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## A Safe G-Code Subset for 3D Printing

Status: Interim

Abstract: This white paper defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG Working Draft. For a definition of a "PWG Working Draft", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This white paper is available electronically at:

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180426.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180426.pdf>

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25 Title: *PWG Safe G-Code Subset for 3D Printing*

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## 73 **1. Introduction**

74 G-Code [ISO6893-1][RS274D][REPRAP] is a commonly-used format for 3D printing with so-  
75 called Fused Deposition Modeling (FDM) printers. Besides the commands used to move the  
76 print head and/or platform and to extrude material, G-Code includes a variety of device  
77 control (e.g., set extruder temperature) and hardware access (e.g., write file to SD card)  
78 commands that pose serious safety and security concerns. To make matters worse, such  
79 commands are often printer-specific or have printer-specific variations in syntax, requiring  
80 the equivalent of printer driver software to produce G-Code suitable for a particular model or  
81 firmware version. Finally, differences in filament and extruder nozzle diameters mean that  
82 G-Code created for one print job may not work on the same printer due to changes to the  
83 material or extruder.

84 The IPP 3D Printing Extensions v1.0 [PWG5100.21] define the model and semantics for  
85 networked 3D printing, along with a required high-level 3D file format. However, the  
86 processing requirements of such a format require either improved printer controllers with  
87 greater memory, storage, and CPU capacity or the use of Cloud services to offload that  
88 processing.

89 The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] define the model and  
90 semantics for Cloud printing, however it does not specify an intermediate format suitable for  
91 3D printing.

92 This document defines a "safe" subset of G-Code that can be used for direct and Cloud  
93 printing configurations, along with a description of the capabilities and parameters that will  
94 be needed to generate suitable layers for printing to the target printer.

95 The goal of this document is to enable the use of IPP with existing entry-level FDM printers  
96 that are not able to perform their own slicing and to enable generic Cloud and local  
97 infrastructure services to provide slicing services to existing FDM printers. Support for other  
98 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension  
99 [3MF-SLICE].

100

## 101 **2. Terminology**

### 102 **2.1 Terms Used in This Document**

103 *Cloud*: the environment supporting services such as Cloud Computing.

104 *Cloud Computing*: "... a model for enabling ubiquitous, convenient, on demand network  
105 access to a shared pool of configurable computing resources (e.g., networks, servers,  
106 storage, applications, and services) that can be rapidly provisioned and released with  
107 minimal management effort or service provider interaction." The NIST Definition of Cloud  
108 Computing [NISTSP800-145].

109 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw  
110 layers, sometimes also called material extrusion.

### 111 **2.2 Acronyms and Organizations**

112 *IANA*: Internet Assigned Numbers Authority, <https://www.iana.org/>

113 *IETF*: Internet Engineering Task Force, <https://www.ietf.org/>

114 *ISO*: International Organization for Standardization, <https://www.iso.org/>

115 *PWG*: Printer Working Group, <https://www.pwg.org/>

116

### 117 **3. PWG Safe G-Code Subset**

118 This document defines a safe G-Code subset with the MIME Media Type  
119 "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following  
120 commands which represent the common subset of commands supported by most FDM  
121 printers:

122 G0: Rapid Linear Move

123 G1: Controlled Linear Move

124 G4: Dwell

125 G21: Set Units to Millimeters

126 G28: Move to Origin (Home)

127 G90: Set Absolute Positioning

128 G91: Set Relative Positioning

129 G92: Set Position

130 M82: Set Absolute Extrusion

131 M83: Set Relative Extrusion

132 Tnnn: Set Tool

133 Machine ("M") commands are not allowed since they directly control or access the machine  
134 hardware. Temperature control and other machine settings are the responsibility of the IPP  
135 Printer, which will likely use the IPP Job Template attribute values to send the corresponding  
136 printer-specific G-code commands to a lower-level controller.

137 The line number command ("N") and checksum ("\*") are similarly not allowed because they  
138 are used for direct communications with the controller - IPP provides the necessary  
139 infrastructure for reliable communication of the G-Code file to the IPP Printer.

140 Comments starting with the ";" character are allowed and continue to the end of the current  
141 line.

142 For simplicity, safe G-Code always uses millimeters for the units (the default).

#### 143 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

144 These commands move the current tool (extruder) and/or extrude material for printing.  
145 Parameters for this command are:

- 146 Xnnn: Set X position in millimeters  
147 Ynnn: Set Y position in millimeters  
148 Znnn: Set Z position in millimeters  
149 Ennn: Extrude the specified number of millimeters of material  
150 Fnnn: Set the feed rate in millimeters/minute  
151 Note: The "S" parameter is not allowed in safe G-Code.

### 152 **3.2 G4: Dwell**

- 153 This command pauses printing for a specifies amount of time. The "Pnnn" parameter  
154 specifies the time interval in milliseconds.

### 155 **3.3 G21: Set Units to Millimeters**

- 156 This command explicitly specifies that coordinates are in millimeters (the default).  
157 Note: This command is only provided for completeness - there is no support in safe G-Code  
158 for any other units.

### 159 **3.4 G28: Move to Origin (Home)**

- 160 This command moves the current tool to the home position (end stops). The "X", "Y", and  
161 "Z" parameters may optionally be specified to move the tool on the specified axes - if not  
162 supplied the tool is moved on all axes.

### 163 **3.5 G90: Set Absolute Positioning**

- 164 This command specifies that all coordinates are relative to the origin of the machine.

### 165 **3.6 G91: Set Relative Positioning**

- 166 This command specifies that all coordinates are relative to the current position of the tool.

### 167 **3.7 G92: Set Position**

- 168 This command sets the current tool positions without moving or extruding material.  
169 Parameters for this command are:

- 170 Xnnn: Set X position in millimeters

171 Ynnn: Set Y position in millimeters

172 Znnn: Set Z position in millimeters

173 Ennn: Set extrusion to the specified number of millimeters of material

174 All positions are set to 0 if no parameters are specified.

### 175 **3.8 M82: Set Absolute Extrusion**

176 This command specifies that the extrusion ("E") coordinates in move commands are  
177 absolute.

### 178 **3.9 M83: Set Relative Extrusion**

179 This command specifies that the extrusion ("E") coordinates in move commands are relative.

### 180 **3.10 Tnnn: Set Tool**

181 This command sets the current tool (extruder) to use, starting at 0.

182 **Editor's Note: Discuss how client maps tool numbers to materials.**

183



## 184 4. Generating Safe G-Code

185 IPP Clients [RFC8011] and Infrastructure Printers [PWG5100.18] can generate safe G-Code  
 186 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table  
 187 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-  
 188 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"  
 189 Printer Description attributes which provide a list of all possible materials and those that are  
 190 loaded in the Printer, respectively.

191 **Table 1 - Information Needed to Generate Safe G-Code**

Description	Current IPP Attribute
Accuracy limits/minimum layer height	print-accuracy-supported (collection)
Build platform dimensions	printer-volume-supported (collection)
Build platform shape	platform-shape (type2 keyword)
Extruder nozzle size/maximum layer height	See section 4.1
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section 4.1

### 192 4.1 Material Extrusion Parameters

193 IPP 3D v1.0 [PWG5100.21] does not define attributes or values for the extruder nozzle size,  
 194 nor does it define a way to specify whether retraction is used. These can be added to the  
 195 "materials-col" collection as:

196 "material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder  
 197 diameter in nanometers, with the value 0 indicating the nozzle diameter is less than  
 198 1 nanometer.

199 "material-retraction (boolean)": Specifies whether retraction should be used with the  
 200 material.

201 A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) |  
 202 rangeOfInteger(0:MAX)))" Printer Description attribute can provide the supported nozzle  
 203 diameter values. The presence of 'material-retraction' in the "materials-col-supported"  
 204 Printer Description attribute indicates that the Printer supports material retraction.

### 205 4.2 Support for Additional "Safe" G-Code Commands

206 In addition to the common subset of G-Code commands listed in the previous sections,  
 207 newer FDM printers support additional "safe" commands such as mixing of extruded material  
 208 ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5").  
 209 In order for a generic slicer to support these commands, a printer needs to advertise its  
 210 support for them. The usual method employed for IPP is a PDL-specific capability attribute,  
 211 such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a  
 212 named command.

## 213 5. Printing Safe G-Code

214 Printers that support safe G-Code can largely pass the print file to the controller - typically  
 215 all that is required is to add printer-specific commands to initialize the printer to set  
 216 temperatures and other machine settings, send the print file, and then add printer-specific  
 217 commands to return the printer to an idle state.

218 Status information returned by the printer can be used to set the values of the various IPP  
 219 Printer Status attributes.

### 220 5.1 Adding Printer-Specific Machine Commands

221 IPP Job Template attributes provide the values for extruder and build platform temperatures,  
 222 as well as the list of materials used in the print job. Table 2 lists the standard attributes a  
 223 FDM printer can use to configure the machine prior to printing.

224 **Table 2 - IPP Job Template Attributes**

Description	IPP Attribute(s)	Typical G-Code
Build platform temperature	platform-temperature	M140/M190
Chamber humidity	printer-volume-humidity	M146
Chamber temperature	printer-volume-temperature	M141/M191
Extruder nozzle size	materials-col/material-nozzle-diameter	
Extruder temperature	materials-col/material-temperature	M104/M109
Filament color	materials-col/material-color	
Filament diameter	materials-col/material-diameter materials-col/material-diameter-tolerance	M200
Filament type	materials-col/material-type	
Flow rate	materials-col/material-rate materials-col/material-rate-units	M203
Job Name	job-name	M531
Print accuracy	print-accuracy	M201/M202/ M222/M223
Print quality/speed	print-quality	

225 When an IPP Client does not specify one or more of these attributes, the corresponding  
 226 default attribute values are used - "materials-col-default", "platform-temperature-default",  
 227 "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and  
 228 "printer-volume-temperature-default" for the attributes in Table 2.

### 229 5.2 Printer-Specific Attributes and Values

230 IPP allows implementors to add printer-specific attributes and values as defined in section 7  
 231 of [RFC8011]. However, printers cannot depend on IPP Clients or Infrastructure Printers to  
 232 support such attributes or values, particularly for generation of safe G-Code. Default values  
 233 should be used as a backup when necessary.

## 234 6. IANA Considerations

### 235 6.1 Attribute Registrations

236 The attributes defined in this white paper will be published by IANA according to the  
237 procedures in IPP/1.1 Model and Semantics [RFC8011] section 7.2 in the following file:

238 <https://www.iana.org/assignments/ipp-registrations>

239 The registry entries will contain the following information:

240	Job Template attributes:	Reference
241	-----	-----
242	materials-col (1setOf collection)	[PWG5100.21]
243	material-extruder-diameter (integer(0:MAX))	[SAFEGCODE]
244	material-retraction (boolean)	[SAFEGCODE]
245		
246	Printer Description attributes:	Reference
247	-----	-----
248	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
249	rangeOfInteger(0:MAX))	[SAFEGCODE]
250	safe-gcode-supported (1setOf text(MAX))	[SAFEGCODE]

### 251 6.2 MIME Media Type Registration

252 The MIME media type defined in this white paper will be published by IANA according to the  
253 procedures in the Media Type Specifications and Registration Procedures [BCP13] in the  
254 following file:

255 <https://www.iana.org/assignments/media-types>

256 The registry will contain the following information:

257     Type name: application  
258  
259     Subtype name: vnd.pwg-safe-gcode  
260  
261     Required parameters: N/A  
262  
263     Optional parameters: N/A  
264  
265     Encoding considerations: US ASCII  
266  
267     Security considerations: Safe G-code prohibits machine control commands,  
268     however it is up to the consumer to verify that such commands are not part  
269     of the print file.  
270  
271     Interoperability considerations: While the format is interoperable, the  
272     contents of each file are still specific to the combination of material  
273     parameters and printer capabilities used for the G-code.  
274

275 Published specification: [this white paper]  
276  
277 Applications that use this media type: IPP 3D  
278  
279 Fragment identifier considerations: N/A  
280  
281 Additional information:  
282  
283     Deprecated alias names for this type: N/A  
284     Magic number(s): N/A  
285     File extension(s): gcode  
286     Macintosh file type code(s): N/A  
287  
288 Person & email address to contact for further information: Michael Sweet,  
289 msweet@apple.com  
290  
291 Intended usage: COMMON  
292  
293 Restrictions on usage: N/A  
294  
295 Author/Change controller: The Printer Working Group, c/o The IEEE Industry  
296 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ  
297 08854, USA  
298  
299 Provisional registration? (standards tree only): No

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## 328 8. Author's Address

329 Primary author:

330 Michael Sweet  
331 Apple Inc.  
332 One Apple Park Way  
333 Cupertino, CA 95014

334 USA  
335 msweet@apple.com

336 The authors would also like to thank the following individuals for their contributions to this  
337 white paper:

338 Kris Iverson (Microsoft)

## 339 **9. Change History**

### 340 **9.1 April 26, 2018**

- 341 1. Made a PWG Best Practice working draft.
- 342 2. Added reference to RepRapWiki for G-Code
- 343 3. Added reference to ISO 6983-1 for current official G-Code specification
- 344 4. Section 4: Mention materials-col-database and materials-col-ready
- 345 5. Section 4.1: Retitle as "Material Extrusion Parameters"
- 346 6.

### 347 **9.2 April 16, 2018**

- 348 1. Status: Interim
- 349 2. Introduction: Added discussion of nozzle and filament diameter influencing
- 350 portability of G-code, and why we want this.
- 351 3. Added G21, M82, and M83 commands, and hooks for other printer-specific
- 352 commands (safe-gcode-supported)
- 353 4. Updated T command (set tool) to use 0 as the first index.
- 354 5. Added sections on generating and printing safe G-code
- 355 6. Added IANA registration of new attributes and the MIME media type
- 356 7. Added references to 3MF slicing and RFC 8011.

### 357 **9.3 April 12, 2018**

358 Initial revision.