way of measuring metal detector sensitivity is needed for standardizing the test and evaluation of metal detectors. A CEN Workshop process has begun [2], which aims to achieve such standardization. One goal of the present work was to provide some preliminary experimental evidence to this CEN Workshop.

Note that these measurements, made in air, cannot be used on their own to compare the detection performance of metal detectors. The relative detection performance achieved in air does not necessarily give an indication of the performance on targets buried in soil.

## 2 Technical Approach

Metal detectors for demining are very sensitive instruments, which show a response to tiny changes in the field produced by their coils. These instruments are however designed for use in difficult conditions, by personnel who may have little, if any technical education. Metal detectors are therefore made very simple to operate. There is usually no output signal level display, either in an analogue, graphical or digital form, just an audible alarm signal whose tone and/or amplitude increases with increasing signal. It is therefore difficult to quantify directly the response from a detector to a metal object. The ideal way to set the sensitivity of a detector would be to set a threshold signal amplitude relative to the amplitude of the signal from a simple, well-defined reference target. Some detectors do have the facility for a signal-level output, which can be

displayed and recorded but, since this feature is not generally used in the field, a different approach was adopted.

In order to quantify the relative sensitivity to a given target, the maximum height above the target at which an alarm indication is triggered is measured instead. The higher the sensitivity, the higher is the maximum detection distance for a given target, or the smaller the minimum detectable target at a given height. The alternating magnetic field produced by the coil becomes weaker with distance. The details of the way the field decays depend on the coil geometry. The response is also dependent on the sensor design. For example a differential-response coil will show a different behaviour to a simple coil. Furthermore, the size and shape of the target affect the response and will affect detectors differently according to their design details. Different frequencies will have different skin depths in the targets. The form of the sensitivity curves of detection height as a function of target size may therefore be expected to vary between different detectors.

The ideal target shape for such sensitivity tests is a sphere, because the response will not vary with orientation. In any standard that results from this work, repeatable sensitivity tests would be easy to perform with such targets. The choice of material is considered important for standard targets because the relative responses of all metal detectors to different materials (in particular, any difference between magnetic and non-magnetic materials) may not be the same. For this reason, balls of both magnetic and non-magnetic steels were used for these tests, as well as balls of other metals. In demining areas in developing countries where there is minimal infrastructure to supply engineering materials, the possibility for using widely-available ferritic-steel ball bearings for local production of metal-ball sensitivity standards would be a great advantage. Given that the effective “incremental” permeability of ferritic steels can vary considerably between different steel compositions and different work and heat treatment histories, the degree of variation in detection height between these steels is of particular interest.

One reason that metal balls are an attractive target to use for these sensitivity studies is that predicting the response of such targets in the fields of circular coils is relatively tractable theoretically. An exact solution exists for the impedance change in a circular coil due to a nearby *non-magnetic*, conductive sphere [3]. One interesting result of this work is that for skin depths much less than the sphere diameter, the impedance change is dependent on the sphere volume but independent of the sphere's resistivity. Previous work at JRC [4] has applied the results from reference 3 to particular metal detectors to explain differences observed with these detectors in the relative signal amplitudes from mine-like targets when referenced to signals from metal calibration spheres.

For another application, the change in the impedance of a solenoid due to a conducting, permeable sphere is calculated [5]. Although a solenoid has a more uniform field than does a metal-detector coil, the results for the relative responses of different metals are expected to be qualitatively similar. In [5], the impedance variation is presented as the product of a complex function  $F$  and the cube of the ratio of the sphere radius to solenoid radius. The variation of  $F$  is plotted as a function of the relative permeability  $\mu_r$  and the ratio of the sphere radius to the skin depth;  $u = a/d$ .

### 3 Measurement Method

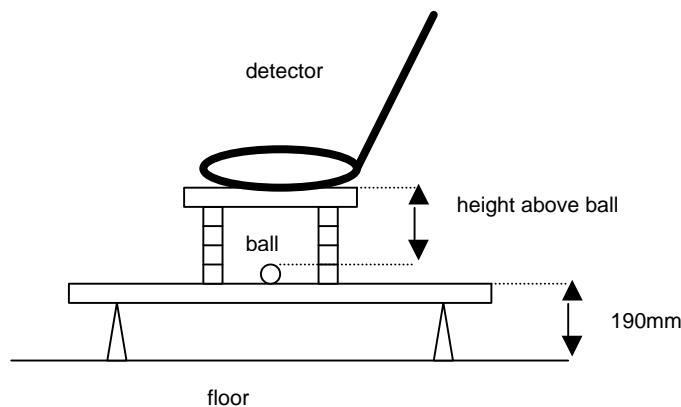
The tests were carried out in the Carl Friedrich Gauss Laboratory, of the JRC's Facility for Humanitarian Demining Technology, which is specially designed to have minimum metal content to eliminate interference to metal detectors from walls, floors and equipment. Balls of several metals were selected to determine how sensitive are metal detector responses to different target resistivity and permeability. For the present tests, metal balls were placed on an insulating board, which is raised so that the upper surface of the board is approximately 190mm above the block-

paved floor. This is to reduce any small effect that the floor has on the detector. Insulating blocks were then built up on either side, so that the coil of the metal detector could be placed or swept at a fixed height above the metal ball.

For each detector the maximum height above the ball at which the alarm sounds was determined, for each ball size and material. The detectors have different characteristics, for example absolute or differential response, with or without auto-zeroing *etc.* In addition, judging the point at which the audio alarm can be considered to be reliably triggered is subjective. Therefore an appropriate criterion was established for each detector and this criterion was adhered to for all tests with that detector. The basic idea was however maintained; that the maximum height giving a consistent (repeatable and not intermittent) detection alarm be recorded.

The sensitivity of a detector is different under different parts of the coil area. The criterion used to determine maximum detection height was to find the maximum height at which an alarm indication is given with the target at any location under the coil. The detector therefore had to be moved both from side to side and forwards and backwards, to determine whether the alarm sounds at any lateral location at that height above the target. In practice, it was quite easy to find this maximum sensitivity spot using this manual method.

The height of the detector above the ball was adjusted by adding or removing wooden blocks, the thinnest of which are 5mm thick. This gives a limit to the measurement precision of the maximum detection height. The height from the top of the ball to the top of blocks was measured. Because of the procedure used, a random error of  $\pm 5\text{mm}$  has been estimated to apply to these measurements unless otherwise stated.



**Figure 1 Maximum Detection Height Measurement**

The height of detection in air is equivalent to that which could be achieved in an “ideal” soil with zero conductivity and magnetic susceptibility. In reality of course, many soils reduce the sensitivity achieved at a given depth, so both target, depth and soil properties will define the sensitivity needed. The requirements for the depth to which land is to be cleared of mines are set out in IMAS 09.10. [6]. This standard does not give a definitive depth because it is recognized that in different environments the requirement may be different, so the clearance requirements may have to be based on local intelligence. This IMAS does however recommend that the clearance depth should not normally be less than 130mm. Assuming a sweep height above the soil of 30mm, the appropriate height for assessing detection sensitivity to comply with this requirement is approximately 160mm. Other demining organizations use their own clearance standards, for example the “normal”

detection depth in MgM standard operating procedures [7] is 150mm (from ground level to the top of the mine).

Of course the metal content of low-metal mines is not usually right at the top, so the location of the metal in such mines needs to be taken into account when choosing the appropriate depth at which to check sensitivity.

## **4 Metal Detectors**

### **4.1 Schiebel AN19/2**

The Schiebel AN19/2 (also known by its US Army designation AN/PSS-12) is a pulsed induction detector with a single receive coil, giving a simple spatial response. The search head is circular, with a 260mm diameter. There is no auto-zero or high pass filtering at the output, so the detector can be used with the coil stationary. An audio alarm sounds when the output signal exceeds a variable threshold – the sensitivity control. The sensitivity control has a continuous adjustment, *i.e.* no pre-selectable positions. For the first phase of these tests, the control was increased to the maximum sensitivity with the detector away from any metal objects and then reduced until the alarm stops sounding. For the second phase, there was a slight change as the control was adjusted until no alarm indication was given from the block-paved floor of the laboratory.

For each diameter of metal ball tested, the height was adjusted to find the maximum height at which the alarm sounded continuously with the detector in any position over the ball. This criterion was used for all tests with this detector. At large heights, the maximum signal occurs when the ball is on the coil axis. When the ball is close to the detector, the maximum signal is with the ball under the coil winding.

### **4.2 Foerster Minex 2FD 4.500**

The Foerster Minex 2FD uses one elliptical excite coil (290mm × 210mm) and two semi-elliptical receive coils in opposition, giving a differential spatial response (the difference between what is "seen" by the two sides of the coil). The coil is excited by two simultaneous continuous wave frequencies (2.4kHz and 19.2kHz). The output signal is derived from the phase-sensitive detected voltages at these frequencies on the receive coils. A weighted difference of the quadrature components is used to minimize the effects of magnetic soils.

The alarm sounds when the output signal exceeds positive or negative thresholds, according to whichever of the semi-elliptical receive coils is nearer to the target. Different sound pitches are used for the positive and negative alarms. There is no auto-zero or high-pass filter function on the output, so the detector can be used stationary.

The criterion used for determining the maximum detection height was that the alarm sound continuously on one side (receive coil) of the detector or another, at any position of the coils over the ball.

### **4.3 Guartel MD8**

The Guartel MD8 is a pulsed induction instrument like the Schiebel AN19/2. There is a 320mm-diameter circular transmit coil and two semi-circular receive coils, connected differentially (like the Foerster Minex). The MD8 is designed to be used in a dynamic manner. There is an auto-zero function that operates every few seconds. The detector can be swept over a target causing the alarm to sound, but the alarm dies away if it is held stationary.



Because of the auto-zero, the tests for ball detection were made in a slightly different way to those for the previous two detectors. The search head was moved up and down as an alarm was sought in different positions over the spacing blocks. The criterion for determining the maximum detection height was that an alarm sounds on one side or another continuously, insofar as it is only cut off by the auto-zero function.

#### 4.4 Vallon ML1620C (Phase Two tests only)

The Vallon ML 1620C is a pulsed-induction, single receiving coil detector (like the Schiebel AN19/2) with an auto-zero function (like the Guartel MD8), so must be operated dynamically. The shape of the search head is elliptical, being longer in the "fore-and-aft" direction, but is slightly flattened at the ends. The search head has length 300mm & width 170mm. The ML1620C has several settings. There is a current level switch with the options of "M"-low current (for metal mines) and "P"-high current (for plastic mines). There is also a continuous sensitivity/gain control graduated up to 7. Two program setting switches are also available, one to select the soil-noise rejection program – depending on the soil conditions, the other to choose the mains voltage suppression frequency (50 or 60Hz)

The method for used for determining the maximum detection height was similar to that used for the Guartel MD8, due to the auto-zero function.

## 5 Ball Diameters and Materials: Phase One

Several different ball materials were used for the tests. Ball bearings of ferritic steel from various sources (exact material unknown), chrome steel 100Cr6 (UNI), ferritic stainless steel AISI 420 were used, which are all ferromagnetic. In addition, a non-ferromagnetic austenitic stainless steel AISI 316 and a bronze ball were used.

**Table 1 Metal Ball Diameters (mm)**

“Bearing”	100Cr6	AISI 420	AISI 316	Bronze
		2.4		
3.2				
4.0	4.0	4.0		
4.7		4.7		
	5.0			
5.6		5.6		
	6.0			
6.35		6.35		
		7.1		
	8.0	8.0		
		8.7		
		9.5		9.5
	10.0			
		10.3		
		11.1		
		11.9		
	12.0			
		12.7		
		13.5		
	14.0			
		14.3		
		15.1		

“Bearing”	100Cr6	AISI 420	AISI 316	Bronze
		15.9	15.9	
	16.0			
	20.0			

## 6 Results: Phase One

### 6.1 Schiebel AN19/2

The results of the tests with the Schiebel detector are shown in Figure 2. The main point to note from these results is that all of the ferritic steel balls lie on the same curve of max. detection height vs ball diameter, to within the estimated height measurement error. In addition the bronze ball also lies on this curve. Only the AISI 316 stainless steel ball lies below this curve, being significantly harder to detect than a ferritic ball of the same diameter.

The sensitivity of the detector (at the setting used for these measurements), in air at 250mm can be defined as that which can detect an 18mm-diameter ferritic steel ball. At 100mm the sensitivity increases to 8mm diameter.

### 6.2 Foerster Minex 2FD 4.500

The results for the Foerster detector at its three sensitivity settings are shown in Figure 3. All of the ferritic steels and the bronze again lie on the same curve, within the estimated measurement accuracy. With this detector the AISI 316 ball is significantly less detectable.

On the high-sensitivity (H) setting, a 15mm diameter ferritic steel ball can be detected at 250mm. At 100mm a 4.5mm ball defines the limit of detection. On the medium- and low-sensitivity settings (M and L), the sensitivity at 250mm is defined by targets larger than those used in the tests. At 100mm however, the appropriate ball diameters are 6mm and 9mm respectively

### 6.3 Guartel MD8

The results of measurements with the Guartel MD8 are shown in Figure 4. Only results at the highest sensitivity (setting III) are shown. Because of the auto-zero function operating on the MD8, the estimate of the accuracy of the maximum detection height was increased to  $\pm 10$ mm. The ferritic steel balls lie on the same curve for this detector also, within the error estimate. In this case however, both the bronze ball and the AISI 316 ball are less detectable than ferritic steel balls of the same diameter. The sensitivity of this detector in air at 250mm is that which will detect a 15mm ferritic steel ball. At 100mm, a ball of about 5mm defines the detection limit.

### 6.4 General Observations

The two differential detectors (Foerster and Guartel) show relatively higher sensitivity at close distances compared to the simple-response Schiebel detector. The sensitivity to the AISI 316 ball is lower than for ferritic steels for all of the detectors.

Note that these results cannot be used to make comparisons of the "absolute" detection capability of the detectors tested. The sensitivity curves presented are those for the sensitivity as set in the test. The sensitivity setting used in field conditions may not be the same. It is however valid to compare the relative detection capability for different materials.

To detect objects with a large metal content at 250mm, while rejecting small metallic “clutter” objects near the surface, requires a low sensitivity to be used. Assuming for example, that the

“Low” setting of the Foerster detector would be typical for this application, a larger metal ball than those used in these tests would be required to define the sensitivity.

## 7 Ball Diameters and Materials: Phase 2

Following the results from the first experiments it was clear that sensitivity of detectors to the two non-ferromagnetic balls used was less than for the various ferromagnetic steels. More balls of non-ferromagnetic metals with different sizes were needed to investigate whether this was true for all materials or ball diameters. Also further balls of ferromagnetic steels were obtained to extend the range tested and to verify the lack of dependence on the exact material type apparent from Phase 1.

In addition to the balls used in Phase 1, the balls listed below were used. Some balls with nominally the same material specification as those used in Phase 1 were used. These balls were however kept separate so that any material property variation between batches - within a given material specification - which may systematically affect the results would be evident. The second batch of each material is denoted by (M) after the manufacturers, Martin & C. srl of Turin.

**Table 2 Diameters of Additional Metal Balls for Phase 2 (mm)**

100Cr6 (M)	AISI 420 (M)	AISI 316	Aluminium
	4		
	6		6.35
		7	
	8	8	
	10		
	12		
	14		
		15.9*	15.9
	16		
18	18		
	20		
25			

\* As used in Phase 1.

## 8 Results: Phase 2

The results of measurements of maximum detection height of metal balls for the four detectors are shown in Figures 5 to 8. The uncertainty in determining the maximum detection height is the same as for phase one. However in these figures, the error bars have been omitted for clarity.

### 8.1 Schiebel AN19/2

The AN19/2 has a continuously-variable knob for sensitivity adjustment on its instrumentation unit. In these tests the sensitivity was deliberately set lower than the maximum in-air used previously. The detector sensor head was placed on the block-paved floor of the Gauss Laboratory (which gives

a metal detector signal) and the sensitivity adjustment reduced until no alarm indication was produced.

The results of the tests with the AN19/2 are shown in Figure 5. The effect of the lower sensitivity setting can be clearly seen if this sensitivity curve is compared with that in Figure 2. The ferromagnetic steel balls with a diameter around 16mm are detected at well over 200mm in the Phase 1 curve but only at less than 200mm in the Phase 2 curve.

All of the points for ferromagnetic steel balls lie on the same curve, considering the  $\pm 5$ mm precision in determining the max. height. The slight kink for the point representing the smallest ball detected occurs because at such a short range the maximum sensitivity occurs under the coil limb.

The non-ferromagnetic stainless steel (AISI 316) balls with diameters 7mm and 8mm are not detected at all. Clearly 316-steel balls of this size produce a much smaller response than do ferromagnetic steels. At 16mm diameter, however the AISI 316 ball is not much less detectable than the ferromagnetic steels.

The other non-ferromagnetic material of particular interest is aluminium. The large aluminium ball (15.9mm) is marginally less detectable than the 316 stainless steel one of a similar size, however the small one (6.35mm) is as easy to detect as the ferromagnetic steel balls. Unfortunately, only two sizes were available, so the results cannot be very conclusive.

## **8.2 Foerster Minex 2FD 4.500**

The results for the Foerster detector at its highest sensitivity setting are shown in Figure 6. The results for the ferromagnetic balls again lie more or less on the same curve, with a maximum detection height of 300mm for a 25mm-diameter ball. There is no systematic trend evident in the results that distinguishes the responses of the different ferromagnetic steels.

With this detector at the setting used, the small 316-steel balls (7, 8mm) are detectable, but much less than the ferromagnetic steels. The larger 316-steel ball (15.9mm) is also more difficult to detect than the ferromagnetic steels but the difference in maximum detection height is smaller.

The aluminium balls also show the same behaviour as for the AN19/2. The small ball (6.35 mm) is as easy (in fact, marginally easier) to detect as the ferromagnetic balls of the same diameter, but the large ball (15.9 mm) is even less easy to detect than the AISI 316 stainless steel.

## **8.3 Guartel MD8**

The results of measurements with the Guartel MD8 at the highest sensitivity (setting III) are shown in Figure 7. The five ferromagnetic steels all lie on the same curve, to within the measurement uncertainty, as for the other detectors.

The balls of stainless (316) steel lie slightly below the ferromagnetic materials, but less so than is the case for the AN19/2 and the Minex 2FD. The same effect is however seen that the larger 316-steel ball is closer to the ferromagnetic steels than the smaller balls.

The maximum detection distances for the aluminium balls are less than for the ferromagnetic steel balls. The small (6.35mm) ball is only marginally harder to detect than the ferromagnetic steel ones of the same size. The large (15.9mm) ball is much harder to detect than both the ferromagnetic steel and non-magnetic 316-steel balls of the same size.

#### **8.4 Vallon ML1620C**

The results of the measurements with the Vallon ML 1620C are shown in Figure 8. The high-sensitivity (P) setting was used with the sensitivity adjustment set to 6. Programs 2 and 5 were used. The five ferromagnetic steels lie on approximately the same curve. The slight kink for the point representing the smallest ball detected occurs because at such a short range the maximum sensitivity occurs under the coil limb.

The small non-magnetic 316-steel balls are much harder to detect than the equivalent size ferromagnetic steel ones. The 7mm ball is not detected and the 8mm ball only when almost in contact with the detector sensor head. In contrast, the large (15.9mm) ball is only marginally harder to detect than the ferromagnetic steel balls.

The small (6.35mm) aluminium ball is as easy to detect as the ferromagnetic steel balls. The large (15.9mm) aluminium ball is significantly harder to detect than both the ferromagnetic balls and the non-magnetic 316-steel ball of the same diameter.

#### **8.5 General Observations**

For all four of the detectors, the maximum detection height of balls of ferromagnetic steels (two batches of 100Cr6, two batches of AISI-420 and the collection of steel bearing balls) lie more or less on the same curve. There are deviations from this curve that could be due to material property differences, but which fall within the measurement uncertainty.

The maximum detection height of the AISI-316 stainless steel balls is always less (for the range of diameters tested) than that for ferromagnetic steel balls for all four detectors. In other words, all four of the detectors are less sensitive to this non-magnetic steel than to ferromagnetic steels. There is considerable variation in the detection capability for AISI-316 between the four detectors.

The maximum detection height of the aluminium balls appears to have a weaker dependence on diameter than do the other metals. For all of the detectors, the sensitivity to the small ball is similar to that for the ferromagnetic steel balls. The sensitivity to the large ball however, is much less than for equivalent balls of ferromagnetic steel. It is also less than for AISI-316.

These results only come from two sizes of aluminium ball and three of AISI-316. The results do however indicate that for all of the detectors, the relative detection capability for aluminium and AISI-316 is reversed as diameter increases.

### **9 Conclusions**

- The detectors tested show a clear dependence of maximum detection height on ball diameter when measured using this simple manual technique. It is possible to use such curves to define sensitivity levels.
- With the metal detectors used, the maximum detection height of balls of ferromagnetic steels is not highly sensitive to the material from which they are made. The maximum detection heights measured for the 100Cr6 chrome steel and for the AISI-420 stainless steel all lie on the same curve, to within the measurement uncertainty of these tests.
- The effective permeability of the ferromagnetic steels has not been measured for these simple tests. It is nevertheless reasonable to expect the differences between the permeability of the chrome steel and the "ferritic stainless" AISI-420 steel to be at least as big as permeability variations between batches of the same nominal steel grade.
- It is feasible to use chrome steel balls as standard targets for metal detector sensitivity measurement.

- The tests with balls of different materials could be used as part of standardized test and evaluation of metal detectors, to determine the relative detection capability for different metals.
- The number of ball sizes of non-ferromagnetic metals used in these tests was only sufficient to give an indication of the detection capabilities for aluminium or for stainless steel. Further tests using more sizes of balls are required, so that complete sensitivity curves for these metals can be produced.

## 10 Proposed Sensitivity Standards

It would be relatively easy to define sensitivity standards for metal detectors based on a small set of different-diameter metal balls. Sensitivity curves, such as those produced above could be created to characterize the in-air sensitivity. A simple jig would facilitate this measurement. A curve is then fitted to the measured points of detection height vs. diameter. The sensitivity in terms of ball diameter at a particular standard distance can then be read from the curve.

For a particular clearance depth, it would even be possible to create a standard sensitivity test piece with the appropriate spacer. This would be placed against the detector sensor head to see if it gives an alarm indication and so verify whether the sensitivity is at or above a certain level. Many manufacturers already provide a test target of this kind, but they are not standardized. The diameter of the ball on the test piece would depend on the search sensitivity required. The required sensitivity depends in turn on the metal content and distribution within the mines sought, the burial depth and the limitations imposed by the level of noise from the soil.

If this method of sensitivity measurement is to be useful, the results need to be related to the responses obtained from real mines and in particular, real mines when buried in realistic soils. Further tests are therefore required;

- to compare realistic target responses to the sensitivity curves,
- to determine how the sensitivity curves change when the targets are buried in soils that affect metal detectors,
- to quantify the sensitivity required to detect buried realistic targets.

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7. MgM (Menschen gegen Minen) Standard Operating Procedures, Section 6.3.15 "Detector" <http://www.mgm.org/e/info/sops.htm> 22-July-1999.

### Metal Ball Detection Sensitivity (Schiebel AN-19/2) Arbitrary Sensitivity

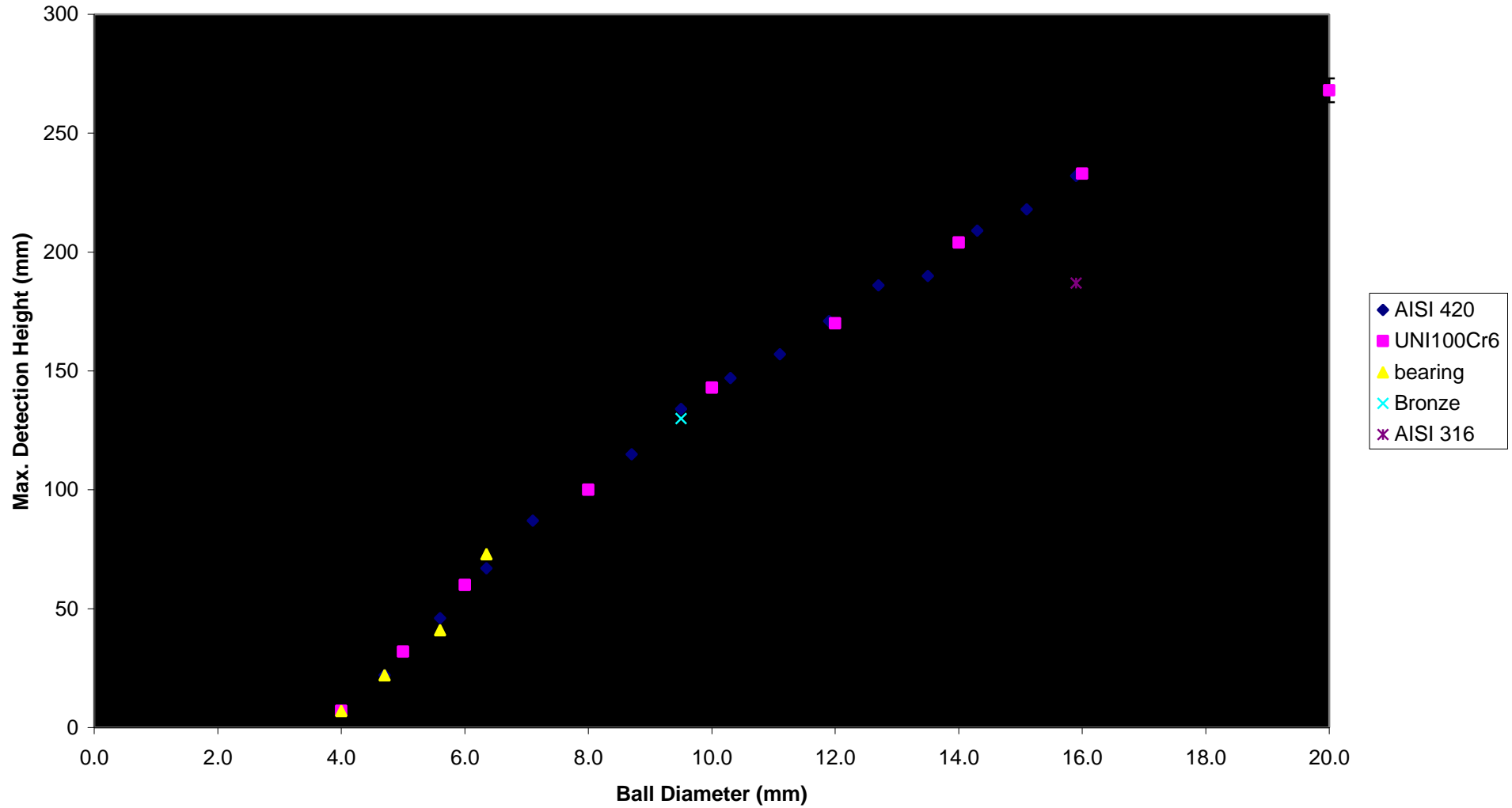


Figure 2: Phase 1 - Schiebel AN19/2 Results

### Metal Ball Detection Sensitivity (Foerster Minex 2FD)

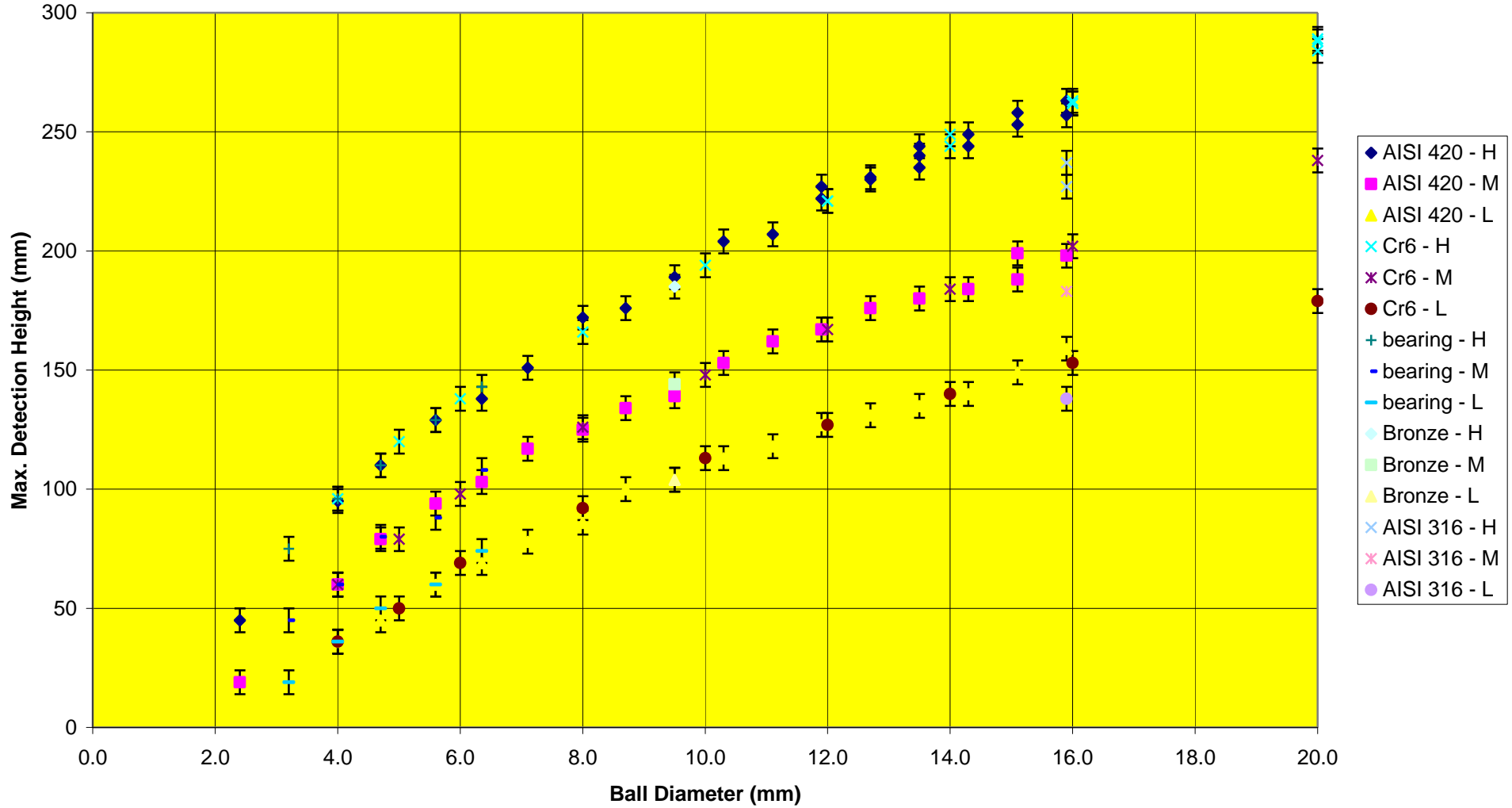


Figure 3: Phase 1 – Foerster Minex 2FD Results (High, Medium and Low Sensitivity Settings)



### Metal Ball Detection Sensitivity (Guartel MD8 - Setting III)

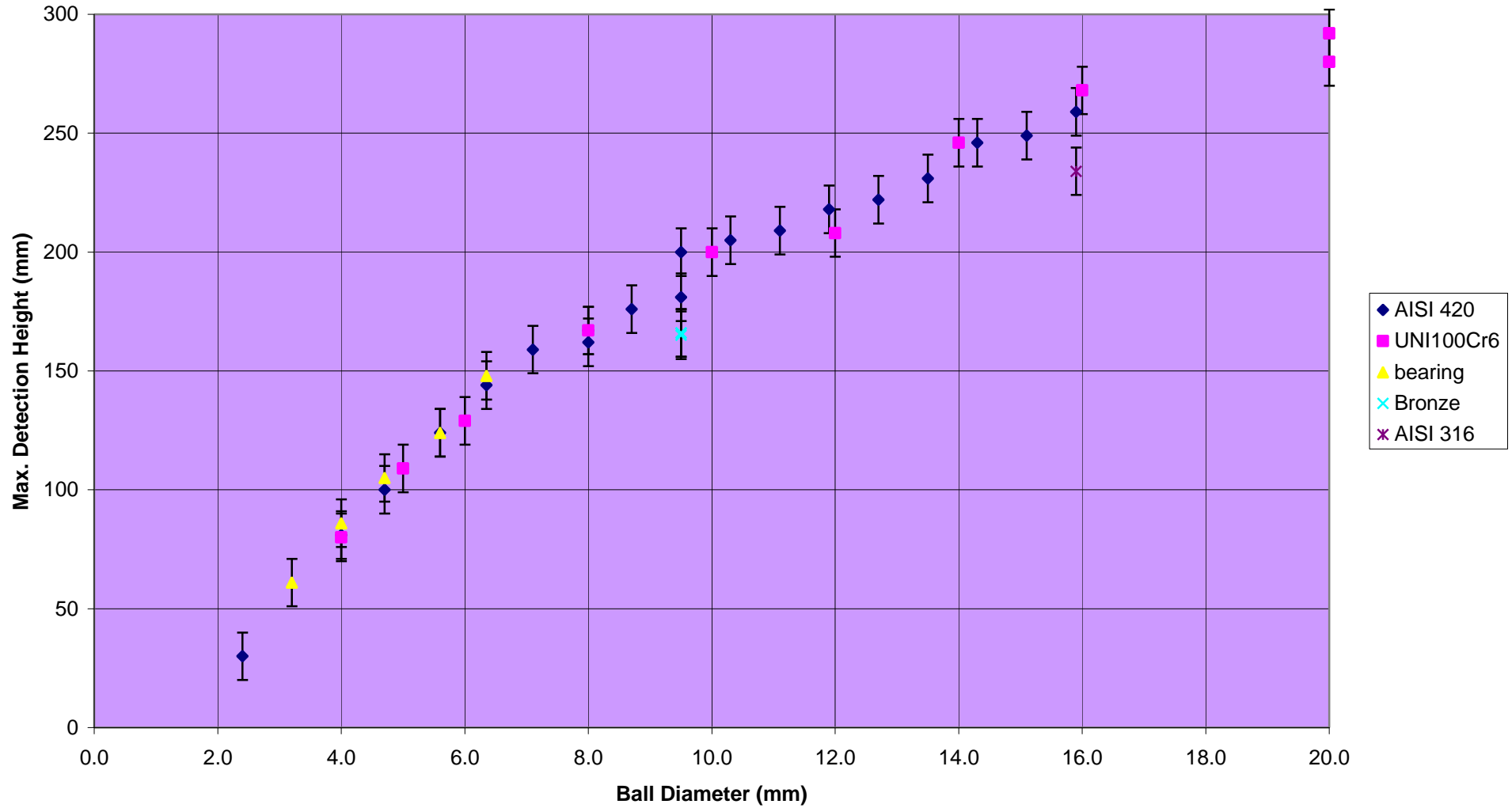


Figure 4: Phase 1 – Guartel MD8 Results (High Sensitivity)

### Metal Ball Detection Sensitivity - Schiebel AN 19/2 (reduced sensitivity)

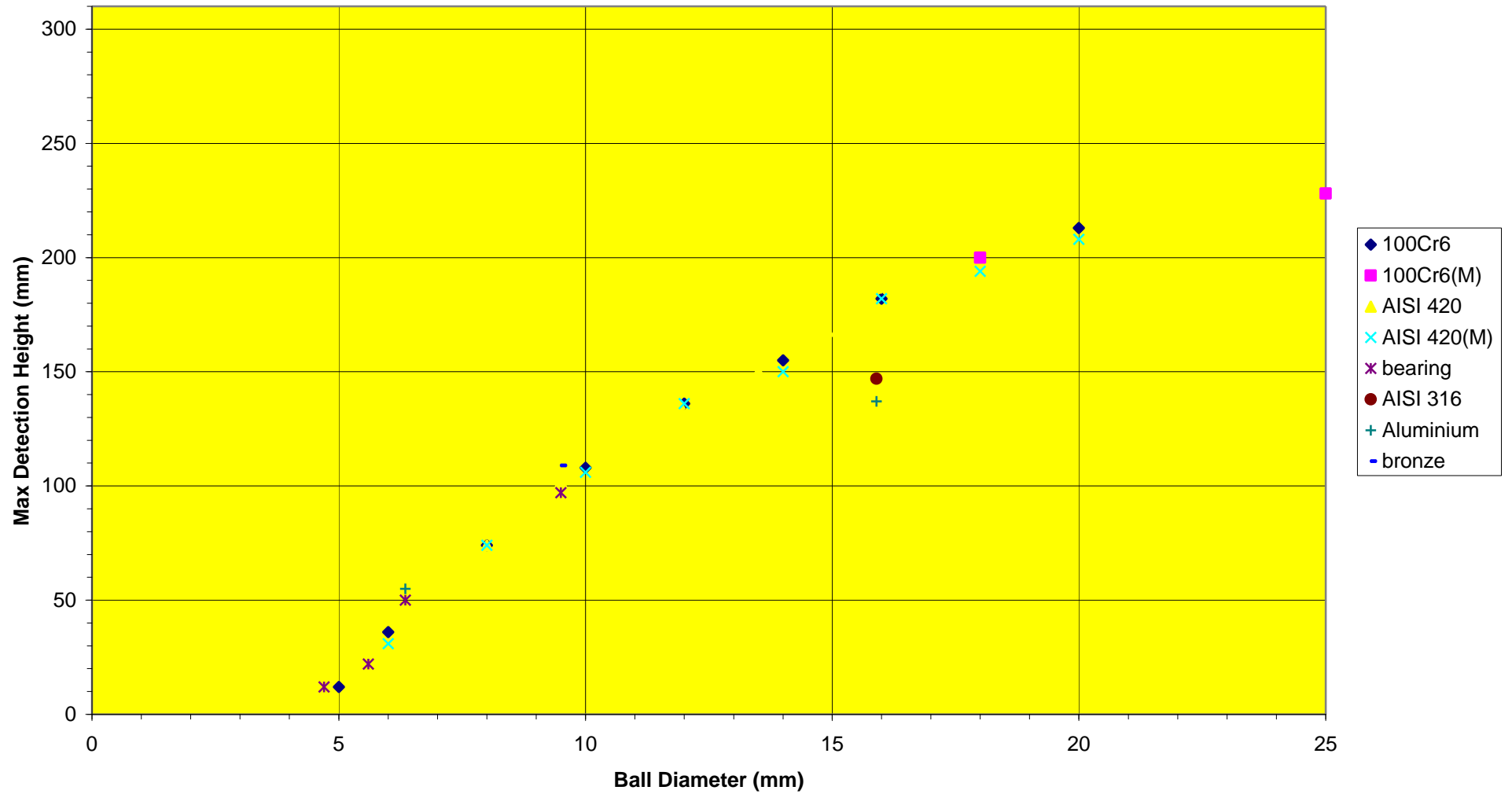


Figure 5: Phase 2 Results for Schiebel AN19/2

### Metal Ball Detection Sensitivity - Foerster Minex 2FD

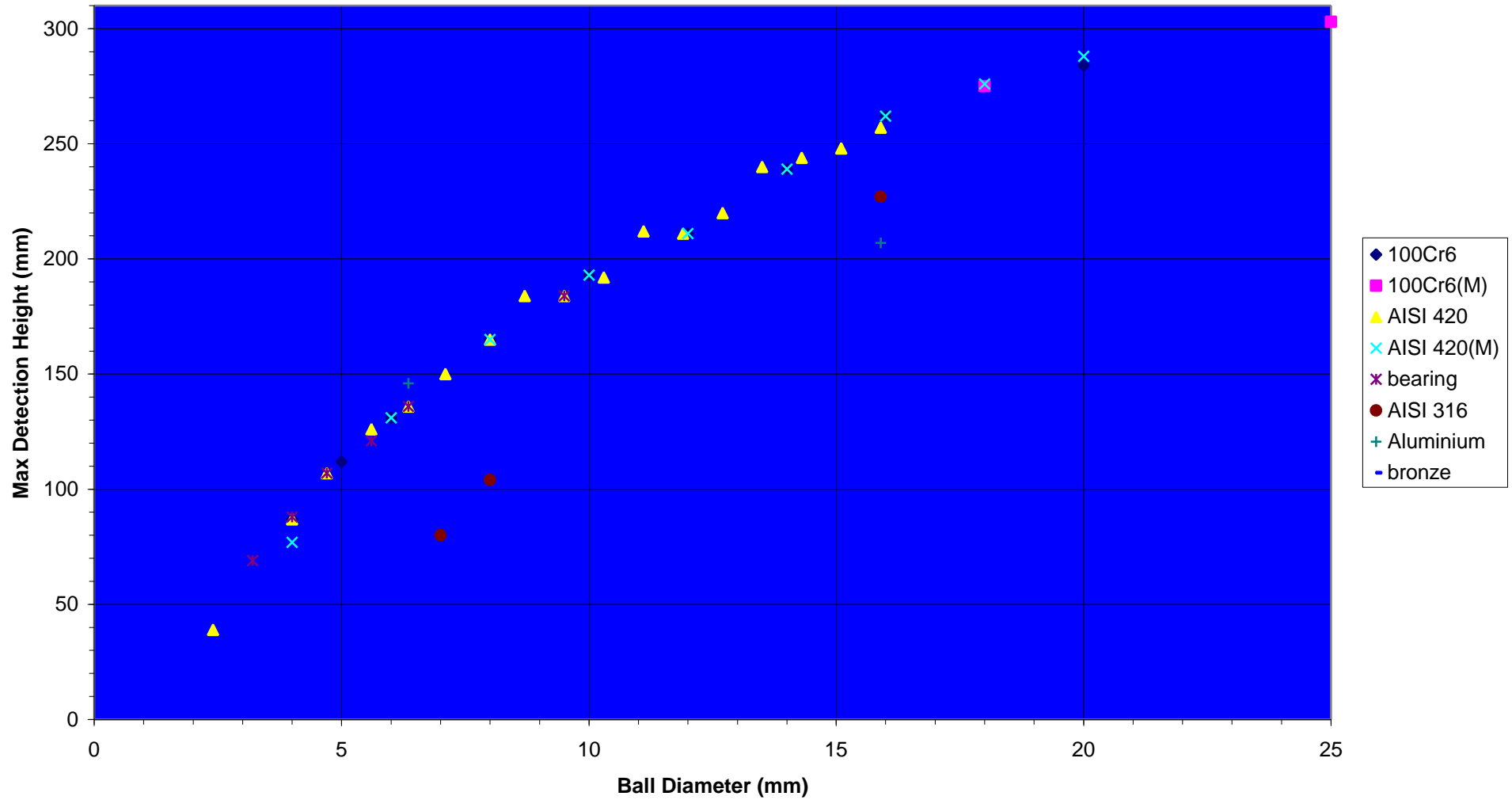


Figure 6: Phase 2 Results for Foerster Minex 2FD

### Metal Ball Detection Sensitivity - Guartel MD8: Setting III

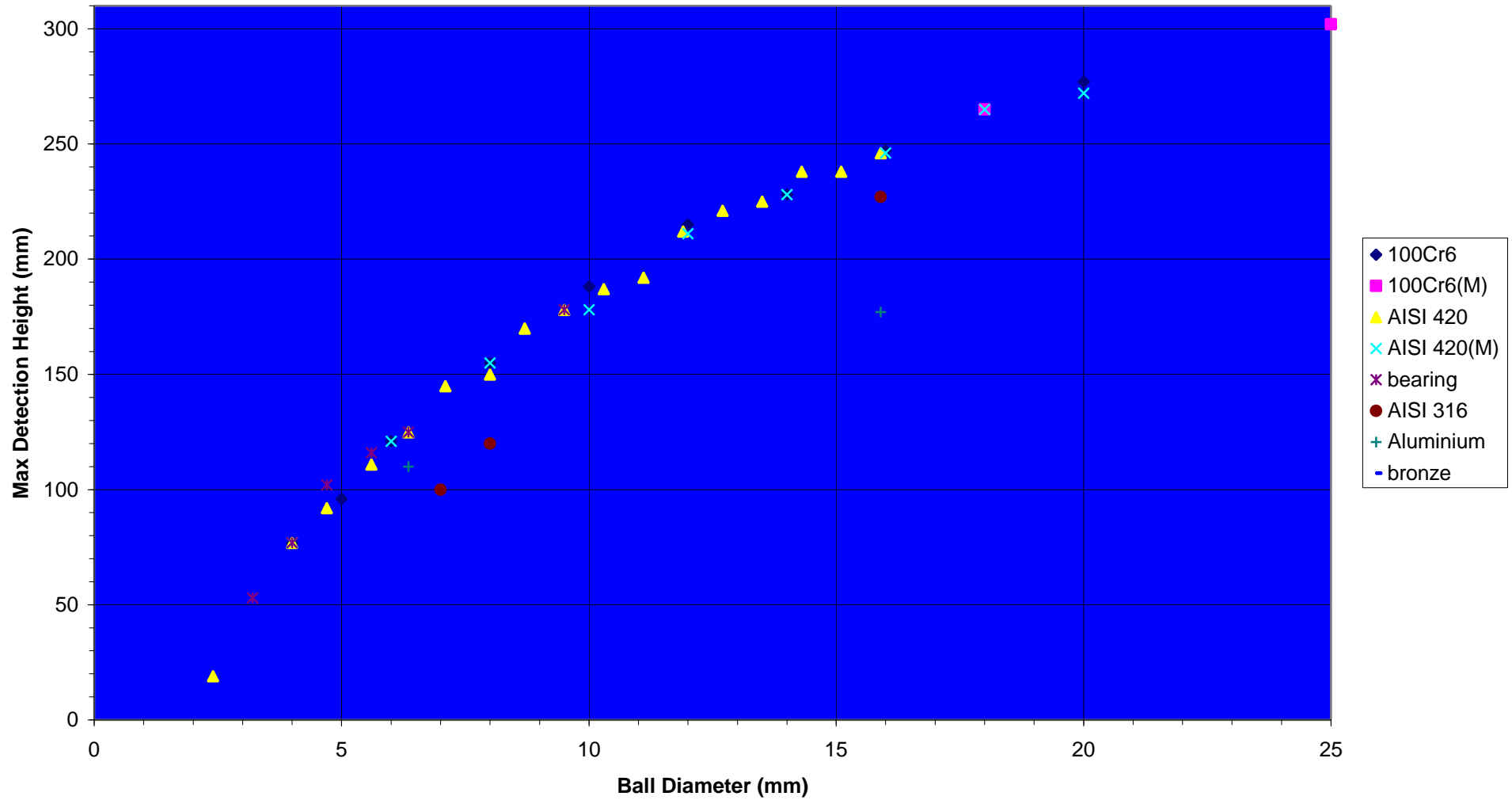


Figure 7: Phase 2 Results for Guartel MD8

### Metal Ball Detection Sensitivity - Vallon ML1620C -Setting P(6), progs 2 & 5

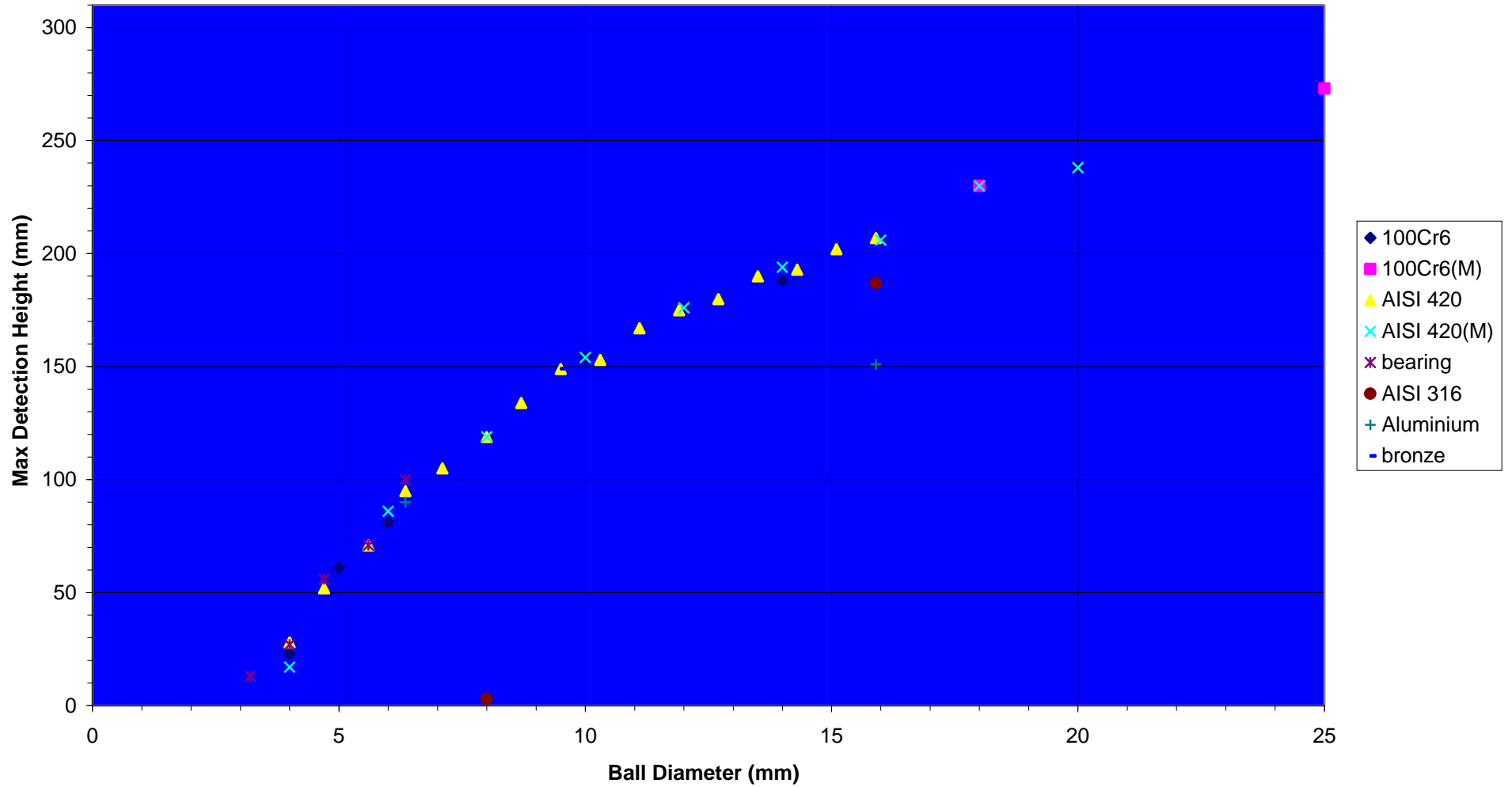


Figure 8: Phase 2 Results for Vallon ML 1620C